UNIVERSITY "CYRIL AND METHOD " IN SKOPJE
FACULTY OF CIVIL ENGINEERING

Kaltrina Agim Spahiu

COMPARATIVE EXPERIMENTAL RESEARCH OF INNOVATIVE SUSTAINABLE CLAY BUILDING MATERIAL FOR FACADES

Doctoral thesis

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Topic:
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A b s t r a c t

Based on the sustainable development approach with a focus on the building envelope, as well as based on the existing concern of human society for the external environment and internal comfort, this study contributes to the research of sustainable bio and recyclable materials by promoting friendly buildings in human and environmental well-being. The change in global climate conditions has influenced human awareness globally with vital innovative approaches to the importance of buildings and in particular the importance of the building facade and the sustainability of development. But since existing building materials, especially bio ones, offer space and opportunities for advancement in improving performance, then the need for research into new products or advancement of existing ones is always increasing.

The methodology used in this research is related to the existing materials, scientific methods and production elements. The methods used in this thesis are as follows: analysis, synthesis, classification, modeling, comparison, mathematical, statistical, case study, research, observation, experimental, measurement methods. All these methods are intertwined, creating a compressive conclusion, a clear framework for interpreting results for the research topic. The methodology used during this research attempt to provide a picture and result regarding the product in terms of physical properties which will be important for the materials used in the building envelope.

From the experimental results of the product, we conclude that the performance of product: density, water absorption, durability, compressive strength, thermal, are within the conditions of European standards. Among which the results of the thermal conductivity have a value of $\lambda = 0.12$ W/m K higher compared to traditional clay bricks. At the end of this research, an attempt is made to provide an overview of the performance of a research product, composed of biomaterials and recycled materials, whose purpose is to be used in the facade of buildings. Such a product will contribute to human well-being, by being involved in the social, economic, and ecological dimensions. It will also make buildings breathe, come alive, and become one with nature. The scientific contribution of this research lies in the fact of the good performance of this sustainable material both in mechanical and physical aspects. The optimization of the components in the mixture offers innovation in building materials, contribution to ecological engineering constructions, potential in industry, expansion of knowledge in the field of engineering, architecture and innovation.

Keywords: clay, façade, slag, sawdust, efficiency, sustainability, recycled materials, biomaterials

Kaltrina Agim Spahiu

KOMPARATIVNO EKSPERIMENTALNO ISTRAŽUVANJE NA INOVATIVEN ODRŽLIV KERAMIČKI GRADEŽEN MATERIJAL ZA FASADI

A b s t r a k t

Vrz osnova na pristapot za održliv razvoj so fokus na obvivkata za gradenje, kako i vrz osnova na postoečkata griža na čovečkoto opštestvo za nadvorešnata sredina i vnatrešnata udobnost, ovaa studija pridonesuva za istražuvanje na održlivi bio i materijali što može da se recikliraat preku promoviranje na zgradi prijatelski za čovekovata blagosostojba i životnata sredina. Promenata na globalnite klimatski uslovi vlijaeše na čovečkata svest na globalno nivo so vitalni inovativni pristapi kon važnosta na zgradite, osobeno važnosta na fasadite na zgradite i održlivosta na razvojot. No, bidejḱi postoečkite gradežni materijali, osobeno onie na baza na bio, nudat prostor i možnost za napredok vo podobruvanje na performansite, potrebata za istražuvanje na novi proizvodi ili unapreduvanje na postoečkite postojano se zgolemuva.

Metodologijata što se koristi vo ova istražuvanje e povrzana so naučnite metodi i elementi što se koristat. Metodite koi se koristat vo ovoj trud se slednite: analiza, sinteza, klasifikacija, modeliranje, sporedba, matematički, statistički, studija na slučaj, istražuvanje, nabljuduvanje, eksperimentalni i merni metodi. Site ovie metodi se isprepleteni, sozdavajḱi seopfaten zaklučok, jasna ramka za tolkuvanje na rezultatite za temata na istražuvanjeto. Metodologijata koristena pri ova istražuvanje ḱe se obide da dade slika i rezultat vo odnos na proizvodot vo odnos na fizičkite svojstva koi ḱe bidat važni za materijalite što se koristat vo kuḱišteto na objektot.

Od eksperimentalnite rezultati na proizvodot, zaključuvame deka performansite na proizvodot: gustina, apsorpcija na voda, izdržlivost, jakost na pritisok, toplinska, se vo uslovi na evropskite standardi. Meǵu koi rezultatite od toplinskata sprovodlivost imaat vrednost od λ = 0,12 W/m K pogolema vo sporedba so tradicionalnite glineni tuli. Na krajot od ova istražuvanje, se pravi obid da se dade pregled na performansite na istražuvački proizvod, sostaven od biomaterijali i reciklirani materijali, čija namena e da se koristi vo fasadata na zgradite. Takviot proizvod ḱe pridonese za čovekovata blagosostojba, preku vklučuvanje vo socijalnite, ekonomskite i ekološkite dimenzii. Isto taka, ḱe napravi zgradite da dišat, da oživeat i da stanat edno so prirodata. Naučniot pridones na ova istražuvanje leži vo faktot za dobri performansi na ovoj održliv materijal i od mehanički i od fizički aspekt. Optimizacijata na komponentite vo smesata nudi inovacii vo gradežnite materijali, pridones vo ekološkite inženerski konstrukcii, potencijal vo industrijata, proširuvanje na znaenjata vo oblasta na inženerstvoto, arhitekturata i inovaciite.

Klučni zborovi: glina, fasada, zgura, strugotini, efikasnost, održlivost, , reciklirani materijali, bio materijali .

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On my journey toward earning my doctorate, I wish to express my profound gratitude to those who have stood by me and provided invaluable support throughout this significant phase of my academic pursuit.

I am deeply grateful to my parents and family, whose dedication and sacrifices have provided me with unwavering love, self-confidence, courage, and invaluable guidance. Their support has been instrumental in shaping my journey, instilling in me the belief that anything in life is possible and achievable. My commitment to science and my pursuit of scientific research are a testament to their encouragement and influence. I extend my heartfelt gratitude to them and will always remain profoundly thankful to my father and mother.

Special thanks are extended to my mentor, Prof. Dr. Kiril Gramatikov, whose unwavering motivation, enthusiastic dedication, and invaluable contributions have made my doctoral journey both productive and inspiring. His time, effort, guidance, insightful suggestions, and generous sharing of knowledge have been profoundly meaningful to me and have played a crucial role in my academic development at this level.

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In the development of experiments in the laboratory of the Faculty of Civil Engineering in Prishtina, I received a support from Prof. Dr. Naser Kabashi, to whom I am deeply grateful. His expertise in laboratory experimentation and extensive knowledge of construction materials have been of great significance to me.

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During this journey, there are many, many other people who helped and supported me by giving me courage, motivational words, support, and positive energy, and I am grateful to all of them.

Thank you everyone!

I declare that the doctoral thesis is an original work that I have produced independently.

Kaltrina Spahiu ____________

I declare that the electronic version of the doctoral thesis is identical to the printed doctoral thesis.

Kaltrina Spahiu, s.r.

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1. INTRODUCTION

The existence of humanity is linked to the existence of their shelter spaces, which have evolved over time in line with human intellectual development. These shelters from old structures have evolved to the perfection of today, depending on their functions. Buildings that provide protection, shelter, function, accommodation, comfort, and all these parameters for humans offer the possibility of existence and development of daily life activities.

In this dissertation work, the combination of biomaterials and building facades helps to reveal a broad perspective, showing a technological approach, as well as a philosophical commitment to diversity and sustainability.

Day by day, with the increase in the population, the land surface of the earth is being filled with buildings of various categories, and in addition to technological and industrial development, attempts are being made to make buildings resemble hi-tech buildings, which incorporate non-recyclable materials, but on the other hand, there are also initiatives to realize buildings that attempt to preserve the environment. The opportunity to preserve the environment through buildings is being achieved in several initiatives: through constructions, building envelopes, urban solutions, interior furnishings, functional concepts, etc. At the same time, these initiatives to preserve the environment are being supported by many world organizations, and campaigns are also being undertaken that favor these buildings. The initiation of these campaigns is also a bonus push for individuals, design companies, architects, engineers, and construction companies to focus on building construction that impacts the preservation of nature.

Of all these parameters of correspondence with nature, co-existence, support and preservation of nature, the facade element (building envelope) carries special importance in this aspect. The building achieves its first contact with man through the facade, the transmission of the building's function to the citizen, whether it is a cultural-social message, is achieved through the facade. The barrier between the external and internal environment of the building is achieved by the building envelope, in this case the facade. Maintaining internal comfort is achieved through the facade and also energy efficiency is achieved with the help of the facade. Likewise, the construction of the building, the location of the building on the urban platform, the internal function of the building is all related to the building envelope, the facade of the buildings. Therefore, research into an optimal product that could be used for building facades and that would contribute to environmental conservation would be a welcome idea for the construction market in general, with benefits in this case for nature.

The treatment of the research thesis is analyzed and extended in these consecutive chapters:

Chapter -1- deals with the part of the methodology used in this research, starting with the hypothesis, the description of the goals that are desired to be achieved in this research, the classification of the research methods, and the presentation of the objectives and concrete steps that will be followed to guide the research process.

Chapter -2- provides a clear overview regarding building facades in general, starting from its role in the environment, human well-being, its impact on psychological perception and on the creation of the urban image. Also, this chapter describes sustainable development, the dimensions of sustainable development: social, ecological and economic. Then the description of the organizations that have sustainable development as their goal and objective with the target of the envelope of buildings.

Chapter -3 - this chapter deals with and describes the potential materials for the formation of the research product, the reasons for their selection.

The materials are described: clay, slag, sawdust, ash wood, lime. Then it continues with their properties and performance based on the characteristics they possess, in the context of use, classification, and also provides conclusions on the reasons for the selection of these materials.

Chapter –4– This chapter provides information about the field combination of selected materials. The combinations of materials, the number of samples and their categorization are indicated. As well as the procedures, the combination technique, the atmospheric conditions and the process of sending to the kiln for final processing. For each combination of them, explanations are given about the result of the samples. Then, this chapter also describes the final combination of materials: clay, sawdust and slag.

Chapter –5 – This chapter provides explanations of the laboratory work that was performed, information on the laboratory conditions, the type of experiments and the samples that will be subjected to these experiments. The experiments performed and described in this chapter are: dimension measurements, bulk density, water absorption, durability freeze-thaw cycles - 50 cycles, compressive strength in dry state conditions, compressive strength after freeze-thaw cycles, thermal conductivity measurement. For each experiment, details are given on the methods, standards, results, model analyses, comparison of results, diagrams and conclusion of the results.

Chapter –6– This chapter describes the selection of sample "18 $_{82\text{-}8\text{-}10}$" in the work of mini walls in the laboratory space which have been subjected to testing. It also describes the development of the experiment "Testing of bonding mortar for the work of mini walls", details are given for the preparation methods of the bonding mortar "Mape Antique Structurale" for the work of mini walls, results, comparison of results and conclusion of results. Then it continues with the description of the development of the experiments "The behavior of the masonry wall under the load – applications" and "Bearing capacity - Compressive strength". These experiments have been developed for three mini walls in the laboratory, for which details are given for the methods, results, analysis of results, diagrams, comparison of results and conclusion.

Chapter –7– In this chapter, general knowledge from the doctoral research is described, including the knowledge gained from the summary of sustainable development regarding the research subject, knowledge from analysis of materials and knowledge from different methods of experiments.

Chapter –8– In the continuation of this chapter, a summary of the information and knowledge gained during this research of this product is presented, conclusions are given based on the analyses made during this phase. For this research thesis, also recommendations are given in this chapter, which provide guidance for future actions, with the possibility of research in several dimensions.

1.1 Research Hypothesis

Based on the specificity of the hypothesis, the following hypotheses can be considered within the framework of this research, which are testable and based on prior knowledge and propose expected results. The results in question are comparative with existing traditional construction products:

- Facades built from biomaterials significantly reduce the environmental impact and improve the comfort of the residents.
- Facades of buildings made from biomaterials are aesthetically acceptable by users, engineers and architects.
- Bio and recyclable products are cost-effective in the long term due to reduced operating and maintenance costs.

Testing of these hypotheses will be done empirically, with laboratory experimental methods, analysis of materials performance data.

1.2 Goals

The goals that we attempt to achieve through this study are also considered objectives that guide the entire dissertation research process, and can be characterized as follows:

- To encourage innovation, materials industries, commercial enterprises in the use of bio and recycled materials in the construction market, based on the demonstrated performance.
- To assess the durability, resistance the thermal performance of these materials through testing in different atmospheric conditions.
- Drafting urban policies and strategies to improve sustainability and life in urban areas.
- To create a more attractive and welcoming environment for residents and building users with bio and recycled facades.
- To reduce the costs of maintenance and repair of building envelopes by offering better economic opportunities.
- To aim for biomaterials to contribute to reducing energy consumption for heating and cooling.
- Promoting the use of bio and recycled materials in building facades, contributing to the sustainable development of the environment.
- Influencing the cooperation of local communities with the construction industry in the production of bio and recycled products for building facades.
- Stimulating the production of regional bio and recycled products, contributing to the development of regional economies.

1.3 Methodology used

The methodology used in this research was developed in the following methods:

- Analysis method - this approach included analysis: quantitative, qualitative, combined, comparative, and statistical. All these methods of this methodology have been implemented starting from the first chapter until reaching the conclusions of this dissertation. This method has also been combined with other methods that will be described below.
- Synthesis method - during the collection of data for the treatment of research from different sources, this research approach helped in the unification and integration of this information and reaching a conclusion.

- Classification method - the results obtained and generated during this study required the ordering, organization and categorization of information according to common or distinctive properties.
- Modeling method - the work of samples of the research product to reach final conclusions represents the use of modeling methods through which the behavior of the samples is described, analyzed and predicted in relation to the experiments to which they are subjected.
- Comparison method - the procedure of comparing the results achieved from the experiments carried out, has helped in reaching conclusions in relation to the behavior of different samples after the completion of the experiments.
- Mathematical method - as a research approach, it is used using mathematical techniques to research the research product. Through this method, the connection of the various variables achieved from the experiments is made until a conclusion is reached.
- Statistical method – presentation of diagrams, graphs, descriptive table forms, are important tools in scientific research, through which the relationships of the variables obtained are understood to predict and reach conclusions.
- Case study method – in this case of research on the building envelope product, the cases of experiments to which the brick samples were subjected, for each type of experiment it was necessary to collect data from other sources to interpret the results.
- Research method – in this case this method was qualitative and quantitative, which was achieved by collecting data through direct observation of the implementation of experiments in the field and in the laboratory.
- Observation method – during this research, to reach a result and conclusion, the method of systematic observation is necessary during the implementation of the experiments. During this method is to understand the behavior of brick samples in different phases.
- Experimental method – research of the product of this dissertation to understand its behavior in different conditions. This methodology was treated in the field and in the laboratory, and to implement this methodology it was necessary to implement these factors: tools, equipment, creation of experimental conditions, data collection, data analysis, reporting of results.
- Measurement method – collection of data from the development of other methods to reach scientific data. Meanwhile, the unit used in these measurements resulted according to the type of experiments that were carried out according to the relevant European

Standards EN, specified in the thesis, in each experiment conducted. Within the framework of this method, direct measurements, time measurements, and intensity measurements were used. And during this method, these steps are carried out: measuring instruments, instrument calibration, data collection, data analysis, interpretation.

1.4 Objectives

The objectives that have been set for this research and which are expected to be realized within the timelines and dimensions of this research serve to help advance knowledge in the use of sustainable materials in construction. In providing concrete and applicable opportunities for the future of construction technology and materials, as well as in reducing environmental impact by contributing to human well-being.
The above objectives begin with preliminary research on building facades, information for an overview of the topic, and campaigns that have been undertaken by global organizations for this dimension of sustainable development. Then the objectives continue with research on bio and recycled materials that have potential for the creation of a research product.

The next objective is to find bio and recyclable materials, create alternative samples from these materials and finalize the processing of samples in the factory. The samples processed in the factory form the central objectives of this research, which are the development of laboratory experiments in accordance with the standards that determine the effects of the material on the efficiency and performance of the building envelope.
By applying the research methodology, other objectives result, which is the analysis of the data obtained from the experiments and the consideration of the possibilities for using the research product in the building envelope. This results in the final objectives, in recommendations and guidelines.

1.5 Literature review

In researching the topic of the doctoral thesis, the literature that was used and which also helped in the objectives of this work are the following, grouped by similar topics:

Building, Facades:

- Carmela Cucuzzella, Negarsadat Rahimi, Aristofanis Soulikias, "The Evolution of the Architectural Façade since 1950: A Contemporary Categorization", 2023 .

In this research paper, a chronology of the historical development of facade cladding since 1950 is given, also classifying facades and their impact on the surrounding environment. At the same time, the design principles are given as generalized, which can be used for the bulk of facades. At the same time, since the 20th century, building facades have been part of the study, which continues even today by applying technologies and principles of sustainable development. The categorization of facades into groups helps in this research for a more coherent approach to the development of facades. As well as the different names of facades that are emphasized in this research, indicating their meaning, also helps in the introduction of this research.

- Philippe St-Jean, Osborne Grant Clark, Michael Jemtrud, "A review of the effects of architectural stimuli on human psychology and physiology", *Building and Environment,* vol. 219, 2022 .

In this research, the treatment of the building envelope, in particular: the shape of the facade, its colors, the materials used in the facade, all of these affect human psychology and physiology. This impact on the facade will then be reflected in their health and well-being. Such an approach, in this research, helps to address the impact of facades on the culture, identity and historical values of a place, which also helps in the formation of collective memory. In this research, such a psychological perception will focus on biomaterials such as: clay, sawdust, which play the role of architectural stimuli with an impact on human psychology.

- S.K. Haldar, “Basic Mineralogy”, vol. 2, Oxford, USA: Elsevier Inc., 2020, p. 341 .

In the chapter of this book, which is also an introduction to basic mineralogy, recalling ancient objects built from biomaterials that the earth's surface offers, an overview of the compressive minerals that make up the earth and their relationship to the sustainability and performance of materials in construction is given. Such an approach of this book influences this research of this dissertation to help and provide factual evidence that the materials that the earth's surface offers have been a continuous part of sustainable development dating back to ancient times.

Clay:

- Abeer Abduljabbar Al-Saeedi, "Clay basics and their physical and chemical properties: Review Paper," *IAETSD Journal for Advanced Research in Applied Sciences,* vol. 10, no. 8, p. 13, 2022 .

Such a research approach will help our research to have a more compressive approach to the specifics of the clay material, starting from the way clay is formed, its constituent minerals, its distribution, its physical and chemical properties, applications in various industrial fields. Applications such as: construction, wastewater treatment, pharmaceuticals, ceramics, etc. Such an article, which has such a compressive coverage of clay, helps to create research on a scientific basis and to better understand the reaction of this material with other materials.

- M Y Muntari, A O Windapo, "Clay as Sustainable Building Material and its Benefits for Protection in Built Environment", *IOP Conference Series: Materials Science and Engineering,* 2021 .

The use of clay as a building material since ancient times and the natural advantages of this material, affect the improvement of the dimension of sustainable development. Such an approach of this research paper will help us in our objectives in creating a focus for the exploration of clay material as a primary material in the combination of the research product for the working dissertation. The 100-year lifespan of clay, ecological, healthy, sustainable material, which is suitable for use in the envelope of the object.

- Neeraj Kumari and Chandra Mohan, “Basics of Clay Minerals and Their Characteristic Properties”, London, W1W 5PF,: IntechOpen Limited, 2021 .

This chapter part of the book Clay and Clay Mineral by Gustavo Morari Do Nascimento , contains the basic specifications and specific properties of the clay material, which helps in our research approach to better understand the behavior of this material in combination with other materials. The description of the constituent minerals of clay, their chemical structure and the classification of clay depending on the constituent minerals, helps to gain an overview of the clay depending on the region from which it is obtained. And this is related to: its color, its reaction in combination with water, its absorption properties, its shrinkage properties during drying, the structure of the product after firing in the oven. All of these are reflected in the final research product of this dissertation, which is subjected to laboratory tests.

- Praise Akisanmi, "Classification of Clay Minerals", *IntechOpen,* 2022 .

Classification of Clay Minerals part of the book “Mineralogy” by Milos Rene, depending on the division of the mineralogical groups that make up clay, it is shown that clay has extensive compositional possibilities in the construction field. Each mineral that makes up clay has its own specifics, which provide reference orientations for the behavior of clay in various fields of everyday life, in geology, in the environment, geotechnics, technology, in construction and in science. This material of this research complements our dissertation and the specifics of the clay material in the performance of the building envelope.

- Na Li, Yalan Zhu, Fang Zhang, Sin Mei Lim, Wangyi Wu, Wei Wang, "Unconfined Compressive Properties of Fiber-Stabilized Coastal Cement Clay Subjected to Freeze–Thaw Cycles," *MDPI ,* vol. 9, no. 2, 2021 .

The approach of this research analyzed how the combination of clay with other materials could show better mechanical performance after the completion of the freeze-thaw cycle process. And such an approach promised that the combination of the research product of this doctoral dissertation, after being subjected to freeze-thaw cycles, would show better results in resistance, which directly affects the durability of the building envelope.

- Jhamir A. Llatas-Contreras & Ángel A. Ruiz-Pico, "Use of steel slag to improve the mechanical properties of subgrades in clayey soils," *Revista DYNA,* vol. 91, no. 231, pp. 128-134, 2023 .

The research of this research paper analyzes the use of slag in clay soils. And from the conclusions, the slag material has the potential to affect the improvement of the mechanical and physical properties of clay soil. Such research in the dissertation topic can be taken as an important parameter during the combination of clay with slag material. Offering the opportunity to improve stability, physical, mechanical performance, and sustainable development.

Slag:

- Wenhao Gao, Wentao Zhou, Xianjun Lyu, Xiao Liu, " Compressive utilization of steel slag: A review", Powder Technology, 2023 .

This research paper, slag as an industrial waste which exists in large quantities, discusses its use in various fields of industry with a focus on sustainable development, which has recently seen its use increase. The use of slag would affect reducing industrial waste, improving mechanical properties, replacing construction materials, and such an approach would result in reducing costs and reducing environmental impact. The possibility of using slag is in construction materials, agriculture, wastewater treatment, civil engineering, ceramics, etc. Such an orientation of the use of slag in our doctoral dissertation research work offers assistance and opportunities for research that the use of slag by improving its mechanical properties in combination with other materials will affect the increase in the lifespan of facades and their performance.

- Maohui Li, Youjun Lu, Yajuan Liu, Jingjun Chu, Tongsheng Zhang, Wei Wang, "Influence of the Steel Slag Particle Size on the Mechanical Properties and Microstructure of Concrete ", *Sustainability,* vol. 16, no. 5, p. 2083, 2024 .

Such an article explores the use of slag as a recycled material in the context of improving sustainability by replacing traditional materials such as sand or gravel. And such an approach of combining slag (with fine particles) with concrete, with the results in the microstructure of concrete improving mechanical properties, and the bonding of materials, helps in our research that the combination of this material with other materials offers innovative possibilities in the durability of the facade. Also, another orientation is the innovative approach with an emphasis on sustainable development.

- Mugahed Amran, G. Murali, Nur Hafizah A. Khalid, Roman Fediuk, Togay Ozbakkaloglu, Yeong Huei Lee,Sani Haruna, Yee Yong Lee, "Slag uses in making an ecofriendly and sustainable concrete: A review ", *Construction and Building Materials,* vol. 272, 2021 .

This article investigates the production of ecological concrete using slag. This results in its resistance to aggressive environments, results in its ability to be more environmentally friendly, facilitates energy costs in concrete production, and reduces carbon emissions as it helps reduce cement production. Such an approach in our doctoral research helps in obtaining information on the possibility of slag interaction with other materials, in the ecological objectives of the combination, by increasing mechanical properties, resistance to deformation, presenting the pozzolanic effect, and providing alternatives for reducing the burden on environmental pollution.

- Mengtong Liu, Hui Liu, Minqi Hua, Chunhong Chen, Xinjie Wang, Xiang Guo,Tianyu Ma, "Potential for Recycling Metakaolin/Slag-Based Geopolymer Concrete of Various Strength Levels in Freeze–Thaw Conditions", *MDPI,* vol. 17, no. 9, 2024 .

The combination of building materials with slag material, after undergoing experiments of 350 freeze-thaw cycles, showed good performance, and in these cases the slag composition was 40%. Such an analysis promised that the combination of slag in the research product could promise sustainable building practices, withstanding external atmospheric conditions for a long time.

Wood, Sawdust:

- Anna Sandak, Jakub Sandak, Marcin Brzezicki, Andreja Kutnar, Bio-based Building Skin, Singapore: Springer Nature, 2019, p. 183 .

Such a book elaborates on the use of bio-materials in building facades. The use of bio-materials plays the role of co-design with the surrounding nature, dealing with their technical aspects. In this case, of the bio-materials treated in this book, for our research, the analyzed specifications of wood and its impact on building envelopes help and serve us. The use of wood material in building envelopes creates high aesthetic values, contributing to the reduction of environmental impact, good thermal, structural, ecological, and biodegradable performance.

- Abraham Mwango, Chewe Kambole, "Engineering Characteristics and Potential Increased Utilisation of Sawdust Composites in Construction - A Review ", *Journal of Building Construction and Planning Research,* vol. 7, pp. 59-88, 2019 .

This research provides data on the production of sawdust material, and the challenges of dealing with its disposal in the environment or in open burning. And the possibility of using this material in combination with other materials, can increase elasticity, affect strength characteristics, low thermal conductivity, and sound insulation. These specifics of the combination of sawdust material with other materials also play an important role in the research for the research product. Specifically, the combination of sawdust with clay material and other proposed materials, which will be discussed during this work.

- Naomi Keena, Marco Raugei, Mae-ling Lokko, Mohamed Aly Etman, Vicki Achnani, Barbara K. Reck, Anna Dyson, "A life-cycle approach to Investigate the Potential of Novel Biobased Construction Materials toward a Circular Built Environment ", *Energies,* vol. 15, no. 19, 2022 .

This research analyzes LCA (Life Cycle Assessment) in the context of bio-based materials, and their use in sustainable construction, with special emphasis in our case on wood. The use of products made from sustainable materials or waste materials helps in human well-being, in a more environmentally friendly approach, in reducing CO2, and in reducing construction waste. Such an approach helps us in our research work, based on the meaning of LCA, trying to categorize our research product in this life cycle, i.e. Life Cycle Assessment.

Wood ash:

- Ece Ezgi Teker Ercan, Lale Andreas, Andrzej Cwirzen, Karin Habermehl-Cwirzen, " Wood Ash as Sustainable Alternative Raw Material for the Production of Concrete - A Review ", *Advances in Sustainable Construction and Building Materials,* vol. 16, no. 7, p. 2557, 2023 .

This research paper deals with the use of ash taken from thermal power plants and local kilns, to test its properties as a binding component. The role of ash, also called fly ash, in this paper is treated as an ecological binder and also as a possibility for replacing cement in the production of concrete, up to 10-20%. This resulted in fly ash being a promising material in construction. Such an approach helps in reviewing the possibility of ash as a material to be proposed as a component of the research product, which would affect strength and durability.

- Piotr - Robert Lazik, J. Bošnjak, Ebru Çetin, A. Küçük, "Application of Wood Ash as a Substitute For Fly Ash And Investigation of Concrete Properties ", *Google Scholar,* pp. 103-118, 2020 .

This research addresses the possibility of using wood ash in construction, as a binding material and substitute for fly ash. Such a use would affect environmental protection, economic efficiency, and the production of bioeconomic products. Such material is also promising for dissertation work, to examine the possibility of combining it with other materials. And a combination with wood ash can improve mechanical properties and ecological benefits by reducing the waste of this material in the environment and in landfills.

- Hamed Gharibi, Davood Mostofinejad, Mohammad Teymouri, "Impacts of Conifer Leaves and Pine Ashes on Concrete Thermal Properties ", *Construction and Building Materials,* vol. 377, 2023 .

Such research addresses the thermal properties of wood ash material in combination with other materials, which shows good performance as an insulating material and low water absorption. This research is also helpful in the doctoral dissertation, which shows that the possibility of combining wood ash contributes to thermal performance and improving energy efficiency performance.

Lime:

- Lei Zhang, Weixiao Han, "Simultaneous Investigation of Mechanical and Hygrothermal Properties of Lime Stabilized Earth Bricks", *OP Conf. Series: Earth and Environmental Science,* 2021 .

The use of lime material in brick products has been analyzed in the above-mentioned research. And the different participation of lime in bricks affected different performances of mechanical, hygrothermal properties. The percentage of participation with 6% showed promising results. Such an approach also helped us in the potential possibility of lime material to be combined with other materials of the research product, contributing to efficiency and sustainability.

2. OVERVIEW

This chapter will address the chronology of the development of building envelopes in the context of Sustainable Development. Considering other factors within the framework of sustainability that meet the criteria of engineering development.

Building facades have a unique history of development, especially those that are built from bio-based materials. These facades play a significant role in society as well as in engineering, affecting energy efficiency. The chronology of their development, including traditional, industrialization, integration of technology, identification of challenges, advantages and trends towards the use of bio-based and recyclable materials, is the overview of this chapter.

2.1 Building facades

This chapter will also discusses the current position of the building envelope in relation to sustainability development, targeting the following dimensions: social, ecological and economic. The building envelope is part of the architectural elements of a building, plays the role of a mediator between the internal structure of the building and the environment and at the same time separates the private sphere of man from the external environment [1].

The following points will provide explanations about the building envelope and its role in structural and architectural engineering:

- functional role,
- reduces energy losses,
- aesthetic role,
- conveys the identity of the building,
- is considered the first contact of man with the building,
- is considered the first contact of environment with the building,
- often reflects the culture of the respective country,
- often plays the role of a transmitter of messages,
- protects the building from climatic conditions,
- creates a comfortable environment in the interior spaces,
- helps energy efficiency,
- reduces noise,
- helps in the penetration of natural light,

By listing the above points, it is concluded that the building envelope plays a multiple role in the life aspect of the building. The building envelope in many cases reflects the culture and identity of a certain society, because the building is completed by people who build a meaningful environment, which is expressed through symbols, elements [2]. Also, regarding the phenomenon of building physics, the facade of buildings designed with specifications based on building standards, creates a suitable and comfortable environment for a person, by managing air pressure, temperature difference, air change, vapor pressure, shown in the Fig. 1. The main challenge of today's architects regarding the building envelope is the balance of aesthetics, functionality and sustainability, all of which are related to the construction of the building. The categorization of facades according to recent design practices can be categorized as follows *[3]* :

- Utilitarian facade (Responds to the structure of the building, the environment and the function)
- Formal facade (determines the form of the building),
- Image facade (transmits communicative messages to the person and the wider public sphere).

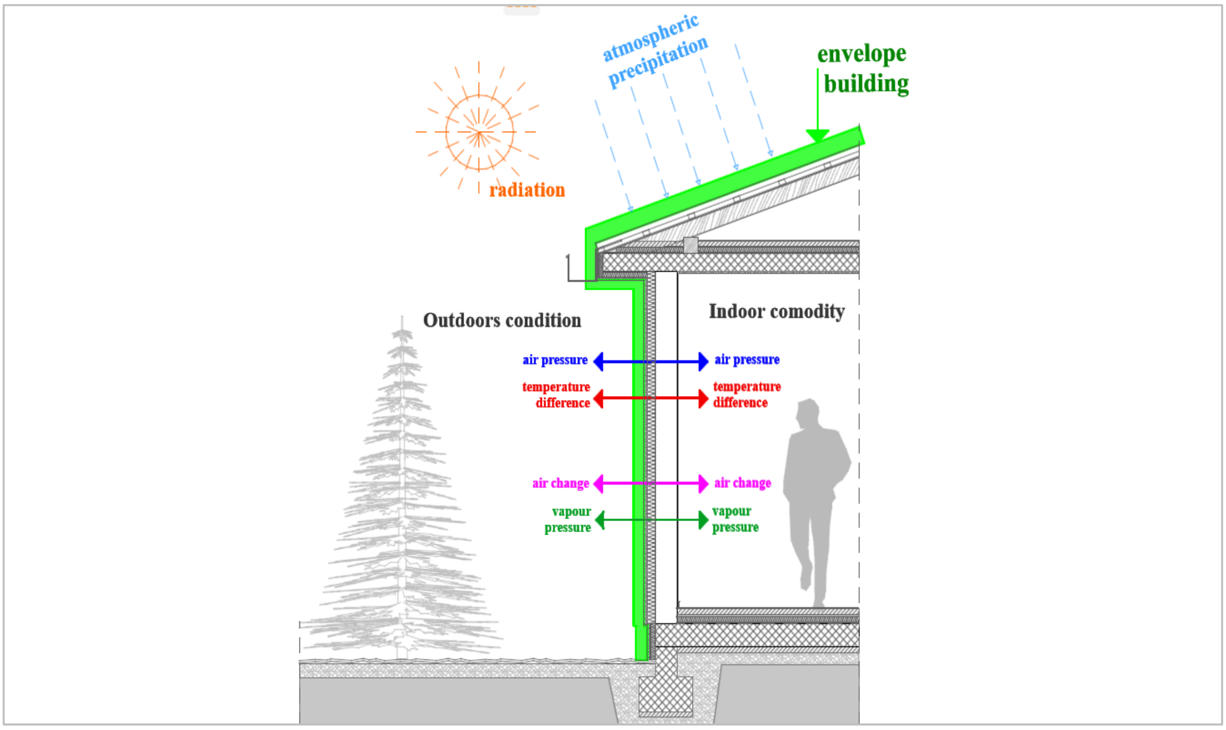


Figure 1.The role of the facade in the external and internal environment, creating a comfortable environment and helping with energy efficiency

2.2 History of facades

The word "facade" derives from the Latin word "facies" or "facia" which means "front" or "face" and corresponds to the English word "appearance" [4]. In the literature and research on building facades, we find expressions such as: envelope, curtain wall, skin and surface, which are used in different contexts, and due to this variety of these expressions for building facades [3] the article provides definitions for each term and their specifics.

During different historical periods, the envelope of buildings has undergone changes in both functional and aesthetic aspects. In these different historical periods, the basic material of the facades has mainly been from local sources, which has reflected the culture and practical needs of the society of a country. In monumental architecture, the primary relationship was the form/function/facade. While in early modernity it became common to take care of the pictorial composition of the facade, from this time the meaning and role of the facade in the field of architecture has had different meanings in the architectural aspect. An example of this situation is the symmetrical facades of the Renaissance, which paid attention to the external appearance.

Then follows Robert Venturi's approach "the facade is the place where architecture takes place" [5] that in Rococo and Baroque we have decorative facades, while in Neoclassicism the classical order was restored. During the industrial revolution, radical changes were made in the use of materials for the structure of facades, with steel and then concrete becoming the primary material [6]. This revolution continued in the second half of the 19th century, enabling the construction of thin walls, which in the first decade of the 20th century enabled the construction of glass facade of buildings. But in the 1970s, due to the lack of oil, concern began to arise about global energy resources, and about the importance of designing energy-efficient buildings, specially building facades [7].

Essentially, the building envelope has played the role of protecting the building from external environment factors. But with the development of technology and the construction industry, the transition from massive facades to lightweight ventilated facades has been made, this change reflects aesthetics, sustainability, technological advances and social development. The biggest change occurred during the 1950s, after the Second World War and until today, which also represents the fastest social developments [3]. During this period, the transition of the envelope through different architectural styles has brought unique contemporary approaches to intelligent facades.

In recent years, the focus of facades has been on passive structures and energy performance [8]. This current state of affairs was envisioned in 1981 by Mike Davis who suggested the building envelope "skin" which could act as a nanometric absorber, a radiator, a reflector, a filter, a transfer device, adapting to external environmental conditions in the same way as human skin, but always paying attention to the visual appearance and optimal performance [9]. Such examples of facade types are shown in several attached views in the Fig.2.

Figure 2. Examples of building facades, Prishtina

2.3 Urban image

The building envelope, in addition to influencing the formation of a living space for humans, is also a vital part of the urban image and defining the identity of the city. This is understood in this way; facades are primary elements that stand out and directly affect the aesthetic and cultural perception of an urban space. Since facades are structural elements of buildings, built in different architectural styles, this also indicates the urban development of certain localities. But if bio and recycled materials are incorporated into the facades, then the image of a city also belongs to a living ecosystem. This can be explained by linking the term “collective memory” between elements of nature and the urban landscape. Facades built from biomaterials help the city to achieve a hybrid combination of sustainability, aesthetics, functionality and the urban ecosystem. Such a need for integrating biophilic design (facades that promote nature) into urban environments helps improve the physical and mental well-being, experience of people and society in general [10]. The use of biomaterials in the building envelope and in the structure of buildings helps to create connections between generations of different generations and increases well-being in protecting the planet. Biomaterials used in the facade can recall the traditional architecture of a region by connecting the modern city with historical and cultural roots, such evidence is the old heritage buildings built from biomaterials. At the same time, such an approach can function as a preserver of history, traditions, and culture for certain regions.

Figure 3. Facades creating the image of the city, Prishtina

Figure 4. Facades creating the image of the city, Skopje

For example, projects supported by UNESCO, which for the restoration of old buildings foresee bio-materials with traditional techniques to preserve the identity, cultural image and historical values [11], [12], [13]. As an example of how the urban image is shaped by the building envelope, several attached photographs are presented in Fig.3 and Fig.4.

2.4 Psychological impact

The facade of buildings creates the first impression and emotional connection with the building. Human behavior, the perception of experience are influenced by: colors, materials, geometry, light, complexity, and the interwoven architectural flow [14]. These experiences can be positive or negative, they can create emotional calm or emotional distress. For this part of perception, neuro-architecture is considered in more detail [15]. And a better understanding of the impact of the facade on human emotional receptors would enable the design of facades that can reduce stress and bring happiness. One of the first pioneers in this field was Roger Ulrich, who in his studies on the effects of nature on health spaces gave importance to the use of natural materials in buildings because of psychological well-being.

Our focus is on how the use of biomaterials in the facade would be experienced by humans, based on this connection with the history of passive facades built from biomaterials, which have offered comfort, naturalness, warmth and well-being from the outside. Biomaterials such as: clay, wood, and plants that have a connection with nature affect the reduction of stress and the improvement of the emotional state and in a more balanced environment. Humans themselves tend to seek connection with nature, in this aspect we have the study Biophilia by Edward O. Wilson [16]. Meanwhile, on how built spaces that incorporate natural materials help reduce stress and improve cognitive focus, we have Keller's study [17].

While organic materials with earthy textures, which often have warm and organic textures, such as clay and wood colors, often offer positive psychological effects such as lowering blood pressure and increasing satisfaction with built spaces [18], this also affects the fact that facades made from organic materials create a greater emotional connection with the space. This natural approach of man to nature represents an ecologically responsible approach to general well-being. And such an approach of man is also documented by ancient buildings made of biomaterials, which in a form are part of passive architecture.

It can be concluded that the building takes shape based on the building envelope, the impact of the building envelope in daily life plays a crucial role in our life dynamics, and personifies a culture of a region, transmits messages, shows the transition, the culture of a place and affects the collective memory. In many cases, the building envelope serves as a locator, as an orienting reference point on the map of a certain place and here it affects how it is perceived by the broad mass of individuals. In everyone, the building envelope is perceived and experienced in different ways, but what is expected from the building envelope is the transmission and creation of a sense of security, comfort or inspiration. Based on the evolution of industrial construction techniques, or the transition from traditional to modern designs, the building envelope is constantly advancing, and the target is human comfort and well-being.

2.5 Sustainable Development

Building facades made from bio and recycled materials are considered part of sustainable development, because with such a composition of materials, they help improve the environment, connect with the environment, save energy, improve energy efficiency in buildings, and create cozy spaces for users. Facades made from bio and recycled materials are considered biodegradable elements, safe for the environment, preserving biodiversity with a sensitivity to nature [10]. These approaches to facades make these elements align with sustainable development in their dimensions: economy, environment, and society.

Sustainable Development, as a terminology, dates back to 1972 at the UN Conference on the Human Environment - Stockholm, at which the UN program on the environment was also created [19]. And since then, it has continued to develop; to advance and many organizations have taken the lead in certifying sustainable building, their part also includes the building envelope.

In Europe, the standards for supporting and advancing energy efficiency performance, which are made by EFP (Energy Performance of Building Standards), are managed by the European

Committee for Standardization (CEN). Based on their statistics for the EU: buildings are responsible for 40% of energy consumption, while 36% of them are responsible for gas emissions. Their policies foresee investments in energy efficiency with a special focus on cultural heritage buildings. While by 2030, according to the European Commission UN, objectives are set for reducing gas emissions by up to 55%, while by 2050 to be the first climate-neutral continent [20], [21] .

One of the first certifiers listed is BREEAM, then LEED [22], while other organizations that are more active in organizing campaigns and initiatives for sustainable development are: the World Commission on Environment and Development (WCED) which has unveiled the “17 Sustainable Development Goals” campaign shown in the Fig.5, which are expected to be achieved by 2030.

Figure 5. "17 Sustainable Development Goals" *[23]*

“17 Sustainable Development Goals”, these objectives are listed as follows [24]:

- No poverty
- Zero hunger
- Good Health and well being
- Quality Education
- Gender Equality
- Clean Water and Sanitation
- Affordable and Clean Energy
- Decent work and Economic Growth
- Industry, Innovation and Infrastructure
- Reduced Inequalities
- Sustainable Cities and communities

- Responsible consumption and production
- Climate action
- Life below water
- Life on land
- Peace, justice and strong and strong institutions
- Partnerships for the goals

Of the 17 goals of the SDG "17 Sustainable Development Goals", some of them are directly or indirectly related to buildings and their role in sustainable development, these are [23] :

- Goal 7: Use of renewable energy in buildings, to reduce energy consumption,
- Goal 9: Use of innovative materials that support economic and environmental development
- Goal 11: Prove sustainable construction, a more environmentally friendly architecture and sustainable urbanism, to create safe cities for residents.
- Goal 12: Use of recycled materials and bio-based materials in construction, which help reduce waste and achieve sustainable construction
- Goal 13: Build low-carbon and climate-resilient buildings
- Goal 15: Use of bio-based materials to preserve terrestrial ecosystems and reduce land degradation.

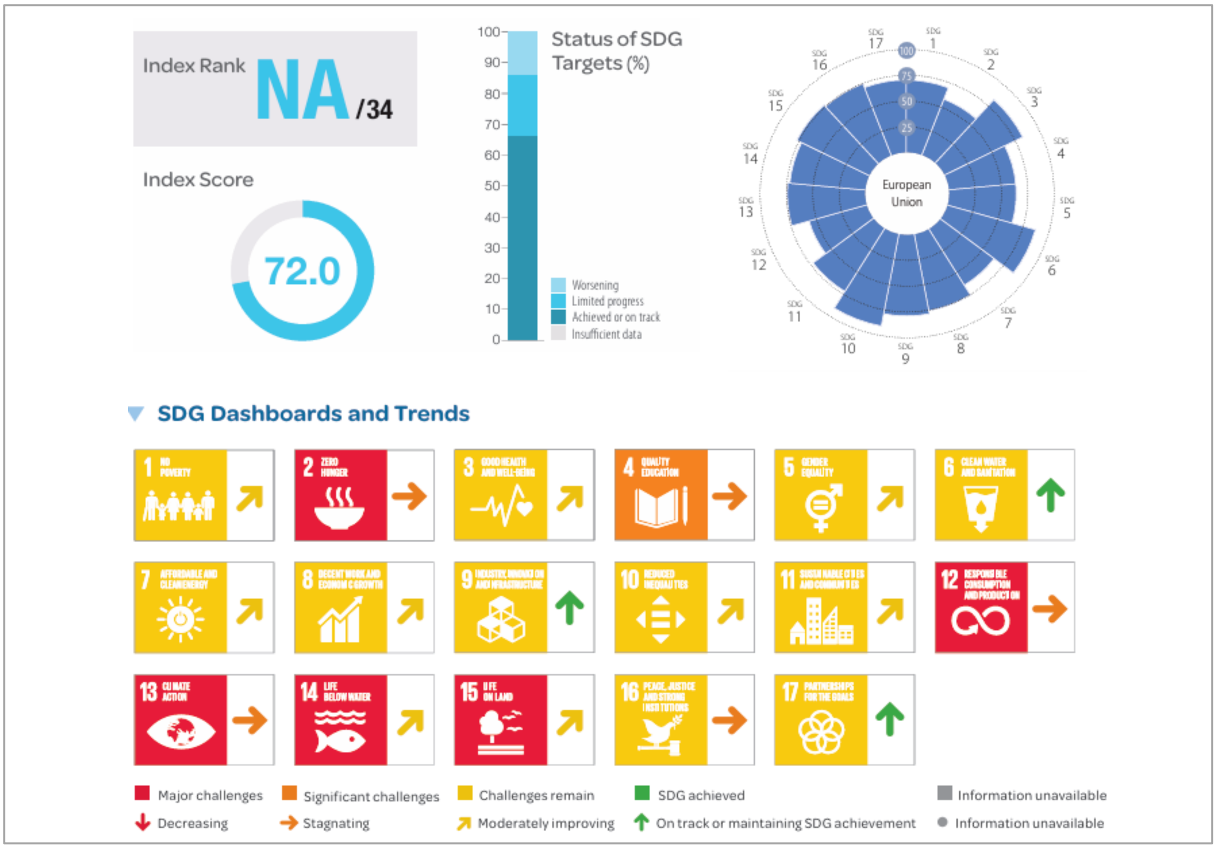


Figure 6. The performance of the states of the European Union for the year 2023-2024 *[25]*

The following is the report for the year 2023-2024, Fig.6, which deals with European countries on their development progress in the "17 Sustainable Development Goals", these results were generated by Europe Sustainable Development [25].

2.5.1 Dimension of Sustainable Development

Within the framework of Sustainable Development, three dimensions are distinguished: social, economic and environmental [26]. These three dimensions encompass the multidimensional sector for Sustainable Development, while how the facade of buildings manages to integrate these three dimensions will be described below in the Fig.7 and Fig.8.

A. Social dimension

This dimension includes people's well-being: mental/physical health, education, and the provision of healthier spaces related to the environment. This includes the psychological experience of bio and recycling facades, which affect stress reduction and improved well-being.

B. Ecological dimension

Even the name of this dimension indicates the connection with nature, and even more so when we are dealing with the main theme "bio facades". In this dimension, the focus is on preserving and improving the environment, using biodegradable materials, which help create environmentally friendly facades. This will contribute to reducing pollution, supporting recycling, and the efficient use of natural resources.

C. Economic dimension

The connection of bio and recycling facades with this dimension is related to energy efficiency. Improving the efficiency of buildings, reducing energy consumption, financial benefits and savings, reducing long-term costs, reducing maintenance costs, which results in the economic sustainability of urban development.

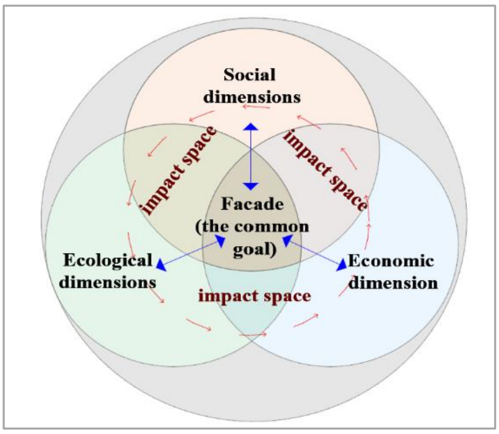


Figure 7. Dimension of sustainable development

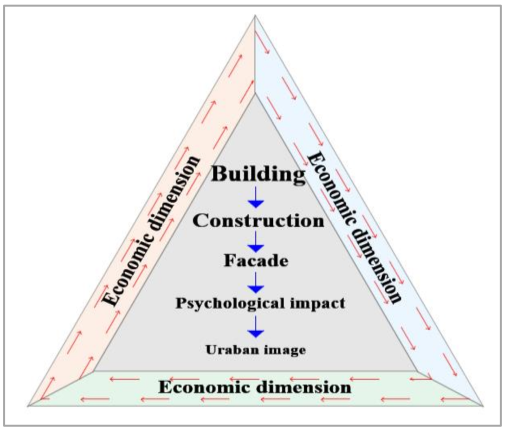


Figure 8. Conceptual Framework of dimension sustainable development, in relation to the building elements

2.5.2 UNEP (United Nations Environment Program)

UNEP is a global organization that operates for all its member countries, and covers topics related to environmental development policies and sustainable development. Their program contributes to the "17 Sustainable Development Goals", while the issues that they consider priority for the European region are [27] :

- Climate Change,
- Biodiversity Conservation,
- Pollution Management,
- Sustainable Cities,
- Circular Economy and Sustainable Production.

2.5.3 LCA (Life Cycle Assessment)

Tool for assessments of the Sustainable Development is LCA, which is a standardized international methodology (ISO 14040 and 14044), which analyzes the impacts of the product on the environment, its service throughout the life cycle until the closure of the biological and technical metabolism, and this potential is possessed by renewable materials [28]. Therefore, the product of this research during the selection of component materials must also be adapted to the LCA methodology, this concept is visualized according to the attached Fig.9.

There are four stages that a product must go through during its life cycle according to LCA [29]:

- goal and scope (purpose of the study, reasons, target audience)
- inventory analysis (collection of data on the energy of the product)
- impact assessment (indicators of environmental impact)
- interpretation (consistency checks, accuracy of results).

The research of the product from bio and recycled materials, during the field research, has passed through the above-mentioned phases. For each phase during the description of the following chapters, it will be proven that the research product is part of the LCA methodology. While in the last phase of the realization of the experiments and the obtained results, the fourth phase of LCA is concluded. The information obtained from the four stages of LCA helps the EPD (Environmental Product Declaration) to act according to the international standards ISO 14025 [30]. The EPD describes these environmental impacts of the product:

- Global Warming Potential
- Acidification

- Eutrophication
- Smog
- Ozone Depletion

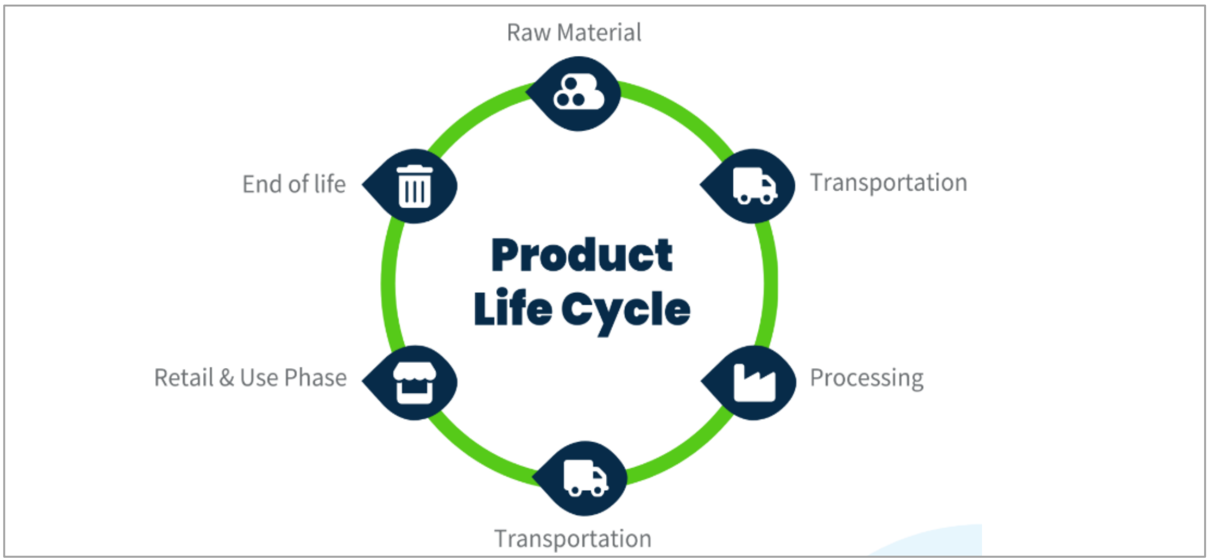


Figure 9. Product Life Cycle *[29]*

In this area of the Dimension of Sustainable Development, the **International Energy Agency (IEA)** also plays an important role. This is an international agency established in 1974 after the oil crisis with the aim of ensuring energy security, promoting and supporting sustainable development and reducing environmental impact for member and non-member countries [31]. The contribution of buildings to energy efficiency policies is also related to the facade of buildings, which affects energy consumption for heating, cooling and lighting. These can be achieved if the materials used in the facade prevent energy loss from the building, retain and distribute energy, increase the well-being of life and the surrounding environment. The IEA also contributes to the "17 Sustainable Development Goals", especially in SDG Goal 7 and Goal 13. For the year 2024, the IEA has reflected the impact values of buildings and their role in the overall energy efficiency performance, according to this, the energy demand in 2023 was over 120EJ, and constituted 28% of global final energy consumption, and according to these reports/scenarios there is progress in energy efficiency by 2023 [32], these activities are reflected in Fig.10, Fig.11, Fig.12, Fig.13. According to the IEA, to meet the 2030 energy performance scenario, buildings should be designed to achieve the Zero Net Emissions Building (ZNE) principle, while existing buildings should promote energy-efficient solutions. This approach means designing and constructing buildings that result in net zero greenhouse gas emissions, i.e. producing as much energy as is consumed [33].

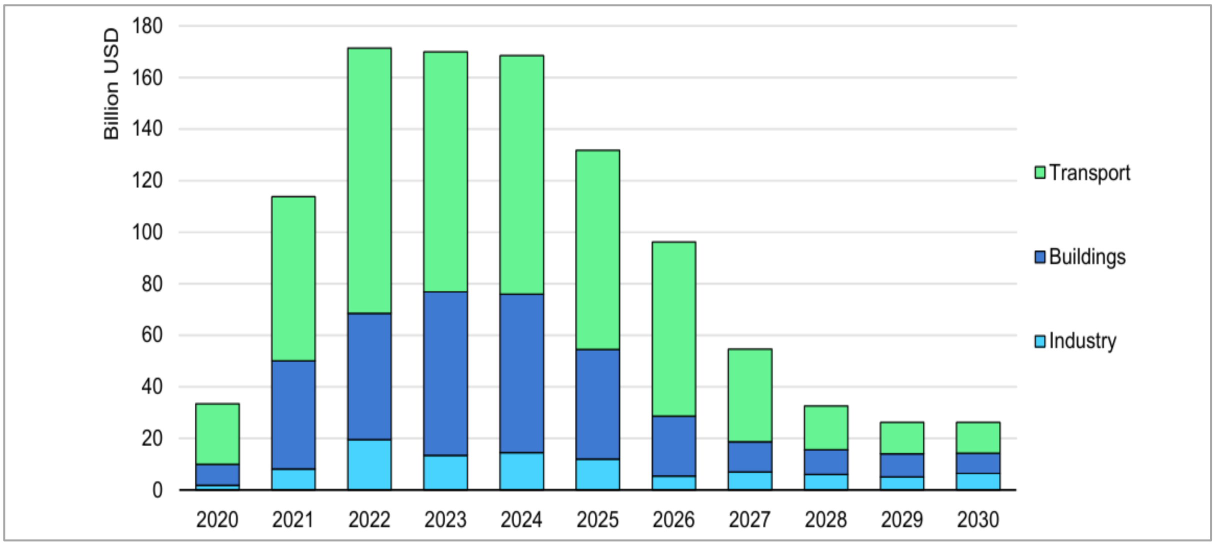


Figure 10. Earmarked government spending for energy efficiency, by sector 2020-2030 *[32]*

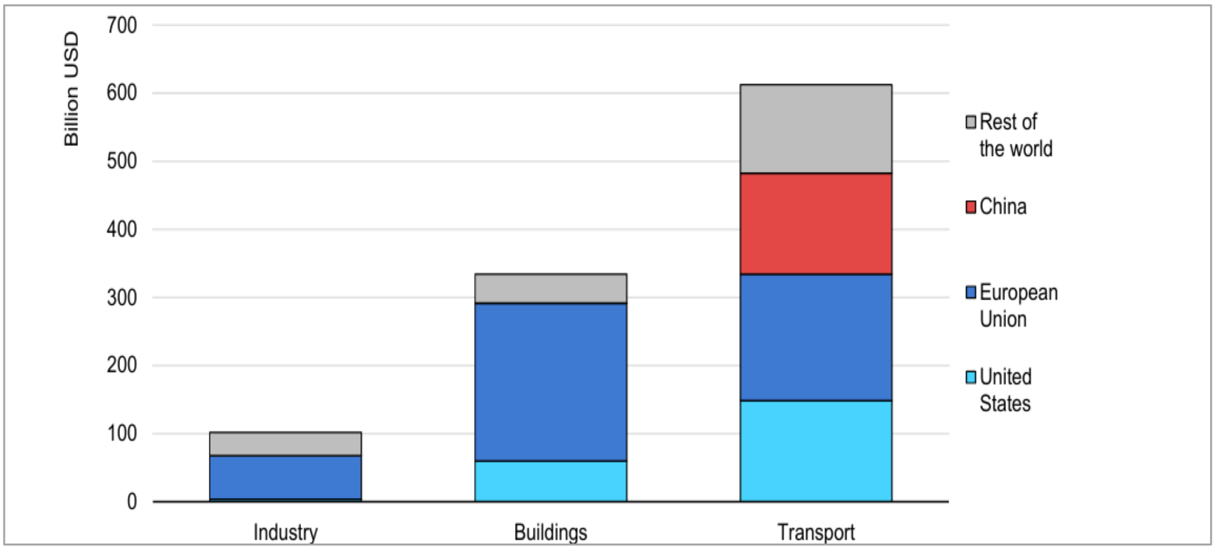


Figure 11. Earmarked energy-related government support, by region and sector 2020-2030 *[32]*

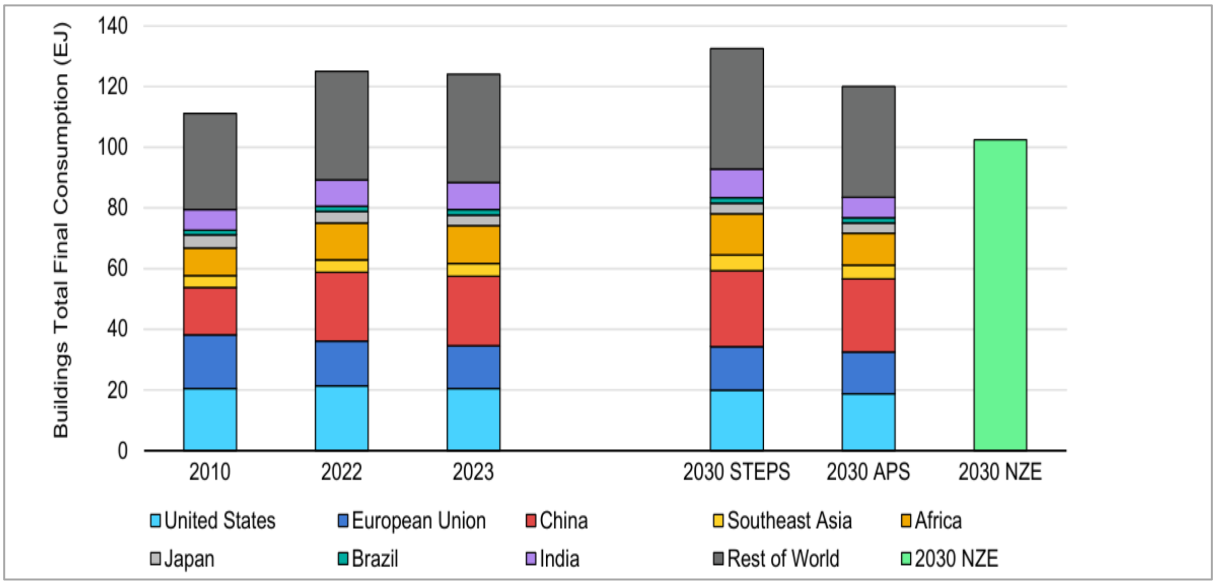


Figure 12. Total final energy consumption for buildings, 2010-2023 *[32]*

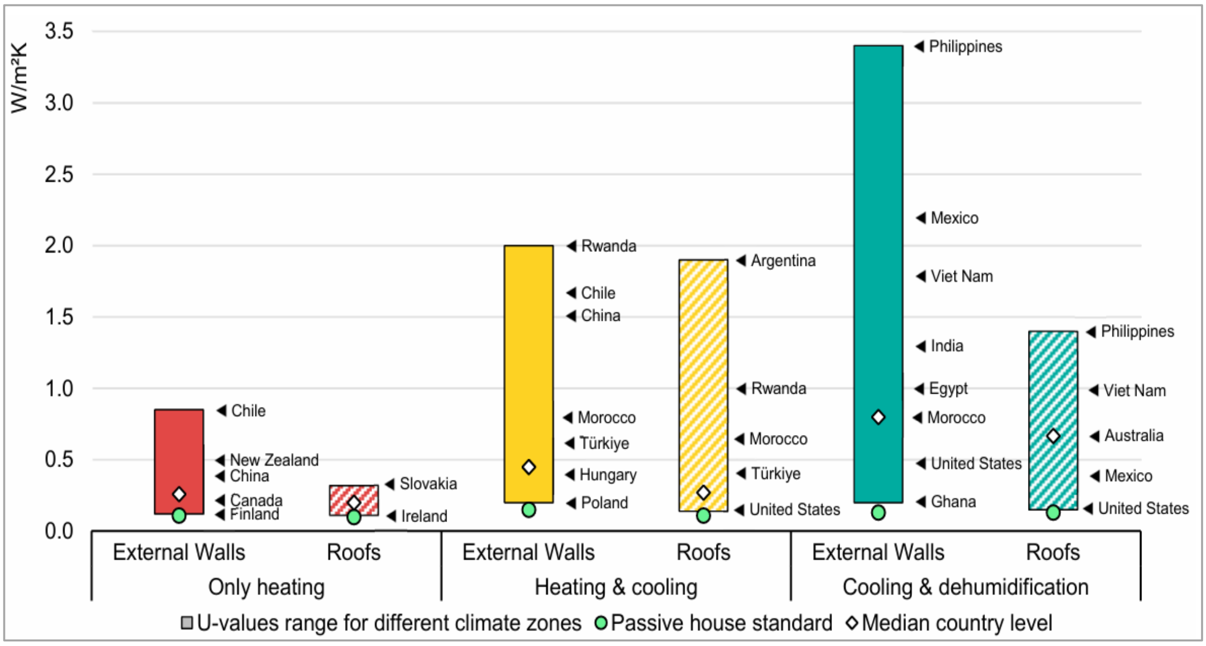


Figure 13. U-values for external walls and roofs by climate zone (W/m2K) based on requirements *[32]*

2.5.5 The Energy Performance of Buildings Directive (EPBD)

EPDM is an example of a policy to encourage the use of sustainable building materials. It is considered European Union legislation to improve the energy efficiency of buildings and also to enable carbon reduction in the construction sector, reducing energy costs for citizens, improving living conditions [34]. For new buildings this directive is expected to be achieved by 2030, while for existing buildings by 2050 [35]. The main objectives of the EPBD:

- Zero-emission building,
- Energy performance certificate,
- Building renovation,
- Green technology integration,
- Intelligent Buildings,

The application of these goals and challenges is related to raising citizens' awareness of the importance of energy efficiency, support and cooperation between states, and financial investments.

The connection of the research product of this dissertation with the EPBD is in the objectives of energy efficiency, sustainability and reduction of environmental impacts. Because the constituent materials of the product aim at thermal insulation by reducing the need for heating and cooling, easy integration into existing building structures, waste reduction, use of recycled materials, creation of products with long life, possibility of recycling after use, increasing the value of buildings in the market because they have improved energy performance.

At the end of this chapter, from the topics discussed above, we can conclude that the building envelope includes a balance between three factors: economic, ecological and social. And if these three dimensions are harmonized, then sustainable development is also integrated into the envelope.

Many organizations listed above play a role in promoting objectives, strategies that aim to reduce negative effects on the environment and efficient energy performance. And the importance of these policies is to set standards by promoting and encouraging the use of sustainable materials, green technologies for a socially responsible and economically responsible life.

3. RESEARCH MATERIALS

The earth's surface is rich in materials that can be used for construction, and their parameters also create conditions for combining with each other and creating composite materials. Since ancient times, as is known in the history of mankind, buildings have been built with natural materials, with materials that have been easy to supply, process and easily put into operation.
The aim of this research was for the product to be composed of regional local biomaterials, but also recycled materials. These materials must be abundant in nature, easy to access, easy to process and put into operation, known in the history of construction and in engineering practice. In recent years, awareness of preserving the planet Earth and contributing to the increase in well-being with nature and man has also influenced the growth of trends towards green construction, encouraging the market and construction industries to invest in sustainable materials, these initiatives are presented in the Fig.14, Fig.15.

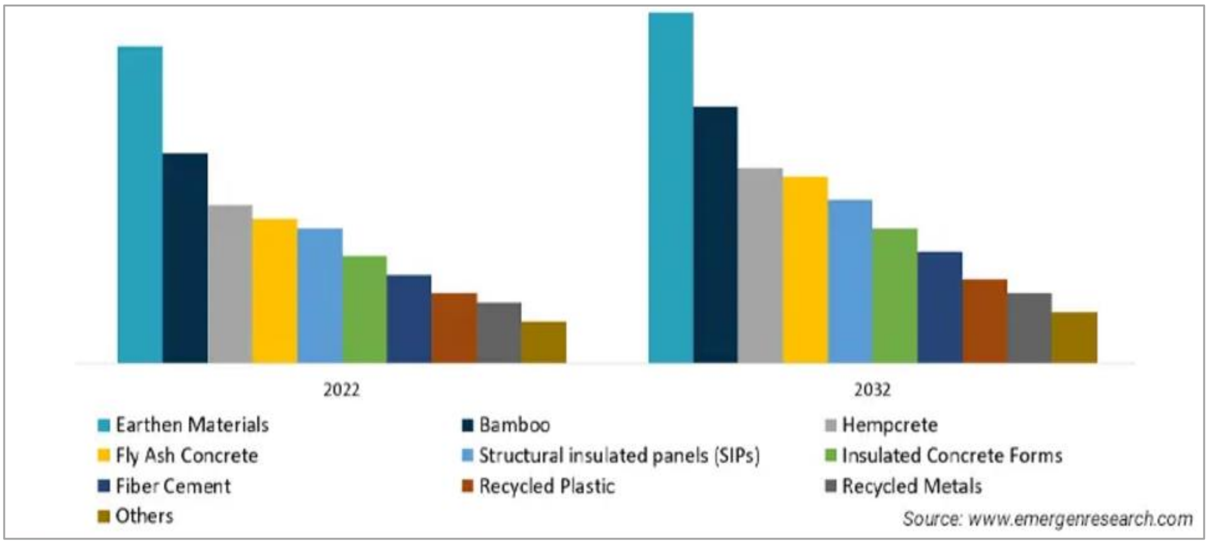


Figure 14. Application of green construction material *[36]*

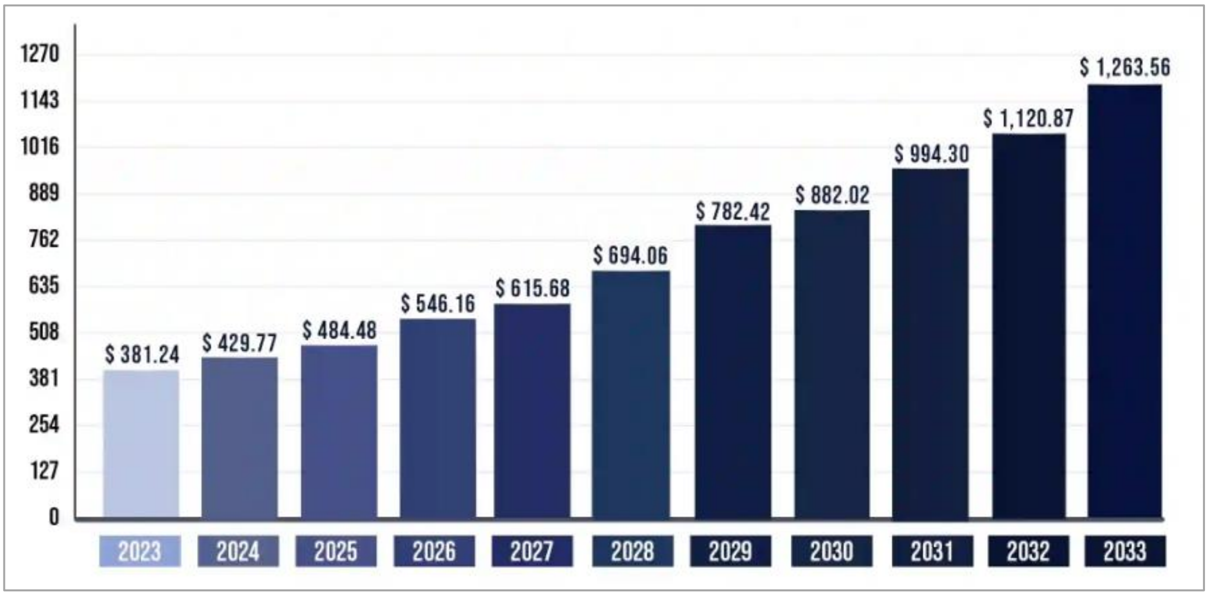


Figure 15. Sustainable construction materials market 2023 to 2030 (USD Billion) *[37]*

This proves that environmental problems are becoming increasingly well-known to architects, builders, investors and consumers. Who are supporting sustainable energy efficiency with preferences for green buildings, in preserving health, in lower energy costs, and in reducing utility bills.

3.1 The constituent materials of the research product

Based on the concepts of bio and recyclable facades, the selection of the constituent materials for the research product has gone through several preliminary selection processes, among them are the following:

- Material availability, how likely is it that the selected materials will be available in quantity and quality, are they common materials?
- Selected materials, how can they affect the structural performance of the building envelope, do they meet technical requirements such as: durability, strength, thermal insulation, etc.
- Accounting for components, do the selected materials fit together, what reactions can be created?
- Ecological properties, the impact of the selected materials on the environmental impact, is there a possibility of their recycling if the product ends its life cycle.
- Cost of work and economic sustainability, is the material economically affordable, how does the total cost affect the final product?
- Ease of processing and workmanship, can existing technologies be used in forming the product, is there a need for special material treatments.
- Aesthetics, what will the visual appearance of the final product look like, is it acceptable for building facades?
- Maintenance, does the product need ongoing maintenance?
- Standards and regulations, do the constituent materials of the product comply with European standards and norms for construction and sustainability.
- The product is selected as welcoming to the community of human groups and as environmentally friendly.

Based on the above specifications that influence the selection of the constituent materials of the product, several materials were selected:

- clay, slag, ash of wood and lime.

Then, during the work in the improvised laboratory in the field work, during continuous testing and research, another combination of materials was selected:

- clay, slag and sawdust.

The change in the combination of materials resulted from the mismatch requested properties of the materials during the creation of the product in the field work this will be explained in the following chapters. Groups of material combinations can be found very easily in nature in considerable quantities, and at the same time are biomaterials obtained from the second subject. However, during the preparation phases of the product in the field, the first material combinations show unsatisfactory results in the physical parameters of the final product. And this created situation leads to the selection of another combination of materials: clay, slag, sawdust in the development of field experiments. These work processes and the factors that have been decisive in the selection of materials will be explained during the phases and procedures of the treatment of the doctoral thesis topic in the future.

The main material in combination with other materials for the research of the construction product, is clay material. This material in combination with other materials is primary in percentage participation, due to the large amount of occurrence in nature compared to other materials, because clay as a material corresponds to nature, harmonizes with the environment, and is a material preferred by the broad masses of people. The classic clay brick is a comparative reference point of parameters during laboratory experiments. While the other materials, slag, ash of oak wood, lime, sawdust are secondary materials or waste from recycling during processing.

3.1.1 Value pH in the combination of materials

Among the specifications and complementary components in the selection of materials, there is also the compatibility of the materials with each other in combination. An indicative factor in the combination of materials is the pH value of the materials, which affects compatibility with the chemical and physical properties of the mixture and its final performance [38]. The pH value is a measurement scale that indicates the acidity or alkalinity of a liquid or water-soluble material, this scale ranges from 0 to 14, pH=7 neutral, pH $<$ 7 acidic, pH $>$ 7 alkaline basic [39]. Among the organizations that take the pH value as a basis as an indicator, technical instrument and contributor to sustainable development is UNEP (United Nations Environment Programme) [40].

<u>pH value of the selection materials:</u>

- Clay (pH 6), a material close to neutral, facilitates combination with other materials by stabilizing the mixture and acting as a binder.
- Slag (pH 10-12), alkaline material, neutralizes acids, increases the durability of materials, creates chemical bonds that prevent the passage of water into the material [41] [42].
- Sawdust (pH 4.5 -6.5) is an acidic material [43], due to its organic substances, which helps to neutralize and manage the pH of alkaline materials, which helps to regulate the viscosity, cohesion, and adhesion of the mixture. It also improves the thermal properties of the materials, depending on the composition of the material in question [44] [45] [46].
- Ash of wood (pH 9 - 14) is an alkaline material [47], [48], this pH value allows its use in construction, as a stabilizer and as a fertilizer in agriculture. Alkaline materials help stabilize the material and reduce water absorption.
- Hydrated lime (pH 13 depending on application) alkaline material, helps neutralize acidity in the soil, improves its chemical and biological qualities, water treatment, is used as a binding material in construction, as plaster, as varnish [49] [50].

Based on these specifications of the selected materials, the combination of materials (clay, sawdust, slag), results in a balanced product and suitable for constructions, which require durability and resistance to moisture. While the other group (clay, wood ash, slag, lime), the product with such a combination will be mainly alkaline, suitable for construction, high resistance to acidity and moisture. These physical, mechanical and chemical properties of the aforementioned materials, serve as a mirror for the characteristic properties of the materials. Depending on the pH values, they guide the possibility of combining the materials with each other, they also provide a mirror for the properties of the final product. At the same time, the results obtained in the field work and in the laboratory during the material processing process, are expected results based on the specifications of the pH values. Also, the combination of different groups of materials (which will be explained in the following chapters of the work), the failure of some groups during field work is also an indicative factor of the combination of pH values.

3.1.2 Selection of materials

During field research to create a bio and recyclable research product, the following objectives and goals have always been considered:

- Factors of sustainable development,

- Impact of sustainable development: social, ecological, economic.
- Psychological aspect,
- Urban image,
- Filters in the selection of materials,
- Ease of access,
- Utilization of locally available materials,
- Reliability of the construction,

All these factors together, if practiced, create a balance between innovation and sustainability in construction. And to provide a more realistic picture of the research product, descriptions of the selected materials in their physical, mechanical and chemical aspects are given below. In these explanations, clay material occupies the primary place, because even in the combination of the research product, clay occupies the primary place with a percentage participation. At the same time, clay, even as a material, is a science in itself, due to the specifics and complexity of its composition.

At the end of the chapter discussed above, it can be concluded that the selection and selection of potential materials is an important phase in the development of the research product. And the use of bio and recycled materials in this product helps the cause of this research. The selection of bio and recycled materials based on their ecological, physical and chemical properties and impact on the life cycle helps in considering also the potential for recycling of the product. During the selection of these materials and in the ability to combine them, an important factor has also been the pH value, which has provided information that such a combination of materials is suitable for the lifespan of the material and the performance of the product.

3.2 Clay

Clay can be considered a fundamental physical and chemical material that affects soil fertility with its constituent minerals, these minerals are part of the soil and surface rocks [51]. Clay minerals affect soil fertility, and plant and animal existence itself are related to clay [52]. Clay on the surface of the earth is formed by the erosion of rocks and soil over long periods of time, which under the influence of atmospheric conditions changes its composition [53]. The environments in which formed clay can be found are: continental, marine, volcanic sediments, as well as rock and geothermal formations [54]. From the parameters of clay which play an important role in its use as a material in the structure of buildings and in the external envelope (this information obtained during this field research) the following physical, chemical and mechanical parameters can be characterized: thixotropy, plasticity, binding ability, color, ability to mix with other organic materials, performance against external atmospheric conditions, ability to withstand mechanical forces, rheological properties. And all of these depend on the composition of the clay minerals, depending on the location.

Depending on the classification of soils, the possibility of their use for construction, and the identification of clays, we can find the following methods and standards, which are practiced:

- ISO 14688-1: 2017 - Geotechnical investigation and testing — Identification and classification of soil [55],
- ASTM D2487 - Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) [56].
- ASTM D2488 - Standard Practice for Description and Identification of Soils (Visual-Manual Procedures) [57],
- Casagrande plasticity chart [58],
- Polidori's plasticity chart [59],
- Atterberg Limits [60],

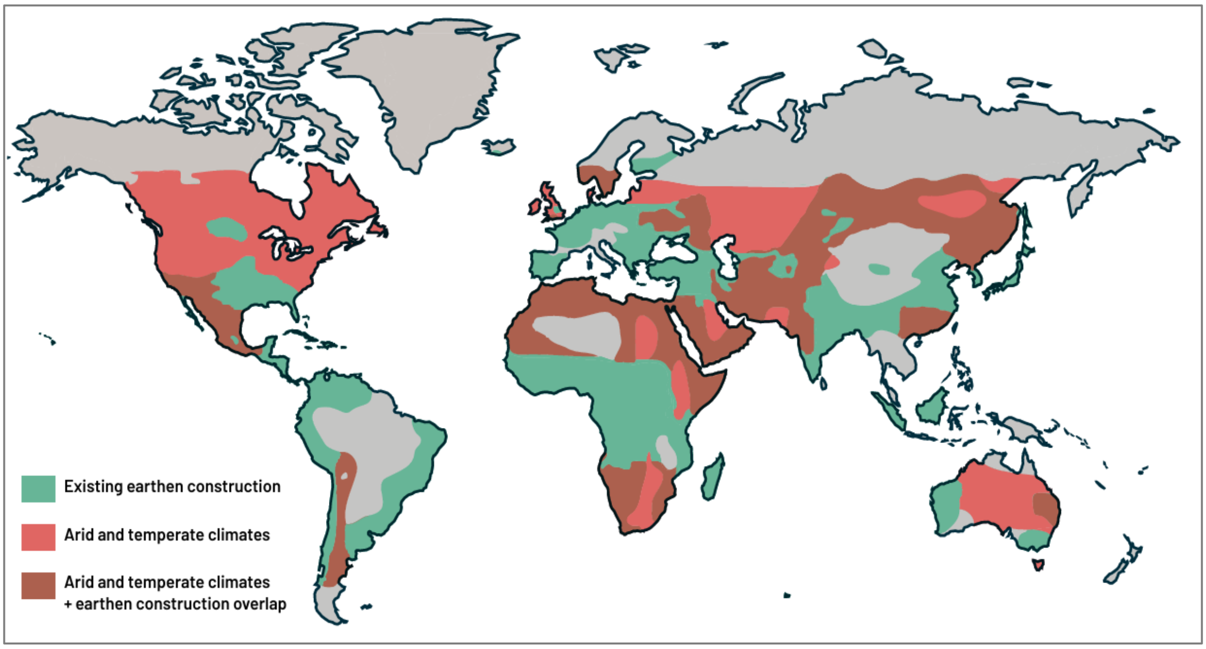


Figure 16. Potential for earth-based buildings *[61]*, *[62]*

In the attached figure Fig.16, it is shown the extent of constructions in the world made of clay material. Constructions made of clay material which are considered sustainable, ecologically healthy, have a duration of 100 years, which retains heat in the winter period and freshness in the hot seasons and also have low encapsulated carbon [63].

The Atterberg Limits test, which can be performed in the field and is simple, is most used, especially by engineers. This test was created by Albert Atterberg himself in 1910 and is a soil consistency test used to distinguish between two types of soil composition, namely silt and clay [64]. The limits in this test are the liquid limit (LL) and plastic limit (PL) which are in accordance with ASTM D4318 "Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils" [65], [66]. This explanation is given in the accompanying figure below Fig. 17.

This test also shows the plasticity index (PI), which represents the difference between the liquid limit and the plastic limit. This indicates the plastic behavior of the soil, and results in the explanation that soils that have a high PI index have a high clay content while the opposite of this indicates soils with a low clay content [65].

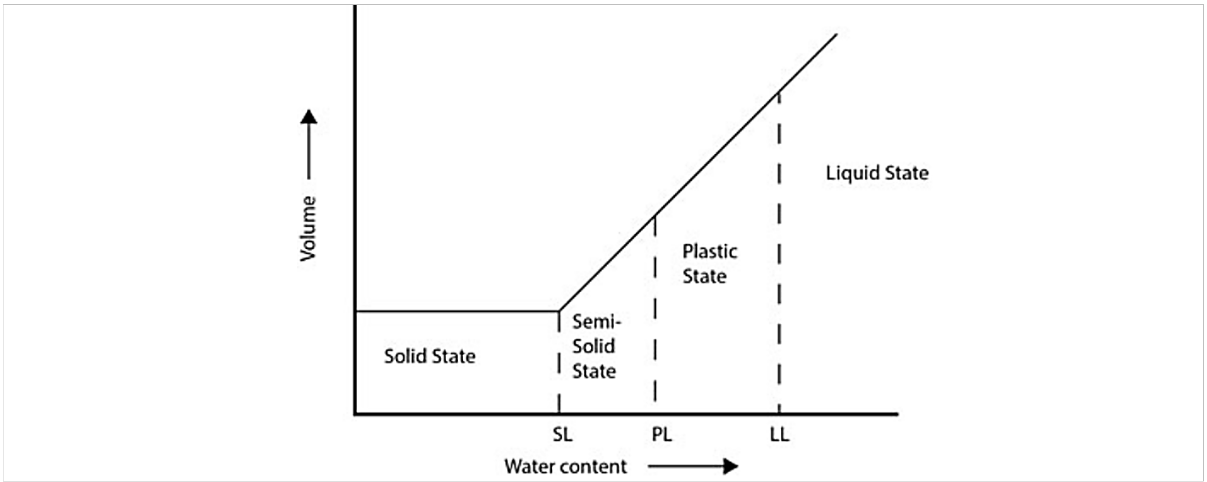


Figure 17. Land classification *[65]*

3.2.1 The history of clay

Easy access to the clay material, as well as easy availability for use, excluding the lack of this material for use, have been indicators that have resulted in clay being used for construction and for elements of work, food and accessories since ancient times. Based on this, traces of the use of clay are found in every region of the globe. In our case, the focus is on buildings, such an example is the residential buildings of Jericho, 7800 years BC [67], this example of such buildings personifies the ancient historical architecture of humanity and construction, also shows the importance given to the clay material in construction. Indirectly, this also reflects the application of biomaterials in construction by contributing quite well to environmental conservation, energy efficient performance and the aesthetics of the building's outer shell. For clay material in industry there is evidence for its use as soap and absorbent, which was reported by the author Pliny the Elder (c. 77 CE) [68], [69].

3.2.2 Chemical and physical characteristics of clay

Velde and Meunier in the book “The Origin of Clay Minerals in Soils and Weathered Rocks” in 2008, identify clay as having minerals with dimensions less than 2 µm (micrometers), which within its composition includes small particles of: silicates, oxides, carbonates [70].
The basic crystalline units of clay minerals are presented in the form of planar hydrous phyllosilicates, which are represented by tetrahedrally structured sheet silicates (Si^{4+}, Al^{3+}, Fe^{3+}) and octahedral sheets (Al^{3+}, Fe^{3+}, Mg^{2+}, and Fe^{2+}) [71], [72], this structure is shown in the Fig.18.

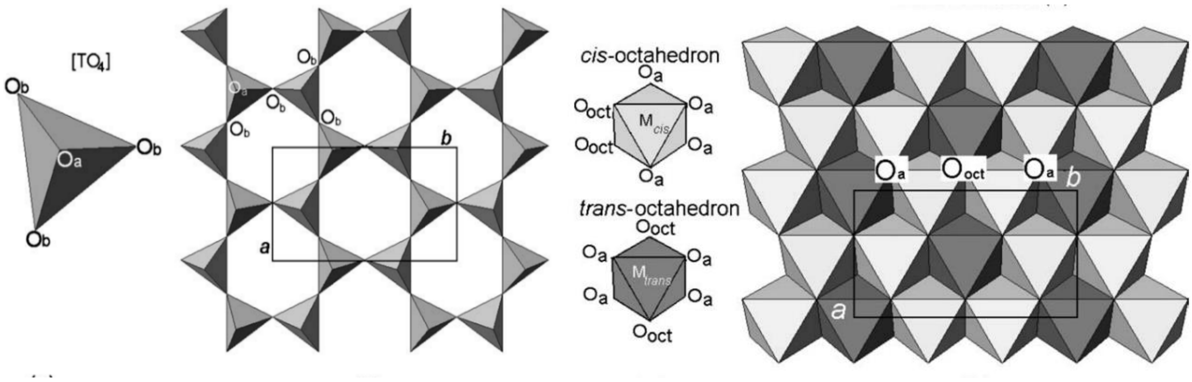


Figure 18. Structural representation of phyllosilicates: tetrahedral sheet and octahedral sheet *[72]*

Sedimentary environments are composed of clay minerals and during the process of clay formation many factors have influenced such as: temperature, weather, organic materials, water, living organisms [54]. According to Ralph E Grim [73] clay depending on the composition can be classified into three large groups of minerals: kaolinite, Illite, montmorillonite. According to Grim the structure of clay minerals Montmorillonite and Illite are similar which have the possibility of change in the processes of diagenesis of sediments, while kaolin does not.
The performance of clay such as: plasticity, bond strength, shrinkage, shape retention, all of these depend on their mineralogical composition. According to Grim in his book “Properties of Clay” [73], the constituent mineral particles have the form of flakes/sheets, which have the ability to attract each other, and the presence of water in these particles creates a distance between these flakes, which are attracted from a distance with a certain force. This also shows the property of plasticity of clays. The larger the surface, the greater the force of attraction, and the greater the force of attraction, the greater the shrinkage during drying. Based on these specifications, clay in combination with water can swell to a unit of measurement from 10 angstrom-thick clay mineral can expand to 19.5 Ångström in water [74].

3.2.3 Behaviors of clays

- Clay has the ability to remove dyes from oil, and this ability is related to the presence of H+ and Al+++ cations [73].
- Based on property, clay can be understood as a bleaching agent and absorbent material for the elimination of soluble dyes in water and other contaminated bodies [75].
- The property of clay to disperse evenly in water is used in the paint industry to distribute color pigment evenly [76] .
- Clay in ancient times was used to make adobe bricks mixed with cob, string wood, which were then used for smashed earth designs, building components (clay mortar, floor tiles, clay paints) and clay earthenware [63] .

In the combination of clay, in the case in question in the manufacture of brick products, the distribution of the particle composition by size is determined: particles >20μm should be 60% or more, particles 2–20μm should <40% and particles <2μm should be <35% [77].

3.3 General classification of clays

Classification based on mineralogical composition, clays have this subdivision of groups: Kaolinite, Smectite, Illite, Vermiculite and Chlorites [78]. Some parameters of clay mineral classification are given in Table 1.

Table 1.Clay groups and their parameters in the distance between layers and volume growth [79]

S. N.	Clay Mineral	Type	Basal Spacing (Å)	Swelling Potential
01	Kaolinite	1:1	7·2	Almost none
02	Montmorillonite/Bentonite	2:1	9·8–20	High
03	Vermiculite	2:1	10–15	High
04	Mica	2:1	10	Low
05	Chlorite	2:1:1	14	None

3.3.1 Kaolinite

It is also considered the main member in the mineralogical composition of clay $Al_2Si_2O_5(OH)_4$, produced by the chemical weathering of aluminum silicate from feldspar of metamorphic and igneous rocks influenced by CO2 [79] [80]. According to Ralph E. Grim [73], this group of minerals does not dissolve easily, the constituent particles of this group of clays are connected to each other so that they prevent the presence of water in it to a certain extent, which results in: plasticity, and shrinkage during drying to be small, compared to the other group of clays Montmorillonite and Illite. Clays of this composition are white in color while other minerals change color from white to yellow [73]. Clays of this type are used in the ceramic industry, in the production of porcelain, as an aid in the production of paper, medical products, cosmetics, the production of white cement, and the production of steel fibers [78].

3.3.2 Smectite

Previously this group was classified as montmorillonite [81]. They are formed by soil erosion or volcanic ash and belong to the hydroxyl alumino-silicate group [82] [83]. It is characterized by the presence of the mineral montmorillonite $(Na, Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2.(H_2O)_n$ and this group has the following mineral composition: Nontronite, Beidellite, Saponite [79]. Within this classification, these minerals play an important role in their behavior towards water [52]. The existence of these minerals in the presence of water affects the high plasticity parameter, the high attractive force of the particles, and after drying the shrinkage of the particles will be visible. This type of clay is used in industry, in paper production, in the production of dyes, in pharmacy, cosmetics, plastics, adhesives, dyes, as a binding clay in the desert, in agriculture in the transport of pesticides, catalyst in the oil industry, binding material for pellets, for drilling mud, absorbent [78].

3.3.3 Illite

This group of minerals is related to the mica group of minerals, which includes 30 other types, the identifying formula KyAl4(Si8-y,Aly)O20(OH)4 [78]. This type of clay is the most common, has a high concentration of potassium, and is formed in mild climates, at high altitudes and reaches the ocean by rivers and wind, and has colors: gray, silver and white, gray and green [78]. Within this group, clays that are composed of Illite, due to the large particles and less space present within its volume, have a smaller surface area, lower bonding strength, lower plasticity, and lower shrinkage during drying. This group of clays is used for the production of bricks, tiles, and glass products [68].

3.3.4 Vermiculite

This type of clay has the identifying formula $(Mg,Fe^{2+},Fe^{3+})_3(SiAl)_4O_{10}(OH)_24H_2O$, and is considered a hydrous phyllosilicate mineral [79]. In its composition, Al3+ dominates strong bonds of Ca and Mg cations, with high charge, and its physical structure can undergo expansion and hydration in combination with water [78]. The crystalline structure of vermiculite which contains water molecules, to remove the water, the exfoliation process is used, in which the vermiculite is subjected to a temperature of 900 ℃ and the water is converted into steam. This forms a product that is fire resistant, with low density, low thermal conductivity, suitable for use in construction as a concrete producer, fire retardant insulating varnish, and also for use in vehicle brake linings [84]. This type of clay is also used in agriculture for soil aeration, hydration, and fertilizer release [78]. It is also used for the removal of algae cells if used as a modified material [85]. The color of this group of clays varies from black to shades of brown and yellow [84]. The location of these clays is found in South Africa, South Carolina, Virginia, Louisa, Enoree district, Montana, Palabora [86] .

3.3.5 Chlorite

Chlorites are hydrated hydrosilicates of magnesium and iron, this group mostly contains Mg^{2+}, Al^{3+}, Fe^{2+}, Fe^{3+}, the color of this group of clays is pale green depending on the iron content [80]. This group of clays, minerals inherited from metamorphic, igneous rocks and hydrothermally altered sediments, chlorites, easily decompose, are considered quite rare and are found in small quantities [87]. This type of clay is found in lateritic soils, for example on the west coast of Africa near the Equator and is considered to be the same old clay sediments as the Illite clay group [68]. Chlorites are considered a group of non-expansive clays because there is no water absorption within the interlayer spaces of Chlorite [78]. The use of this group of clay, as modified, finds application in the paper industry, drinking water treatment, and wastewater treatment [88].

3.3.6 Categorization of clays in other formats

A. Categorization of clays according to mechanical characteristics and method of use: Marine clay, alluvial clay, lake clay, eolian clay, glacial clay, stony clay [89].

B. Categorization of clays according to mechanical characteristics and method of use: soft clays and hard clays [90] [89] **.**

- Soft clays have ductile viscos-elastic-plastic properties, accept high water content and plasticity can be restored, but during drying the tendency to crack increases.
- Hard clays are brittle materials, with low water content, difficulty in recovering plasticity, otherwise known as saddles, and this property of them can change.

C. Categorization of clays according to chemical composition and color: white clays, black clays, red clays, brown clays, and yellow clays. The color of clay is a result of the presence of iron oxides and manganese compounds, for example [89] [91] :

- White clays contain: Hydrated aluminum silicate, aluminum, sulfur, iron, boron, potassium and calcium,
- Black clays contain titanium, aluminum and magnesium silicate, calcium and magnesium carbonate, silicon oxide, zinc, and sulfur, while
- Red clays have a higher level of iron oxide and copper oxide.
- Brown clays: Rich in silicon, aluminum, titanium; low iron content
- Yellow clays: Rich in silicon dioxide,
- Green clays: iron oxide associated with calcium, magnesium, potassium, manganese, phosphorus, zinc, copper, aluminum, silicon, selenium, cobalt, and molybdenum.

3.4 Clay used for research and specifications

The clay used for product research was taken in Kosovo from three locations, which have this categorization, attaching to the description the structural geology according to the Independent Commission for Mines and Minerals [92] [93]:

- **Prishtina – Llazareva, Obiliq; this location is categorized: Outer Vardar Subzone - Kosovo Basin**. According to the geological study available to the business that supplies this type of clay at this location, this clay is classified as Pliocene. This area is certified for clay exploitation for the development of businesses in the production of clay blocks [94] [95] .

  Pliocene clay is known for its high surface deposits, which are composed of the group of clays: smectite, kaolinite, which is distinguished by its properties to immobilize quantities of heavy metals [96]. Pliocene clays are characterized by the absorption of metal ions, which can also be used in wastewater treatment [97] . The clay in question is gray-yellow, red-brown in color. The clay contains the following mineral compositions: Quartz, Feldspar, Mica, Smectite, Kaolinite.

  Clay used for product research, according to the geological study report [95] contains the following chemical elements: silicon dioxide (SiO_2), iron trioxide (Fe_2O_3), aluminum trioxide (Al_2O_3), calcium oxide (CaO), manganese oxide (MgO), sulfur trioxide (SO_3).
- S**kenderaj - this location is categorized: Drenica Area – The Neugene Basin of Drenica**- This area, are certified for clay exploitation for the development of businesses in the production of clay blocks [94]. Based on these ownership reports for certification,

supply and utilization of clay [98], this clay is classified as mergelo, sandstone, with these parameters: yellow in color, ash-colored, red in yellow, and many colors of sandstone and in-depth clay with limestone concretions. The clay contains the following mineral compositions: Quartz, Feldspar, Mica, Chlorite, Vermiculite, Hydromica, Kaolinite, Carbonates, Limonite. Chemical composition: Silicon dioxide (SiO_2), titanium dioxide (TiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), manganese monoxide (MnO), magnesium oxide (MgO), calcium oxide (CaO), sodium oxide (Na_2O), potassium dioxide (KO_2). It is classified as a medium plastic clay, with water moisture, with iron oxide content that gives it a red color during firing [98].

- **Prishtina – Raskov; this location is categorized: Outer Vardar Subzone - Kosovo Basin**. This type of clay was taken near the river valley of the Llap - Obiliq. From a visual point of view, this clay is noticeable as containing fine sand, moisture and the color of dark grey. Near this location, using the "Hand making" brick technique [99], the inhabitants of this area were supplied with clay. In the local language, the bricks they made were called "Qerpiq" [100] [101] [102], known in literature and in other regions as: "adobe" sun dried brick with mud as its main ingredient [103] [104] [105] [106] .

The selection of the first two locations for clay supply was made due to the performance they have shown in the production of clays in the country. During the product research, in combination of these two types of clays with other materials, different results are provided in the final research product samples. These results will be shown in the following chapters of the doctoral dissertation.

3.4.1 Demonstration of clay consistency - Atterberg Limits

Initially, to demonstrate the functioning, formation and stability of the three clays selected as part of the research product, these are attached in the figure below Fig.19, the consistency test for these clays was carried out as part of the Atterberg Limits test [60] , [107].

Figure 19. Clays selected for testing: a) Llazareva, b) Skenderaj, c) Llap River

In our research case for the consistency property of selective clays, this test is carried out in this way: from a small portion of clay approximately 20g in combination with water, a small ball is made, and from the clay in combination with water, a 10cm long stick with a diameter of 3.2mm is made.

- The clay ball after drying if it does not show cracks in its structure, also if this ball is taken and tried to be destroyed under the pressure of the hands and no deformations appear, this indicates the stability of the clay, Fig. 20.
- A small amount of clay is combined with water and rolled on a smooth surface that does not absorb water, during this process of continuous rolling we form a 10cm stick with a diameter of 3.2mm. And if we can repeat this test several times, this is the property that the soil has moisture with plastic properties. This also indicates the plastic limit of the clay which according to Atterberg Limits is taken to be 3.2mm, and if the stick does not manage to roll up to this diameter, then the soil is considered non-plastic [65].

Figure 20.Clay consistency testing

As a conclusion, in our testing “Atterberg Limits test “ for the plasticity of these three types of clays, the clay from Llazareva and Skenderaj showed positive results in consistency and plasticity. While the third clay from the Llap River was unable to form a 10cm rod with a diameter of 3.2mm, because the rod during the rolling process began to separate before reaching a diameter of 3.2mm, and such a type does not continue further in the combination process.
And from these three types of clays, for further testing of the research product samples, Skenderaj clay and Llazareva clay were adopted.

3.4.2 Demonstration of clay consistency - Traditional test for working clay in brick

For these three clays, to demonstrate the local construction practice for the production of handmade bricks in the Kosovo Plain region, a clay consistency test was also conducted. The information’s were obtained from elderly people living in the Kosovo Plain, who in their time made bricks by hand and fired them in small field kilns, where brick production was once known as a family craft. The preliminary testing of clays for brick production was done in a traditional way. Such a way of testing clays was also part of the process of the manual brick making technique, which aims at sustainable development. Also, the application of such clay testing techniques is found in manuals for the formation of clay bricks, in various regions of the world that have these capabilities, and these manuals promote sustainable development. [99] , [108], [109]. Traditional testing tested the strength and durability of the working clay by forming a small ball the size of a golf ball and a 10 cm disk sample with a thickness of 5 mm, this technique is presented in the following in the Fig. 21.

Figure 21.Traditional local test of the Kosovo Plain, for testing clay for brick making

- To understand the stability of the clay, a ball shaped to the size of a golf ball is thrown from a distance of 1m. And after 10 hits, its external structure is checked for damage and stability.
- While a 10cm diameter disc with a thickness of 5mm, after hardening and drying, its structure is visually examined from the outside, and it is determined whether its structure is stable and whether there are cracks.

In our testing for the stability of these three types of clays "according to traditional test", the clay of Llazareva and Skenderaj have shown positive results of consistency, no cracks have appeared, and the structure is stable, while the clay sample of the nearby Llap river was damaged during this test. Throwing the ball from a height of 1m has caused the structure to crack, as well as the disk after a period of drying has cracked on its outer surface. This results and shows that the clay of the Llap river has in its composition other impurities, does not show sufficient plasticity and does not show stability for the processing of brick samples. And the results of this traditional test match the results of the Atterberg Limits test.

3.4.3 Useful properties of clays for the research product

- Plasticity, the binding property, creates cohesion between components and resistance to deformation.
- Reduction of heat loss; Stabilizer and balancer in combination with other materials.

- Responds to the dimensions of sustainable development,
- Historically known in community construction practice,
- Acceptable for nature and man
- The possibility of supply is considered easy,
- Recyclable material.

3.5 Slag

Slag are nonmetallic byproducts of many metallurgical operations, and they consist primarily of calcium, magnesium, and aluminum silicates in various combinations [110]. Efficient use of resources and treating waste-to-wealth are keys to achieving a sustainable environment and economy.

In this research work, the sag material is among the materials added to the clay, supplied by the Ferronikeli factory in Drenas, Kosovo. Slag in this work is considered waste from the processing of nickel and cobalt. The location from which the slag material was obtained serves for the exploitation, processing and beneficiation of nickel and cobalt alloy since 1984 [111] . Metals are considered conventional materials that continue to be used as construction materials, which are suitable for recycling, and if used recycled, contribute to a reduction of up to 75% of embodied carbon, because they save energy for the production of concrete and composite materials [62]. In 2023, global steel production was estimated at 330-390 million tons, the high volume of slag produced annually worldwide has led to a continuous increase in interest in this material. The focus has been on its use as a construction material, in the recycling or recovery of secondary metals and as an additive material in mixtures with other materials. It competes with: fly ash, metakaolin and volcanic ash pozzolans [112].

Nickel

It is considered a pure chemical element with a silvery white color and is stronger than iron. It is a component of igneous rocks [113]. This element's ability to resist corrosion at high temperatures also has the ability to resist corrosion from seawater. In industry, it is used in the production of coins, in the production of armored coatings, wires, gas turbines, rocket engines, In other sectors, from research conducted by others, nickel in small amounts of concentration affects the growth of plants, cereals [114]. The normal human diet contains 0.3-0.5 milligrams of nickel per day. About 65% of the nickel in the industrial world is used to make stainless steel [110], [115].

Cobalt

It is considered to have ferromagnetic properties with resistance to high temperatures, and enables the production of permanent magnets, it is also known for its high metallic properties [116]. The properties of cobalt allowed it to be used as a superalloy for aircraft engines, batteries, catalysts, and carbides [117] . It is also known for its anti-corrosion properties and has found applications in industries such as connectors, electronics, and in catalyst batteries. Cobalt in human health helps in the metabolism of vitamin B12, which helps in maintaining iron levels in the body, energy production, and maintaining health [118].

3.5.1 Use of slag

The use of such materials, in our case slag, contributes to the reduction of industrial waste, minimizing environmental pollution, and paving the way for economical construction materials. The use of slag has recently seen a wide range of involvement in various industries [119]. The size of the slag particles in a mixture with other materials affects the mechanical properties of the product, for example the density of the structure [120].

Studies regarding the use and combination of slag with other materials include the combination of slag with cement, this mixture minimizes the carbon footprint associated with cement [121]. Then there is the possibility of partially replacing cement with slag and sawdust in the binder mortar, which improves thermal properties, reduces CO_2, has high compressive strength, and is low cost [122]. Also, combining slag with sawdust ash increases the performance of concrete in terms of density, transverse strength, and compressive strength compared to traditional concrete [123].

Then there are studies on the use of slag in improving and stabilizing the engineering properties of soils with clay content, which affects the improvement of the properties of compaction, stability, and density [124]. Or using slag in combination with lime as a base material to stabilize the surface of roads and sidewalks [125].

The use of slag is also an alternative as a substitute for natural aggregates, and such an approach preserves the soil and prevents the extraction of stones and sand for aggregate, preventing environmental degradation, while also saving natural resources and energy [126]. Due to the importance of metals such as nickel and cobalt, interest in extracting them from secondary sources has resulted in strategic growth [127].

3.5.2 Useful properties of slag for the research product

- Increase corrosion resistance,

- Suitable for long-term applications,
- Chemical stability of the product,
- Use in harsh environmental conditions,
- Durability and strength stability,
- Protection against high temperatures,
- Reduction of industrial waste.

3.6 Sawdust

Wood as a building material, specifically its use in the facade of buildings has been widespread since ancient times, contributing to sustainable buildings with passive architectural methods. The unique properties of wood material in terms of physical, mechanical, chemical aspects, local production, minimum transport costs, are influencing the continuation of its use even today by reviving bio architecture, both in the exterior and interior of the building. Other important components of wood can be characterized: mechanical resistance, dimensional stability, low thermal conductivity, acoustic and electrical properties, chemical resistance, morphological appearance, specific surface [128]. Also, replacing conventional materials with wood material can reduce global emissions by 14-31%, which affects the mitigation of climate change [62].

When using wood for construction elements, it is recommended that the maximum moisture content of untreated wood be preferably below 15% [129], [130]. Therefore, based on this the European Union Timber Regulation (EUTR), as a legal act of the European Union, aims to regulate the trade of wood and wood products in the European market, which applies to both imports and domestic use [131]. Part of the wood material is the sawdust material used in combination for the research product, which was obtained from the Kosovo plain, and is from beechwood "Quercus pubescens", otherwise known in the local language as "Bungu" wood [132]. As a wood species it is widespread in Europe, Asia, North America [133]. Used sawdust is a fine material created by wood processing, in cutting, milling or drilling wood. Many countries that are wood producers produce up to 2 million m3 of sawdust per year, while some countries throw this material into landfills, and this presents an environmental challenge in the destruction of ecology [134]. The application of sawdust in engineering due to the reduction of weight and cost has been used in combination with concrete material for 40 years now [135].

Beechwood is considered one of the strongest woods, with high density, resistant to mechanical damage. It is distinguished by a homogeneous structure, small pores, and if treated with steam it is suitable for bending [136]. The color shade is distinguished by yellow to reddish brown, but if it is treated at temperatures, it changes color [137] .

As for how wood can be used in different variations depending on the constructive elements of buildings, the attached figure is presented in the Fig.22.

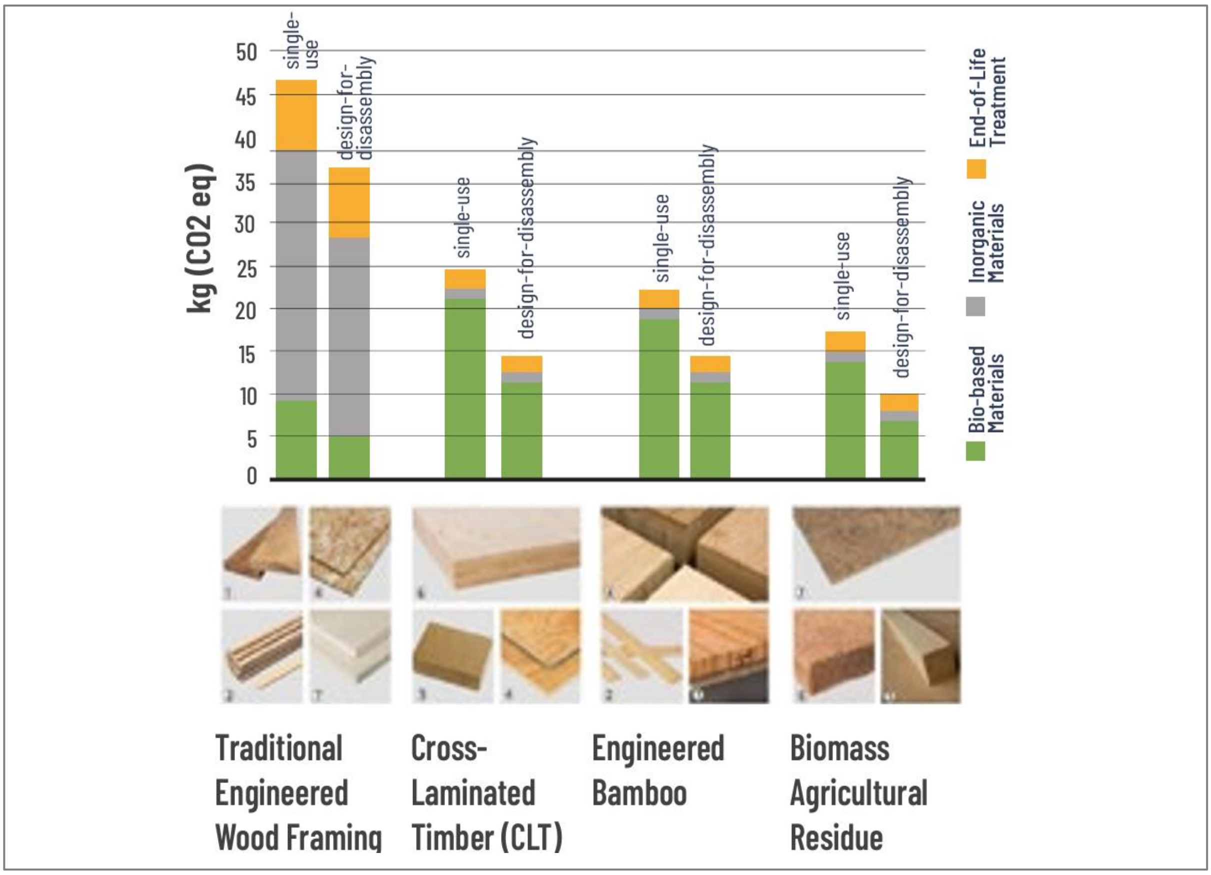


Figure 22.Wall systems made from cross-laminated timber, bamboo and coconut-biomass residues show emission savings *[62]*, *[138]*

3.6.1 Use of sawdust

The application of beechwood in everyday life has a wide scope, for example we have a list of its uses: application in high-quality furniture, flooring, production of musical instruments, handicrafts, fuel for energy (pellets) [139], industrial equipment, constructive elements, etc. In the history of the development of constructions, beechwood has been used in the connection of railway tracks with specific applications and processing [140].

3.6.2 Useful properties of sawdust for the research product

Based on the above information, several summaries of sawdust material specifications can be reached, which are promising in product research for building facades:

- Light and porous material,
- Weight reduction in construction materials,

- Thermal and acoustic insulation,
- Good energy efficiency performance,
- Easily combined with other materials,
- Reduction of industrial waste,
- Biodegradable material,
- Environmentally friendly,
- Increasing the well-being of human life.

3.7 Ash of wood

Wood ash is considered the residue left after burning wood and consists of oxides of calcium, potassium, magnesium, and other mineral compounds [141], [142]. Its specifics and properties depend on the type of wood, the proportion of wood burned, and the burning conditions [143]. Wood ash mainly originates from local power plants and kilns. While in this study of the research product, wood ash was obtained from local kilns, which used “bungu” wood for heating and firing. The amount of wood ash dumped on land surfaces, environmental pollution, its unique and suitable specifications in combination with other materials, low cost of use, make this material a potential material for reconsideration of its application in the research product.

3.7.1 Use of ash of wood

In construction, ash material is used as an ecological binder and partial replacement for cement in concrete, to reduce the negative effects of cement on the environment, this also means improving the strength and durability of the material [144]. While the amount of fly ash is decreasing due to the closure and downsizing of thermal power plants in the world, replacing fly ash in engineering with biomass and wood ash is being considered as an alternative [145] , [146], [147]. Wood ash is considered a porous material and helps to improve the insulating properties, which affects the energy performance [148] .

In agriculture, it is used as a fertilizer and soil acidity regulator, improving its fertility, through elements such as calcium and potassium [149]. n today's conditions, there is a lack of standardization in the production and quality of wood ash, which makes it difficult for users to predict the performance of wood ash for its application [142].

3.7.2 Useful properties of wood ash for research

- Good energy efficiency performance,
- Easily combined with other materials,

- Ecological bonding of materials,
- Improved mechanical resistance,
- Reduction of industrial waste,
- Biodegradable material,
- Environmentally friendly,
- Increases the well-being of human life,
- The aesthetic and natural appearance of the coating.

3.8 Lime

Lime, due to its unique and ecological properties, is seen as a potential material for sustainable applications when applied with other materials, in the specific research case we have hydrated lime. The possibility of easy access to this material, the cheap cost of the raw material, the ease of use, the possibility of recycling, biodegradable material, all these properties make lime among the biomaterials with applications since ancient times. Lime is produced from limestone through a thermal process that creates calcium oxide, and in combination with water produces hydrated lime-calcium hydroxide [150].

3.8.1 Use of lime

The earliest documented use of lime is from around 4000 B.C. in Egypt for plastering the pyramids [151], Vitruvius provided basic instructions for the use of lime mortar mixtures [152]. In the restoration of historic buildings, it is considered a key material for application, as it is compatible with the original materials of the buildings being restored [153].

It is considered an ecological material, because during its use the carbonization process helps to reduce its carbon impact on the environment, it also finds use as a long-term binder of materials, used for plastering, as mortar and in the construction of walls [154]. Lime has porous properties and allows the passage of water vapor, preventing the creation of moisture in it, affecting its antibacterial and antifungal properties [153]. The porosity of lime also affects the thermal compatibility with the materials it is combined with. In this regard, there are studies on the reaction of lime in bricks in a certain percentage in terms of mechanical resistance, durability, and thermal [155]. The organization that deals with the protection of the interests and product legislation of the lime industry, based on sustainable development in Europe, is known as EuLA (European Lime Association) [156].

3.8.2 Useful properties of lime for research

- Good energy efficient performance,
- Easily combined with other materials,
- Ecological connection of materials,
- Reduction of industrial waste,
- Biodegradable material,
- Environmentally friendly,
- Increasing the well-being of human life,
- It affects the aesthetic and natural appearance of the coating.

4. FIELD WORK, TEST COMBINATION OF MATERIALS

One such way of forming bricks, envisaged in this research thesis, is known as the “handmaking” or “hand moulding” method [99], which is one of the oldest methods, considered an environmentally friendly technique, and helping in a way to sustainable development. This working technique is also known as a general artisanal process brick production, followed over the years. For these techniques of forming and producing bricks, there are manuals and guidelines within the framework of quality standards, which provide knowledge for individuals, projects or departments that aim to produce bricks with a minimal infrastructure [157], [109], [108], [99], [158] .

The location where the external field work in the formation of the product is carried out is the workspace organized as a working studio. The space in which the combination and working of the samples was carried out was covered in the upper part with a shelter, for reasons of ensuring suitable conditions for the development of the works. The entire procedure of combining the materials was carried out by manual process with the help of accompanying elements.

The outdoor field experiments for the realization of the product combination were carried out at an outdoor temperature of: 21℃ - 23℃ and an average relative humidity of 70%. The tools that were used for the realization of the mixing of the components, some of them were worked and modified according to the need and adaptation in the field, for the mixing of the materials to be uniform and the mass to be compact and uniform. For example, we have molds, the hand mixer with its conveying elements, the hand element for spreading the material in the mold, trowel for leveling surfaces, the scale for measuring the materials and other auxiliary elements, Fig.23, Fig.24 and Fig.25, [159], [109], [158]. The stages developed for the formation of the research product up to the interpretation of the results are presented in Fig.27. The molds for the sample preparation were made of MDF (pressed wood) panels, with dimensions of 21.5cm x 10.2cm x 6.5cm, Fig.26. The adoption of such dimensions is appropriate for the samples in question, because these are dimensions determined according to the European standard BS 3921:1985 [160], and the results generated from the experiments allow comparison with global research.

Figure 23.The elements used for the realization of the composition of the components of the materials,

Figure 24. a) Measuring tools and b) Work tools for achieving the flat surface of the bricks

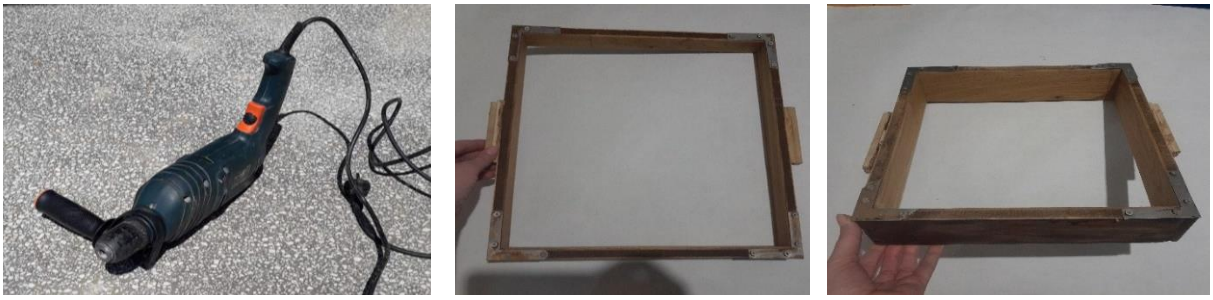


Figure 25. Mixer, mixing tools and molds for forming the product for thermal measurement

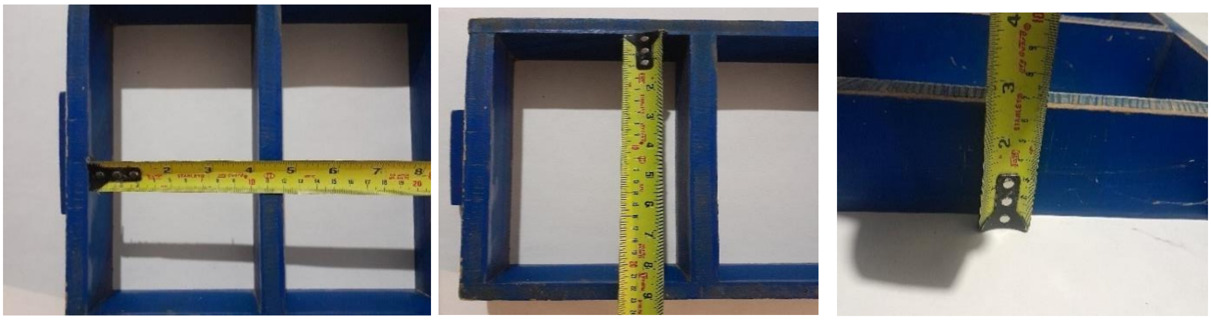


Figure 26.Molds for making brick samples

Figure 27.Stages of research product formation

4.1 Brick dimensions

The dimensions adopted to produce the product in the formwork are: length 215mm x width 102.5mm x height 65 mm, according to the standards: BS 3921:1985 [160], BS EN 771-1:2011 and BS EN 772-16:2011, which are the harmonization and implementation of European standards EN 771-11:2011 [161] and EN 772-16:2011 [162]. These bricks are subjected to European standards during testing, depending on parameter requirements [163]. These bricks made with these dimensions are suitable for modular projects in the facades of buildings, widely used in industry, suitable for machinery and technologies in the production of products. The adoption of these dimensions for the research product is based on these specifications [164]:

- Ergonomics (easy to operate),
- Modular dimensions (more practical option for use in building envelopes, due to dimensions).
- The construction structure has regular finishes,
- Flexibility,
- Efficiency,
- Sustainability,
- Cost optimization,
- Low material consumption.

It can be defined that these dimensions of this research offer an equilibrium between functionality, durability and economy. The attributes of brick with these dimensions make these samples ideal for use in many buildings.

4.2 The combination of the first test materials

The first selection of test materials to be combined and formed into the product were: clay from the Skenderaj location, slag, lime, wood ash. In this combination, clay had the largest percentage of the composition while the other components varied in different percentages, this amount of them was measured on a numerical scale. The materials used in the combination are shown in Fig.28 and the location of the supply of the materials is described in the previous chapters in the explanation of the constituent materials of the product. To identify how each sample is acting during its processing process, the samples were named from the number "0" to "16", each mixture min. 3 pieces for preliminary testing. The mixing of the components was done with the help of the tools shown on Fig.29. Initially, the clay mass was mixed with water until a compact elastic plastic mass was formed.

Figure 28. a) Clay, b) Slag, c) Lime, d) Wood Ash

Then this mass was left for 2 days in outdoor conditions to be subjected to the processes of combination with other materials. This process is known as tempering, homogenizing the composition of the clay [109]. The amount of water in this mixture with clay was in the ratio of 15-20%, depending on the humidity of the clay that it possessed in the state taken from the field.

Figure 29. Mixing the ingredients

The reason for the clay to stand as a mass for such a period of time before being mixed with other ingredients was to create a uniform compact mass and to make mixing with other ingredients easier. Then other ingredients were added to the clay mass. Other ingredients added to the clay mass were slag, wood ash and lime. These ingredients were mixed for several minutes, and after a uniform composition of the mass was achieved, the mixture was then poured into wooden molds, Fig.30. The formed mass has remained in the mold for several minutes, and the upper surfaces of the mass have been processed uniformly with the leveling tools, then the product is removed from the molds to be shaped, Fig.31. This method of forming the product with molds, which are without a lid and bottom, and pulling them out is known as "Slop Moulding" [109]. To prevent the mixture from sticking to the wooden molds, the inner surface of the molds is coated with engine oil, and also to have a result in the formation of bricks, the molds must be cleaned after each work process. Also, the surface on which the bricks are placed after being pulled from the molds must be leveled and must be covered with a 2-5 mm layer of sand, to prevent the bricks from sticking to the work surface.

Figure 30. Placing the combination of materials in the mold

Figure 31. The process of molding the mixed mass

The mass formed into a brick shape was left outdoors for approximately 10 days, covered with a roof on top, to protect it from the weather. While according to traditional technical methods of brick formation, 7 days is the minimum for the bricks to remain in the external flow [158], but in addition to this, external conditions and the state of the mixed product also depend.

Figure 32. Brick prepared for pre-drying process

The external conditions were favorable for the brick to dry into a solid mass, the temperature was 21-23°C and the average relative humidity was 70%, Fig.32 and Fig.33. During this process the bricks should be in a flat position and also on their side edge for several days to allow air circulation and for better drying. Also, during this process, under the influence of air currents and sunlight, moisture begins to evaporate on the surface of the bricks. This physical condition obtained from the preliminary drying enables the bricks to be transported to the factory for complete drying at temperature 110 °C and firing at high temperatures 900°C. Such a state of the brick structure is known as "Leather Hard" [158] .

Figure 33. Brick pre-drying process

Some of these bricks during the drying process in the outdoor environment have developed cracks in their structure. These cracks are caused along the structure of the brick Fig.34, which are visible from the external visual appearance.

Figure 34. The appearance of cracks in the brick structure

4.2.1 Drying and firing of the samples in the factory kiln

After 10 days of standing in the outdoor environment for drying, the bricks are observed to have begun to take shape and release moisture, it is also observed that the bricks have begun to change dimensions, that is, they have begun to gradually shrink in all three of their dimensions. After this time, the other bricks that have shown good external physical condition without cracks, are sent to the factory to finalize the deep drying and firing process in the tunnel kiln, Fig.35, Fig.36.

Figure 35. Brick drying and firing factory: Llazareva, Kosovo

Figure 36. Bricks during the drying and firing process in the factory

Figure 37. a) The bricks taken from the kiln, b) External structure of the sample before firing and after firing in the kiln

In the factory, the bricks were subjected to a deep drying process at 110℃ for 24 hours, in special rooms for drying bricks and blocks. Then they were subjected to a fire process at 900℃ for 24 hours in the tunnel kiln. After this period, the samples were taken from the factory and it is observed that they have acquired a shade of red to brown, Fig.37, and have also shrunk in dimensions.

Figure 38. Shrinking the dimensions of the test bricks

Shrinkage was happened in three dimensions of the brick. Shrinkage was on average in these values: dimension “a”=14.88 %, dimension “b”=12.2 %, dimension “c”=13.85%, Fig.38, Fig.39.

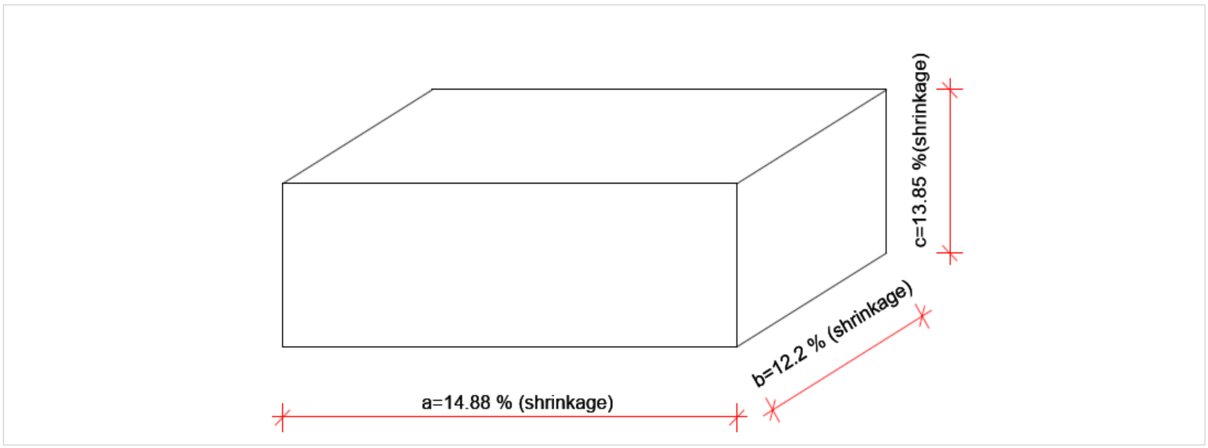


Figure 39.Shrinkage happened in three dimensions of the brick

This property of the brick resulted from the property of the constituent clay which accepts amounts of water in its composition, and gains the ability for easy processing of it, but during the drying process, the water begins to evaporate and the mass of the brick begins to shrink, this results in changes in dimensions. But in addition to these changes that have resulted in shrinkage, also in some samples of bricks we can see cracking along their structure which is caused by the presence of lime grains, which after firing in the kiln have cracked and caused cracks in the external structure of the brick, Fig.40. And which in the composition of the product should not be more than 1mm because they cause them to explode during firing [158].

These cracks occurred because the mixing of the materials was done manually without the pressure of the apparatus. But also the presence of lime grains during the high-temperature firing process has developed chemical reactions, in this case the calcination process, in which limestone ($CaCO_3$) decomposes into calcium oxide (CaO) and carbon dioxide (CO_2), during this process an internal pressure is created that causes an explosion resulting in surface cracking, usually the presence of smaller limestone causes faster calcination, while limestone sizes greater than 1mm result in slower calcination causing possible cracking [165], [166]. This process is also known as “Lime Blowing” or the decomposition of limestone in brick and ceramic products [167], [168] .

This result shows that the composition of the bricks: clay from Skenderaj, wood ash, slag and lime, which is worked under the conditions described above, and the cracks presented after the firing process in the brick structure, do not provide conditions to proceed further in the laboratory testing steps of the product. The attached table shows the testing participation of the materials, Table 2.

Figure 40. Cracks caused in the test bricks after drying and firing in the kiln

Table 2. Combination of test materials, first combination

Nr.	Sample name	Clay %	Slag %	Ashwood %	Lime%
0	0-1	77	15	4	4
	0-2	77	15	4	4
	0-3	77	15	4	4
1	1-1	72	20	4	4
	1-2	72	20	4	4
	1-3	72	20	4	4
2	2-1	67	25	4	4
	2-2	67	25	4	4
	2-3	67	25	4	4
3	3-1	77	15	8	4
	3-2	77	15	8	4
	3-3	77	15	8	4
4	4-1	72	20	8	4
	4-2	72	20	8	4
	4-3	72	20	8	4
5	5-1	67	25	8	4
	5-2	67	25	8	4
	5-3	67	25	8	4
6	6-1	73	15	12	4
	6-2	73	15	12	4
	6-3	73	15	12	4
7	7-1	68	20	12	4
	7-2	68	20	12	4
	7-3	68	20	12	4
8	8-1	63	25	12	4
	8-2	63	25	12	4
	8-3	63	25	12	4
9	9-1	81	15	4	8
	9-2	81	15	4	8
	9-3	81	15	4	8
10	10-1	76	20	4	8
	10-2	76	20	4	8
	10-3	76	20	4	8
11	11-1	77	15	8	8
	11-2	77	15	8	8
	11-3	77	15	8	8
12	12-1	72	20	8	8
	12-2	72	20	8	8
	12-3	72	20	8	8
13	13-1	67	25	8	8

	13-2	67	25	8	8
	13-3	67	25	8	8
14	14-1	73	15	12	8
	14-2	73	15	12	8
	14-3	73	15	12	8
15	15-1	68	20	12	8
	15-2	68	20	12	8
	15-3	68	20	12	8
16	16-1	63	25	12	8
	16-2	63	25	12	8
	16-3	63	25	12	8

4.3 The combination of the second test of materials

The first combination of materials did not show success, then an attempt was made to investigate with another combination. Instead of clay from Skenderaj, Llazareva clay was used, and we have the following combination: Llazareva clay, slag, lime and wood ash, Table 3.

The pre-preparation of the clay with water for the formation of the plastic mass, the method of combining the materials with the working tools, the atmospheric conditions of the samples' standing under the influence of air currents, all of these are the same as the first combination of materials. In this case, in each group of samples, three bricks are worked, the same as in the first combination. And after the samples' standing for 10 days under the influence of air currents, they are sent to the factory for deep drying for 24 hours and fire for 24 hours. After removal from the oven, it is observed that the samples do not have a stable structure, are easily damaged by external mechanical forces, especially at their edges, are also light in weight, have a very brittle mass and also have the ability to absorb water Fig.41.

This condition of the bricks of this combination is due to the fact that wood ash in combination with lime, affects the reduction of the plasticity index and linear shrinkage [169]. Also during the kiln firing process, mineral decomposition of lime develops due to thermal stress [170] [171], all these parameters create internal tension in the product which causes cracking.

Figure 41. Samples taken from the factory; the samples show the ability to damage at its edges

Table 3.Combination of test materials, second combination

Nr.	Sample name	Clay %	Slag %	Wood ash %	Lime%
1	1-1	79	4	2	15
	1-2	79	4	2	15
	1-3	79	4	2	15
2	2-1	77	4	4	15
	2-2	77	4	4	15
	2-3	77	4	4	15
3	3-3	72	4	4	20
	3-4	72	4	4	20
	3-5	72	4	4	20
4	4-1	82	4	4	10
	4-2	82	4	4	10
	4-3	82	4	4	10
5	5-1	84	2	4	10
	5-2	84	2	4	10
	5-3	84	2	4	10

4.4 The combination of the third test of materials

To identify which of the materials in the combination: clay, wood ash, lime and slag, is causing cracking in the structure of the samples during their drying in the outdoor environment (under the influence of air flow), another combination of samples is then worked on:

- Llazareva clay with wood ash,
- Llazareva clay with lime,
- Llazareva clay with slag.

And in this subchapter, the combination of Llazareva clay with wood ash will be shown, while explanations will be given for the other combinations in the following subchapters. The combination of this product is carried out in outdoor atmospheric conditions at an average temperature of 21-23℃ and an average relative humidity of 70%.

The mixture of clay with wood ash is carried out with the same conductive working tools as the first testing of the combination of materials. The clay mass is previously worked with water and then combined with wood ash. Three sets of the mixture are worked with three bricks each. The residence time in the air flow is approximately 10 days, some bricks appear to be drying, Fig.42, then they are sent to the kiln for 24h drying and 24h fire in the tunnel kiln. After taking it from the kiln, it is observed that there is also cracking in the structure of the bricks, because of the high temperature of 900℃ of firing in the kiln. Conclusion of this combination: clay and wood ash, does not offer satisfactory results to continue this mixture for further processing.

Figure 42. Material combination: clay and wood ash, during outdoor drying

From the observation of these bricks during the drying days, this condition of this combination is the cause of non-uniform and rapid drying, the so-called “shrinkage cracks” [158] the presence of wood in the clay affects the increase in porosity and water absorption [172], creating internal tensions which lead to the rapid drying process, from which cracks also appear. The attached table shows the test participation of the materials Table 4.

Table 4.Combination of test materials, third combination

Nr.	Sample name	Clay %	Wood ash %
1	H-1	96	4
	H-1	96	4
	H-1	96	4
2	H-2	92	8
	H-2	92	8
	H-2	92	8
3	H -3	85	15
	H-3	85	15
	H-3	85	15

4.5 The combination of the fourth test of materials

The other combination of materials, which is a test to see how the materials react with each other, and to understand which of the materials is affecting the non-compact structure of the samples, is Llazareva clay and lime. Also, the method of combining the materials was carried out under the same conditions as the previous combinations of materials.

In this combination, three sets of three bricks were made, and after taking them from the kiln, it is observed that the samples in question have shown cracks in their structure, Fig.43. This condition of the bricks is a result of the lime which affects the plasticity and the increase in moisture content [173]which under the influence of thermal stress of high temperatures also causes mineral decomposition [174]. And the high moisture content in the product increases the degree of shrinkage, which results in the appearance of cracks after baking [158]. The attached table shows the testing participation of the materials Table 5.

Figure 43. Material combination: clay and lime, during outdoor drying, after deep drying and firing in the kiln

Table 5.Combination of test materials, fourth combination

Nr.	Sample name	Clay %	Lime %
1	G-1	96	4
	G-1	96	4
	G-1	96	4
2	G-2	92	8
	G-2	92	8
	G-2	92	8
3	G-3	85	15
	G-3	85	15
	G-3	85	15

4.6 The combination of the fifth test of materials

The other combination of materials is Llazareva clay and slag. Also, the way of combining the materials was realized under the same conditions as the previous combinations of materials.

In this combination, three sets of three bricks were realized, and in these sets the percentage of slag participation varies as in the attached table (table 5) and after taking it from the kiln it is observed that the samples in question have shown good final results. The structure of the samples is compact, stable without any noticeable external visual change, Fig.44. This is explained by the fact that the slag material affects the durability and stabilization of the clay [175] . The attached table shows the test participation of the materials, Table 6. This result of this combination promises to be used in subsequent combinations of this research.

Figure 44. Material combination: clay and slag, during outdoor drying, after deep drying and firing in the kiln

Table 6.Combination of test materials, fifth combination

Nr.	Sample name	Clay %	Slag %
1	S-1	96	4
	S-1	96	4
	S-1	96	4
2	S-2	92	8
	S-2	92	8
	S-2	92	8
3	S-3	85	15
	S-3	85	15
	S-3	85	15

From the test combinations of materials explained in the previous subchapters, it is observed that the promising combination of the research product for building facades is the participation of Llazareva clay, with a certain percentage of slag and also with another binder material in this combination, with the aim of increasing physical, mechanical and visual performance. This combination will be tested in the following chapter of this dissertation. From this test research, the presence of wood ash and lime did not provide satisfactory results in the structure of the brick samples. The presence of these materials affected the appearance of cracks, created an unstable structure of the samples, a structure with easy damage potential, and a friable structure with high water absorption potential.

4.7 Final combination of materials

Since the combination: clay, slag, wood ash, lime, did not show satisfactory results, for research into potential material for building cladding, then it is attempted to combine other components with clay. In this case we have the combination: clay from the Llazareva region, slag and sawdust, Fig.45. The choice of these components was thought to be acceptable in relation to the conditions offered by the country, and the possibility of conducting research into a potential product for building cladding. The genesis of the supply and the more detailed range for these components is explained in the previous chapters.

Similar research cases, for the possibility of combining such materials we have: the combination of clay with sawdust as a complementary additive to avoid rapid drying of the brick which also results in avoiding deformations [156]. Or research into the possibility of combining slag with clay to improve its mechanical and physical properties [176]. The clay used in this combination does not show the presence of lime in large fractions, which could cause cracks in the brick structure. The process of preliminary mixing of clay with water was the same as in the other test mixtures, in this case the clay also accepted water into itself, to form a plastic mass. Then the formed clay mass stood for two days for further plasticization.

Figure 45.   a) Clay, b) Sawdust, c) Slag

The combination of clay with other materials was carried out manually with the help of mixing equipment. The working techniques in the mold are the same, as well as the time of standing in the open environment is the same, i.e. at a temperature of 21-23℃ and an average relative humidity of 70%.

4.7.1 The process of samples before delivery to the laboratory

During the 10-day exposure of the brick samples to external atmospheric conditions, it is observed that the brick samples, apart from shrinkage in dimensional changes, have not shown any other changes or cracks throughout their structure, Fig.46, Fig.47. The structure of the samples is observed to be compact and stable.

Figure 46. Bricks during the drying process in the open environment

Figure 47.brick samples with the final materials, during the drying process in an outdoor environment

After 10 days, the samples were sent to the factory for 24h drying and 24h firing, Fig.48. After this 24h deep drying process and the firing process at 900 ℃, the samples showed good results in terms of physical appearance, i.e. no cracks appeared in their structure. This result enables the brick samples to be subjected to other laboratory experimental processes. But beforehand, to be subjected to the testing process, they must remain for 14 days in the laboratory ambient conditions.

Figure 48. Bricks during the drying and firing process in the kiln factory

4.7.2 Participation of the combination of materials

The number of samples that were made in external field work is a total of 54 bricks. Their combination varies depending on the percentage of the ingredients. The largest percentage of the mixture is from clay. The numbering of the samples has started from “17” to “25”. The percentage of these combinations is given in Table 7.

Table 7. Percentage of brick ingredients for final experiment

Nr.	Sample name	Clay %	Sawdust %	Slag %
17	17-1	86	4	10
	17 -2	86	4	10
	17-3	86	4	10
	17-4	86	4	10
	17 -5	86	4	10
	17-6	86	4	10
18	18-1	82	8	10
	18-2	82	8	10
	18-3	82	8	10
	18-4	82	8	10
	18-5	82	8	10
	18-6	82	8	10
19	19-1	78	12	10
	19-2	78	12	10
	19-3	78	12	10
	19-4	78	12	10
	19-5	78	12	10
	19-6	78	12	10
20	20-1	81	4	15
	20-2	81	4	15

	20-3	81	4	15
	20-4	81	4	15
	20-5	81	4	15
	20-6	81	4	15
21	21-1	77	8	15
	21-2	77	8	15
	21-3	77	8	15
	21-4	77	8	15
	21-5	77	8	15
	21-6	77	8	15
22	22-1	73	12	15
	22-2	73	12	15
	22-3	73	12	15
	22-4	73	12	15
	22-5	73	12	15
	22-6	73	12	15
23	23-1	76	4	20
	23-2	76	4	20
	23-3	76	4	20
	23-4	76	4	20
	23-5	76	4	20
	23-6	76	4	20
24	24-1	72	8	20
	24-2	72	8	20
	24-3	72	8	20
	24-4	72	8	20
	24-5	72	8	20
	24-6	72	8	20
25	25-1	68	12	20
	25-2	68	12	20
	25-3	68	12	20
	25-4	68	12	20
	25-5	68	12	20
	25-6	68	12	20

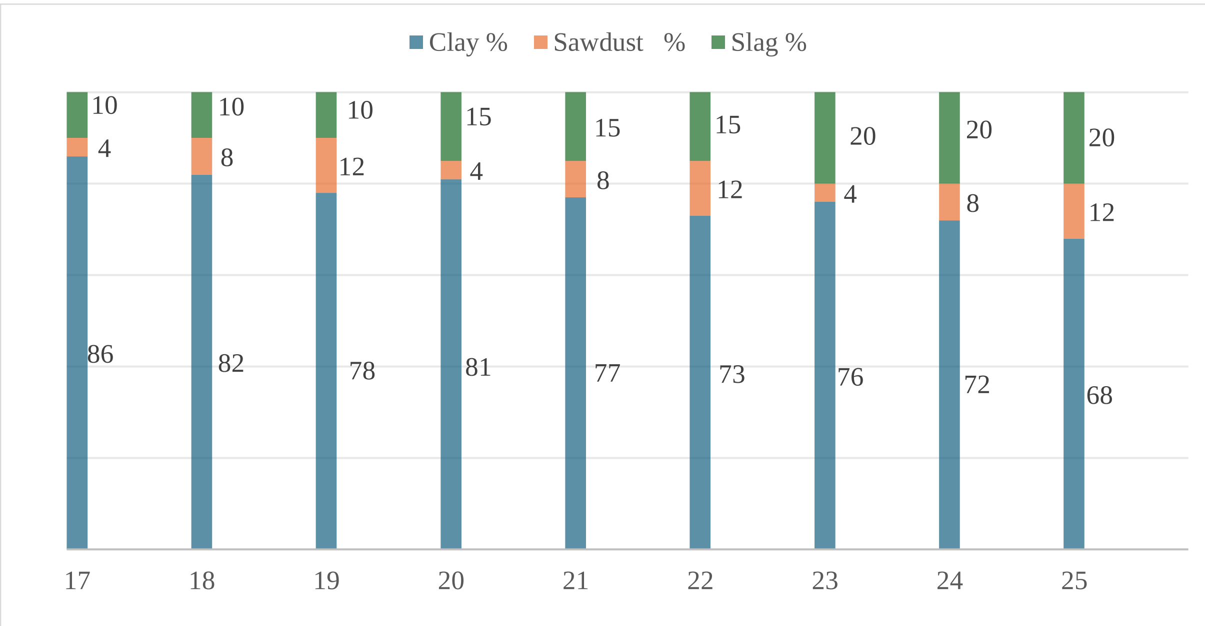


Figure 49. Participation in percentage of materials in all samples

4.7. Interpretation of results

The graphical representation of the participation in percentage (%) in relation to the sample is presented in the figures Fig.49. About final product combination, it can be explained that the harmonization of field work, the development of field research, the development of field experiments, the preparation and combination of selected materials, help in an analytical model and in the results for the research of this topic.

Taking samples after the completion of the deep drying and firing process was an important factor in showing whether the samples are acceptable as a product to be subjected to further laboratory testing. The differentiation of the composition in percentage of materials in certain samples of the research product, is based on optimizing the composition with an impact on stability, as well as on performance. While the attached analytical modeling provides a more detailed overview of the composition of the samples.

5. EXPERIMENTAL WORK

Laboratory experiments of the research product were conducted in the Civil Engineering Laboratory, University of Prishtina. While for some samples, the measurement of the thermal conductivity coefficient was carried out in the laboratory of the Faculty of Engineering in Skopje. The environmental conditions in which the experiments were conducted in the Civil Engineering laboratory in Pristina are: temperature 20 +-2 ℃, relative humidity 50%.

5.1 Laboratory experiments

According to the EN 771-1:2011 standard, to test and evaluate a product for quality, mechanical properties, performance evaluation, resistance to external mechanical forces and climate changes, the following laboratory experiments were carried out:

- dimension experiment,
- bulk density,
- water absorption,
- durability, freeze-thaw cycles - 50 cycles,
- compressive strength in dry state conditions,
- compressive strength after freeze-thaw cycles,
- thermal conductivity,
- testing bonding mortars for the work of mini walls,
- the behavior of the three mini walls under the load applications,
- bearing capacity-compressive strength of three mini walls,

All these laboratory experiments were carried out according to European standards, some of which also provide recommendations regarding the properties of clay bricks. The standards are : EN 771-1:2011 [161], EN 772-1:2011 [177], EN 772-13:2000 [178], EN 772-21:2011 [179], EN 772-22:2018 [180], Eurocode 6 (EN 1996-1-1:2005) [181], Eurocode 6 (EN 1996-2:1198) [182], BS EN 1052-1:1999 [183], EN 1015-11:2019 [184], EN 998-2:2016 [185], BS 3921:1985 [160], BS 5628-1:1992 [186], BS 5628-2:2000 [187], BS 5628-3:2001 [188].

The following samples with the following names were brought to the laboratory for testing:

- sample “17”,
- sample “18”
- sample”19”
- sample”20”
- sample”21”
- sample”22”
- sample”23”
- sample”24”
- sample”25”

The samples in question brought to the laboratory, as mentioned in the chapters above, have proven to be suitable and stable in physical appearance after removal from the kiln and after 14 days of standing in indoor laboratory conditions. The standing of the bricks in the laboratory for 14 days at a temperature ≥15℃ at a relative humidity ≤ 65%, according to the reference standards EN 772-1:2011 must be carried out for the purpose of achieving the pre-preparation of the samples for the following tests according to the reference standards.

5.2 Amount of samples

The quantity of samples brought to the laboratory, Fig.50, according to the time of the tests, results with the requirements of the European standards EN 771-1:2011 and EN 772-1:2011 and the series of these standards. Each sample in question, according to the name, has this quantity of bricks for the implementation of the experiments:

- 6 for measuring dimensions,
- 6 for measuring bulk density,
- 6 for measuring water absorption,
- 6 for measuring freezing and thawing cycles,
- 6 for compressive strength in dry state condition,
- 6 for compressive strength after freezing and thawing cycles,
- 3 for measuring the coefficient of thermal conductivity,
- 3 mini walls for measuring the behavior of the masonry wall under the load-applications and bearing capacity.

Figure 50. Bringing samples to the laboratory for testing

In conclusion of this chapter, it can be emphasized that the experimental work in the laboratory, and their realization helps in the accuracy of the final results of this research work. Experimental work influences the evaluation of the properties of the tested samples, while the quantity of samples for testing enables us to obtain an average variable of the final result, approaching accuracy. The development of the experimental process contributes to the evaluation of the performance of the product, as well as in the suitability of the product for application in the building envelope.

5.3 Experiment I - Dimension

This experiment was carried out in laboratory conditions at a temperature of ≥15℃ and a relative humidity of ≤ 65%. This test included measuring the dimensions of 9 samples of bricks, each sample of brick consisted of 6 bricks, 9x6=54 bricks. The dimensions to be measured are: a (mm), b (mm) and c (mm), and their angles, Fig.51, Fig.53. The dimension of brick before drying was: length 215mm x width 102.5mm x height 65 mm. The tools used in this experiment were: metal ruler, metal angle gauge, vernier, Fig.52. The experiment was carried out according to EN 771-1:2011 [161], according to this standard the coefficients and properties of bricks must be declared by the manufacturer.

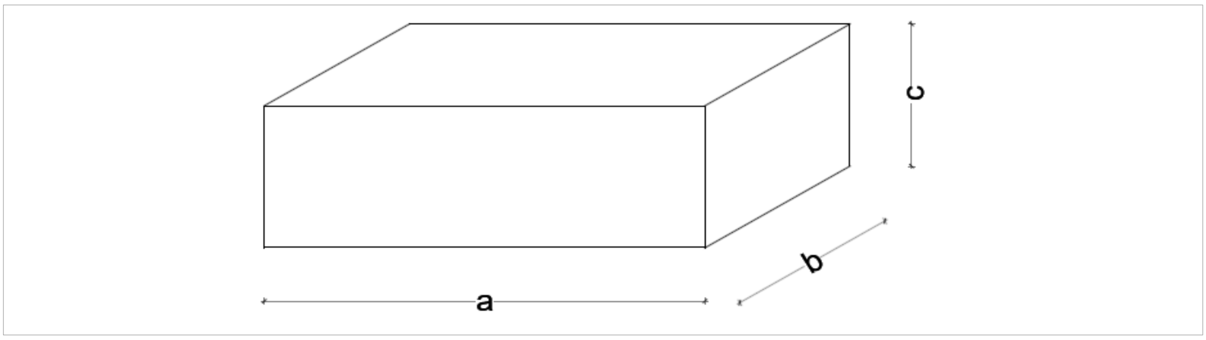


Figure 51.Brick dimensions for measurement

Figure 52. a) metal measuring angle, b) metal ruler, c) vernier

Figure 53. Measuring the dimensions of the samples in the laboratory

Figure 54. Measuring the dimensions of the samples in the laboratory

Using the tools mentioned above in the text, all samples are measured in all their dimensions Fig.84. From these measurements it is observed that each group of samples has changes in dimensions caused by the shrinkage of the product. The values obtained in the laboratory during the realization of the first experiment in measuring the dimensions of the research product are arranged in Table 8.

5.3.1 Results

Table 8. Measuring the dimensions of the bricks

Sample	Sample	Clay (%)	Sawdust (%)	Slag (%)	Average dimension after shrinkage **(a)** mm	Average dimension after shrinkage **(b)** mm	Average dimension after shrinkage **(c)** mm	Average shrinkage **(a)** (%)	Average shrinkage **(b)** (%)	Average shrinkage **(c)** (%)
17	17/1	86	4	10	195.6	92.7	56.7	9.02	9.59	12.74
	17/2									
	17/3									
	17/4									
	17/5									
	17/6									
18	18/1	82	8	10	195.5	93.3	59.3	9.05	8.98	8.72
	18/2									
	18/3									
	18/4									
	18/5									
	18/6									
19	19/1	78	12	10	200.0	96.3	59.9	6.97	6.08	7.82
	19/2									
	19/3									
	19/4									
	19/5									
	19/6									
20	20/1	81	4	15	194.3	94.0	59.5	9.63	8.33	8.44
	20/2									
	20/3									
	20/4									
	20/5									
	20/6									
21	21/1	77	8	15	197.2	95.6	60.0	8.27	6.73	7.74
	21/2									
	21/3									
	21/4									

	21/5 21/6									
22	22/1 22/2 22/3 22/4 22/5 22/6	73	12	15	199.0	95.8	60.2	7.43	6.50	7.33
23	23/1 23/2 23/3 23/4 23/5 23/6	76	4	20	194.1	94.3	58.4	9.74	8.03	10.23
24	24/1 24/2 24/3 24/4 24/5 24/6	72	8	20	197.1	96.2	57.9	8.31	6.11	10.92
25	25/1 25/2 25/3 25/4 25/5 25/6	68	12	20	197.6	95.0	59.6	8.12	7.32	8.38

5.3.2 Comparison of the results

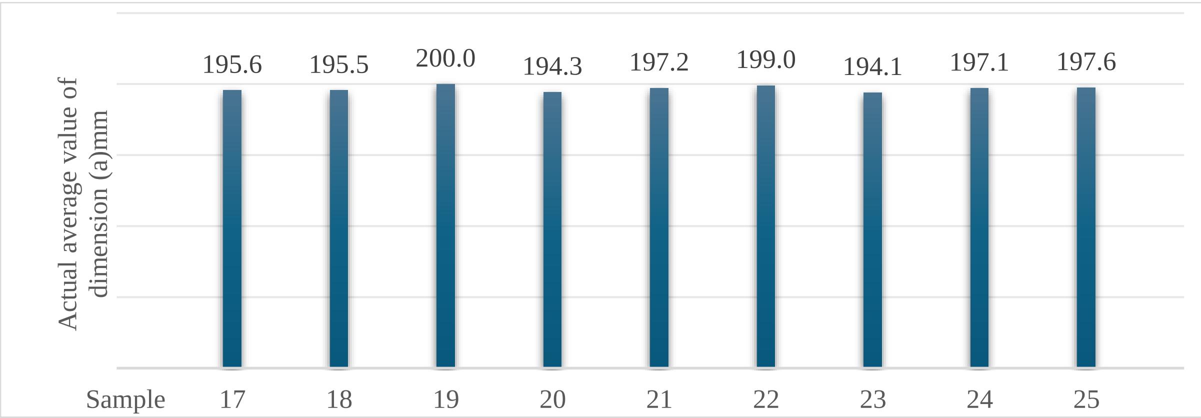


Figure 55. Average value of dimension **"a"** (mm)

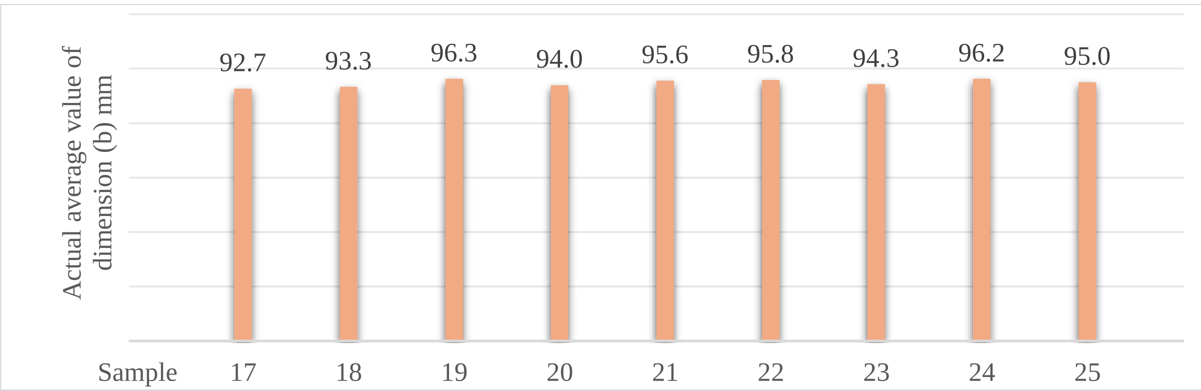


Figure 56. Average value of dimension "**b**" (mm)

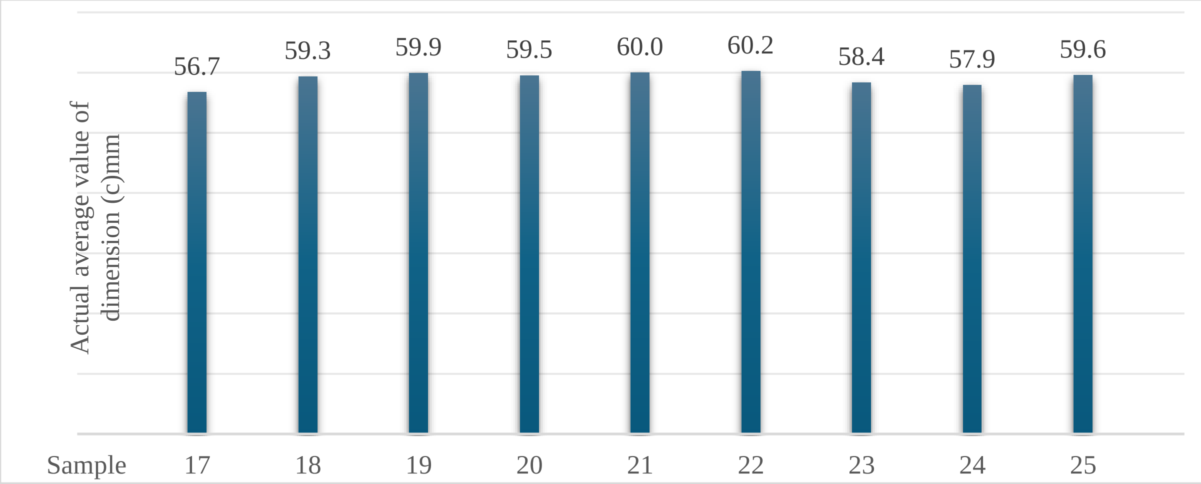


Figure 57. Average value of dimension “**c**” (mm)

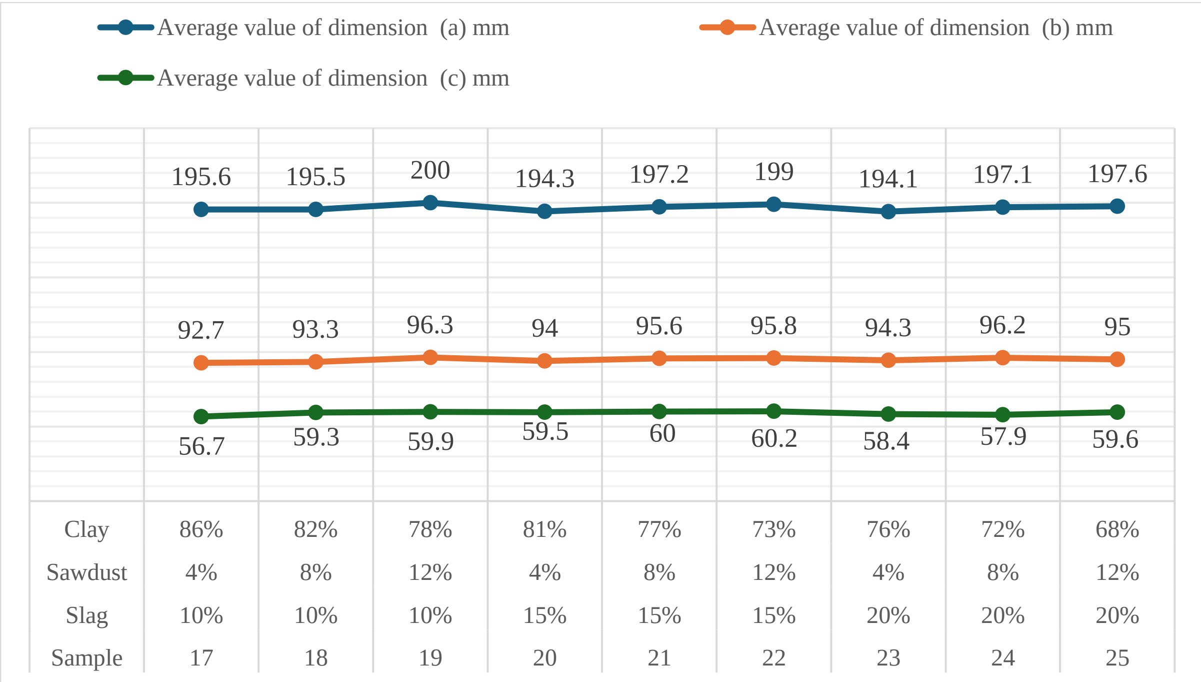


Figure 58. Average value of dimension (mm)

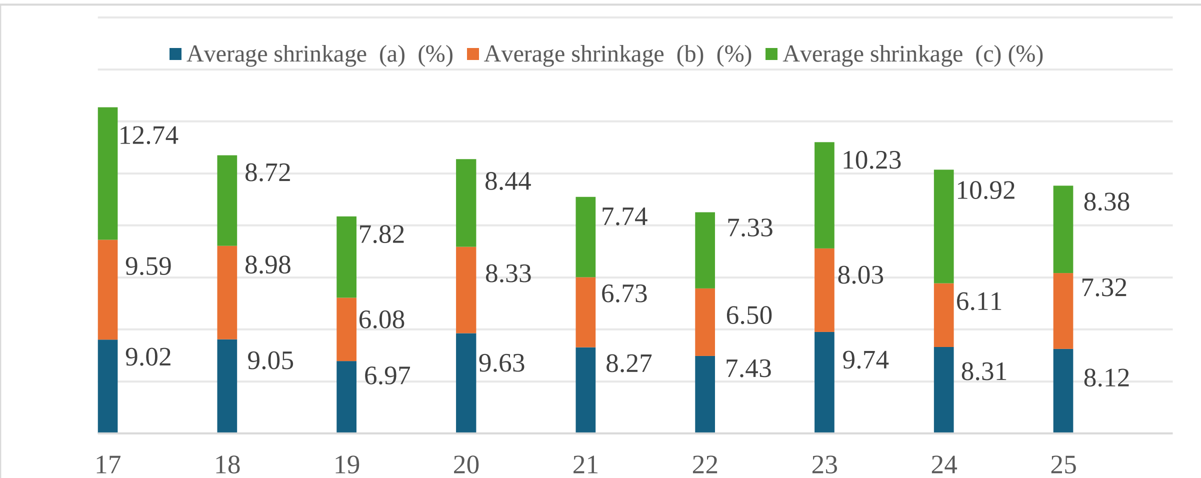


Figure 59. Average shrinkage value (%)

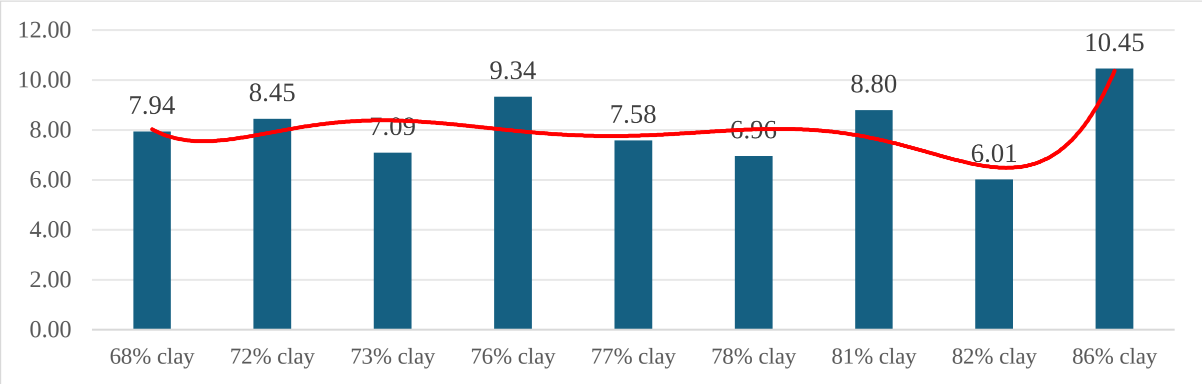


Figure 60.Average shrinkage (%) in relation to clay (%)

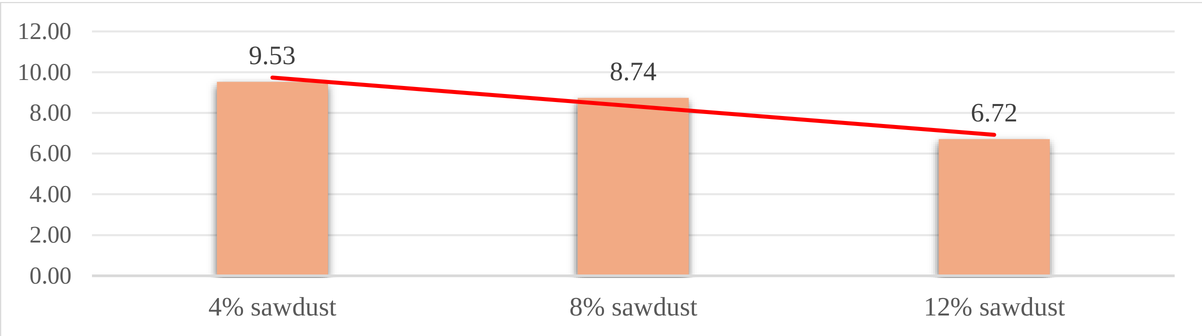


Figure 61. Average shrinkage (%) in relation to sawdust (%)

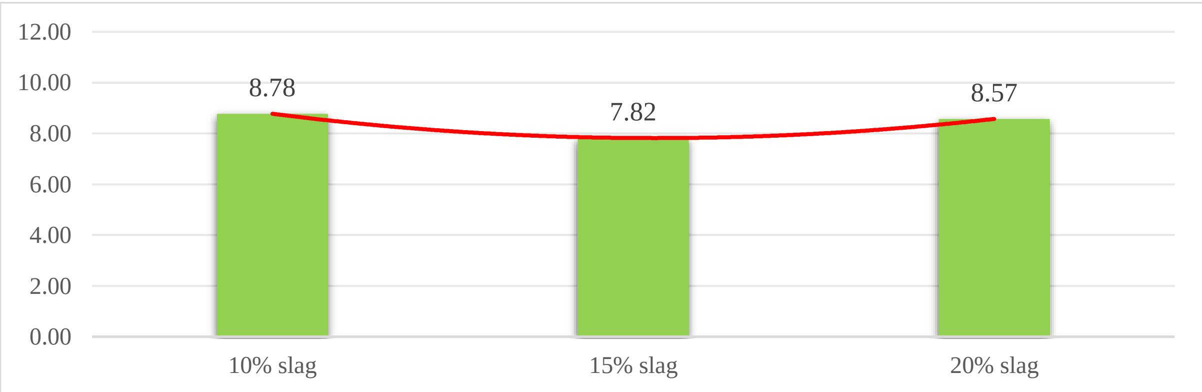


Figure 62. Average shrinkage (%) in relation to slag (%)

In the attached diagrams from Fig.55-Fig.57, the actual dimensions of the samples are shown, for dimension “**a**”, dimension “**b**” and dimension “**c**” of the bricks, Table 8. In Fig.58 an overview of the general ratio of the change in dimensions depending on the constituent materials in the samples is given. While in diagrams Fig.59 - Fig.62, the initial dimensions of the bricks before shrinkage are compared with the dimensions of the bricks after shrinkage.

5.3.3 Interpretation of results

In this experiment, it is observed that each dimension of the brick: **“a”**, **“b”**, **“c”**, has undergone changes. All three dimensions of the brick have decreased as a result of the shrinkage factor, this is characterized by the plasticity property of the clay that it contains.

In general, the smallest shrinkage occurred in sample “$19_{78\text{-}12\text{-}10}$” (with shrinkage percentage: length 7.82 %, width 6.08 % , height 6.97 %) . While the largest shrinkage occurred in samples “$17_{86\text{-}4\text{-}10}$” (with shrinkage percentage: length 12.74%, width 9.59% , height 9.02%), Table 8. This shrinkage varies in each brick depending on the combination of constituent materials. In bricks that have mainly higher clay content in combination with small sawdust content, there were differences in shrinkage. And the presence of slag constantly affects the dimensional shrinkage values of the samples. While according to brick-making manuals with traditional manual tools, the shrinkage of clay bricks ranges from 5% to 11% after drying and firing [109]. While clays that have less than 4% shrinkage are not preferred because they do not show a stable bond between the substances, shrinkage greater than 10% results in the creation of bricks susceptible to drying out.

5.4 Experiment II- Bulk density

The second experiment conducted in laboratory conditions is the measurement of the bulk density of the bricks, for each sample, Fig.63. The measurements are carried out in laboratory ambient conditions and the test samples must be previously dried without the participation of moisture in them.

Figure 63. Measuring the gross weight of the brick

According to EN772-13 [178], before measuring the mass, the samples must be dried at a temperature of 105℃ ±5℃, in a time interval of 24h. After this time, the mass of the dried sample m (g) is measured. The mass of the sample in relation to the volume of the sample calculates the bulk density: Density ρ (g/cm3) = Mass m (g) / Volume V (cm3). The tool used for this experiment is the electronic scale. During the implementation of this experiment, changes in bulk density are observed in each brick. This is due to these factors: different ingredients, due to changes in dimensions during shrinkage, due to manual work in creating the product in the mold, and also due to the manual mixing of the ingredients of the product under investigation.

5.4.1 Results

To better demonstrate the change in density in the brick samples, the following summary is presented in Table 9. From these obtained data, diagrams are worked to better show the behavior of the samples in this phase of the experiment. In the attached diagrams and worked from Fig.64, an overview of the average for bulk density for all experimental samples is given. While in Fig.65 an overview is provided with the curve depending on the change in bulk density and constituent materials in the samples. In the diagram Fig.66, Fig.67, Fig.68, the ratios of the constituent materials of the samples to bulk density are given.

Table 9. Bulk density of samples

Sample	Sample	Clay (%)	Sawdust (%)	Slag (%)	Dry state mass (g)	Volume (cm3)	Bulk density (g/cm3)	Average Bulk density (g/cm3)
17	17-1	86	4	10	1660.7	999.66	1.6613	1.68
	17 -2				1734.5	990.56	1.7510	
	17-3				1738.7	1,044.30	1.6649	
	17-4				1770.9	1,036.88	1.7079	
	17 -5				1729.3	1,044.30	1.6559	
	17-6				1748.1	1,053.46	1.6594	
18	18-1	82	8	10	1634.6	1,048.59	1.5589	1.54
	18-2				1718.8	1,060.90	1.6201	
	18-3				1720.6	1,105.44	1.5565	
	18-4				1707.8	1,099.56	1.5532	
	18-5				1597.1	1,105.44	1.4448	
	18-6				1613.8	1,075.45	1.5006	
19	19-1	78	12	10	1549.1	1,156.93	1.3390	1.37
	19-2				1582.1	1,156.40	1.3681	
	19-3				1576.9	1,196.14	1.3183	
	19-4				1585.6	1,142.40	1.3880	
	19-5				1587.9	1,153.48	1.3766	
	19-6				1615.3	1,116.39	1.4469	
20	20-1	81	4	15	1797.2	1,083.22	1.6591	1.66
	20-2				1844	1,091.83	1.6889	

	20-3				1824.4	1,094.16	1.6674	
	20-4				1848.8	1,074.10	1.7213	
	20-5				1755.7	1,099.80	1.5964	
	20-6				1745.5	1,076.70	1.6212	
21	21-1	77	8	15	1719.7	1,115.86	1.5411	1.52
	21-2				1737.6	1,115.81	1.5573	
	21-3				1718.8	1,134.78	1.5147	
	21-4				1738.4	1,128.60	1.5403	
	21-5				1685.8	1,153.69	1.4612	
	21-6				1695.1	1,134.47	1.4942	
22	22-1	73	12	15	1691.2	1,140.84	1.4824	1.46
	22-2				1700.2	1,153.21	1.4743	
	22-3				1629.8	1,165.34	1.3986	
	22-4				1636.2	1,163.43	1.4064	
	22-5				1652.1	1,133.01	1.4582	
	22-6				1740	1,136.69	1.5308	
23	23-1	76	4	20	1811.00	1,062.95	1.7037	1.73
	23-2				1856.2	1,082.79	1.7143	
	23-3				1873.2	1,062.13	1.7636	
	23-4				1873.8	1,082.07	1.7317	
	23-5				1877	1,057.53	1.7749	
	23-6				1818.5	1,056.79	1.7208	
24	24-1	72	8	20	1763.7	1,078.10	1.6359	1.58
	24-2				1718	1,078.10	1.5935	
	24-3				1748.2	1,113.28	1.5703	
	24-4				1753.8	1,083.89	1.6181	
	24-5				1728.7	1,127.43	1.5333	
	24-6				1675.4	1,110.11	1.5092	
25	25-1	68	12	20	1709.6	1,111.50	1.5381	1.51
	25-2				1682.5	1,111.50	1.5137	

	25-3				1636.5	1,128.60	1.4500	
	25-4				1697.8	1,122.02	1.5132	
	25-5				1683.8	1,129.38	1.4909	
	25-6				1707.1	1,102.00	1.5491	

5.4.2 Comparison of the results

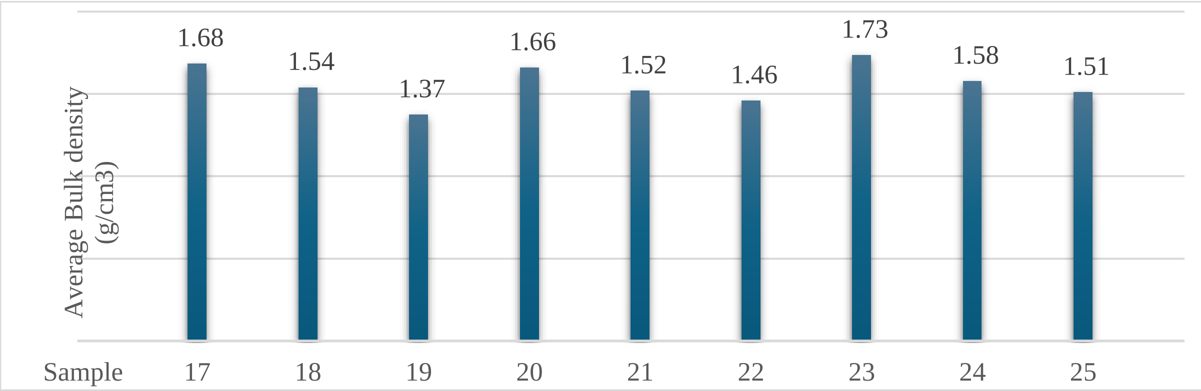


Figure 64. Average bulk density (g/cm3) for the sample

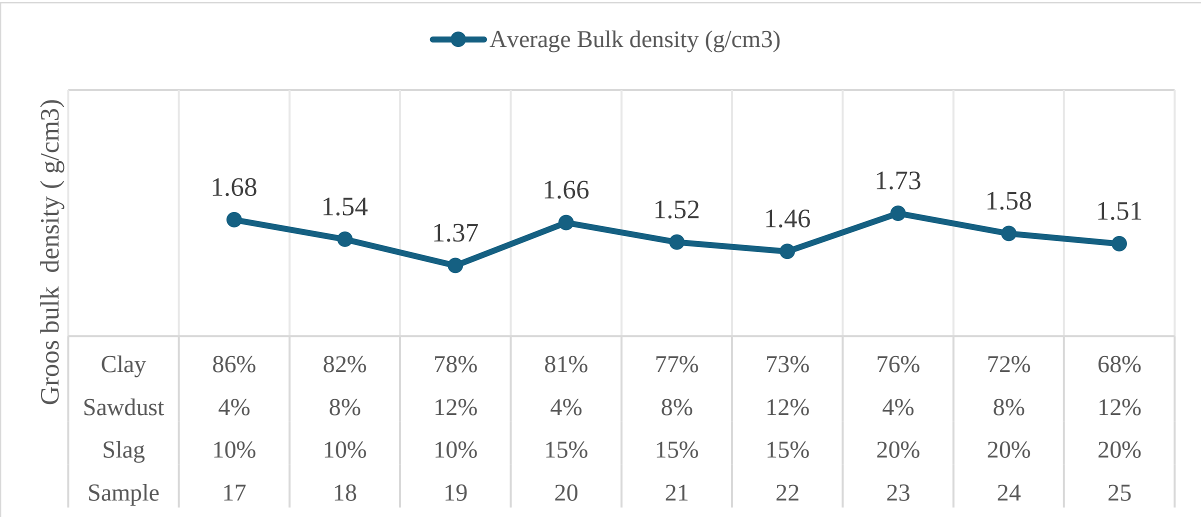


Figure 65. The ratio of clay, sawdust and slag in (%) comparing the values of bulk density in each sample

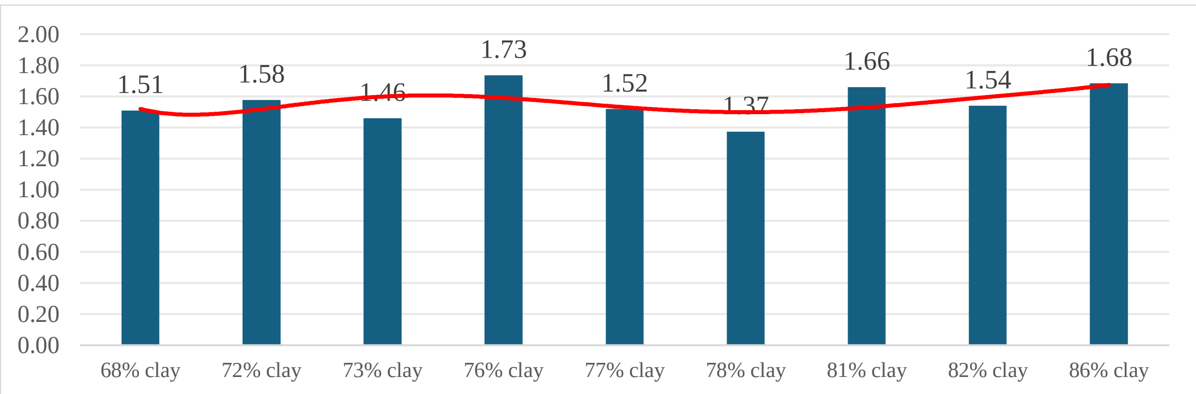


Figure 66. Average bulk density (g/cm3) in relation to clay (%)

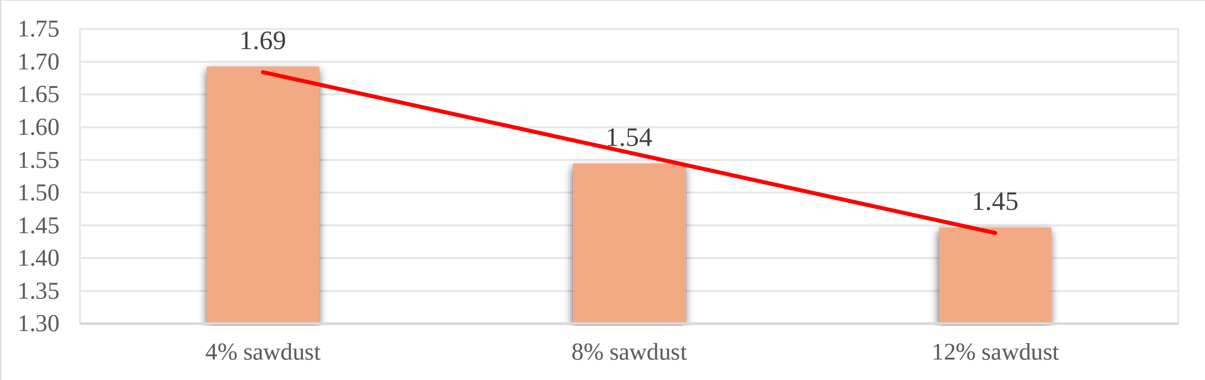


Figure 67. Average bulk density (g/cm3) in relation to sawdust (%)

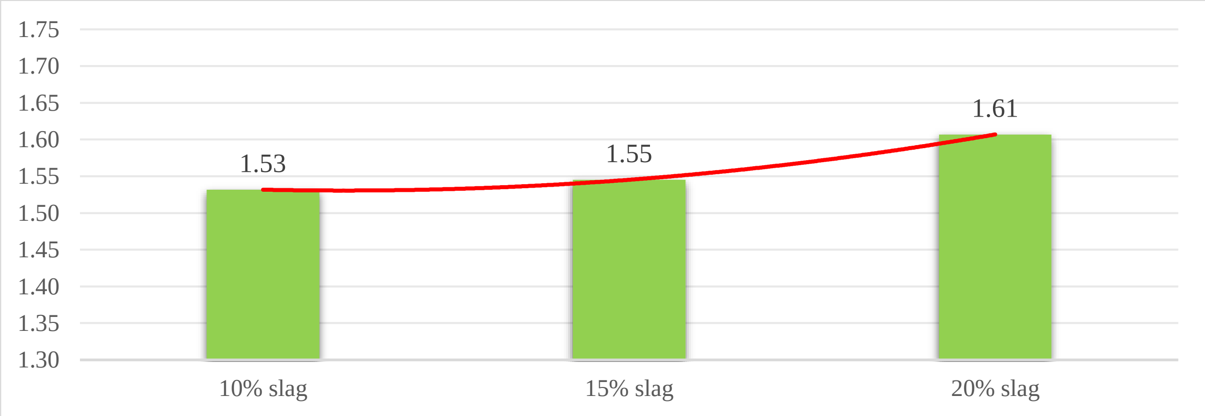


Figure 68. Average bulk density (g/cm3) in relation to slag (%)

5.4.3 Interpretation of results

From these results it is observed that sample "19 $_{78\text{-}12\text{-}10}$" has the lowest density ρ=1.37 g/cm3, while sample "23 $_{76\text{-}4\text{-}20}$" has the highest density ρ=1.73 g/cm3. Meanwhile, clay bricks available on the market, depending on the production method, with dimensions of 215mm x 102mm x 65mm, have densities of 1.7 g/cm3 – 2.1 g/cm3 [189]. From practice, it is known that clay has a high natural density but after drying creates a porous structure, while sawdust has a low density, which affects the creation of a porous material, and slag has a high density and helps increase mechanical strength.

From the results of the brick samples, it can be seen that the presence of slag components affects the increase in the density of the brick samples, while the presence of sawdust affects the low density of the samples, and the presence of clay affects constant values. The results obtained range from 1.37 g/cm3 to 1.73g/cm3, according to the standard EN 771-1:2011+1:2015 [161], these bricks are classified in the category of high density HD bricks. Also, according to this standard, bricks with a density higher than 1,000kg/m3 are considered suitable for protected and unprotected walls, for structural construction to withstand mechanical loads and contributing to the stability of load-bearing walls [161] .

5.5 Experiment III - Water absorption

The third experiment conducted in laboratory conditions is the measurement of water absorption for each set of bricks brought to the laboratory. Such testing is important for building materials, not only for the aesthetic and functional part but also for their durability and longevity. This process also shows how the material in question is managing its structure during the moisture process and after moisture. Materials that have optimal water absorption are less prone to cracks and damage the product structure.

The development of this experiment for brick samples has gone through these phases and according to EN 772-21:2011 [179] :

- The bricks are weighed in their dry state beforehand,
- The bricks are placed in water on a plasticizing grid that allows water penetration at room temperature 20℃ ±2℃, Fig.69.
- They are left to stand for 48 hours immersed in water (to ensure water penetration into the bricks),
- Under the surface of the samples and above them, the water circulation is free without obstacles,
- The distance between the bricks is 10mm on average,
- After 48 hours, the bricks are taken out of the water, and for 2-5 minutes they stand for water drainage, they are dried with a cloth on the surface, and then the weight of the bricks is measured, Fig.70.

Figure 69. Placing the bricks in water for 48 hours

Figure 70. Measuring the weight of bricks after water absorption

Calculation of water absorption according to EN 772-21:2011 [179] is done with formula (1), in which M_S is the mass of the specimen after absorption M_D mass of the specimen after drying:

$$W_S = (M_S - M_D) \times 100\,\% \,/\, M_D \qquad (1)$$

5.5.1 Results

The bricks after being removed from the water do not show any appearance of salts, or any eventual change in color. There are no cracks in their structure, and there is no damage to the outer surface of the bricks. To better demonstrate the ratio of water absorption with the constituent materials of the brick, it is presented Table 10, and in the accompanying diagrams below. From the diagrams Fig.71, Fig.73, Fig.74, Fig.75, it is observed that with the increase in the percentage of clay and sawdust, the degree of water absorption in the brick samples also increases. While in the diagram Fig.72, a summary overview of the influence of materials on water absorption is shown.

Table 10. The result of the water absorption samples

Sample	Sample	Clay (%)	Sawdust (%)	Slag (%)	Gross dry mass (g)	Weight after 48 hours in water (g)	Water absorption (%)	Average water absorption (%)
17	17-1	86	4	10	1660.7	1936.3	16.60	16.97
	17 -2				1734.5	2037.4	17.46	
	17-3				1738.7	2041.7	17.43	
	17-4				1770.9	2065.2	16.62	
	17 -5				1729.3	2023.1	16.99	
	17-6				1748.1	2040.8	16.74	
18	18-1	82	8	10	1634.6	1935.3	18.40	16.77
	18-2				1718.8	1978.8	15.13	
	18-3				1720.6	1966.8	14.31	
	18-4				1707.8	1950.9	14.23	
	18-5				1597.1	1905.9	19.34	
	18-6				1613.8	1923.8	19.21	
19	19-1	78	12	10	1549.1	1876.9	21.16	22.71
	19-2				1582.1	1956.5	23.66	
	19-3				1576.9	1954.9	23.97	
	19-4				1585.6	1933.2	21.92	
	19-5				1587.9	1962.3	23.58	
	19-6				1615.3	1970.4	21.98	
20	20-1	81	4	15	1797.2	2084.6	15.99	16.27
	20-2				1844	2136	15.84	
	20-3				1824.4	2109.7	15.64	
	20-4				1848.8	2137.7	15.63	
	20-5				1755.7	2055.5	17.08	
	20-6				1745.5	2050.4	17.47	
21	21-1	77	8	15	1719.7	2052.8	19.37	18.48
	21-2				1737.6	2039.3	17.36	
	21-3				1718.8	2017.5	17.38	
	21-4				1738.4	2039.9	17.34	
	21-5				1685.8	2031.5	20.51	

	21-6				1695.1	2016.3	18.95	
22	22-1	73	12	15	1691.2	2047.1	21.04	21.22
	22-2				1700.2	2031.2	19.47	
	22-3				1629.8	1996.6	22.51	
	22-4				1636.2	2001.9	22.35	
	22-5				1652.1	2024.4	22.53	
	22-6				1740	2077.6	19.40	
23	23-1	76	4	20	1811.00	2095.8	15.73	15.61
	23-2				1856.2	2148.3	15.74	
	23-3				1873.2	2169.1	15.80	
	23-4				1873.8	2169.1	15.76	
	23-5				1877	2167.3	15.47	
	23-6				1818.5	2094.3	15.17	
24	24-1	72	8	20	1763.7	2079.3	17.89	20.10
	24-2				1718	2066.5	20.29	
	24-3				1748.2	2086.4	19.35	
	24-4				1753.8	2106.9	20.13	
	24-5				1728.7	2099.2	21.43	
	24-6				1675.4	2036	21.52	
25	25-1	68	12	20	1709.6	2064.4	20.75	21.41
	25-2				1682.5	2050.7	21.88	
	25-3				1636.5	1997.8	22.08	
	25-4				1697.8	2054.9	21.03	
	25-5				1683.8	2059.6	22.32	
	25-6				1707.1	2055.6	20.41	

5.5.2 Comparison of the results

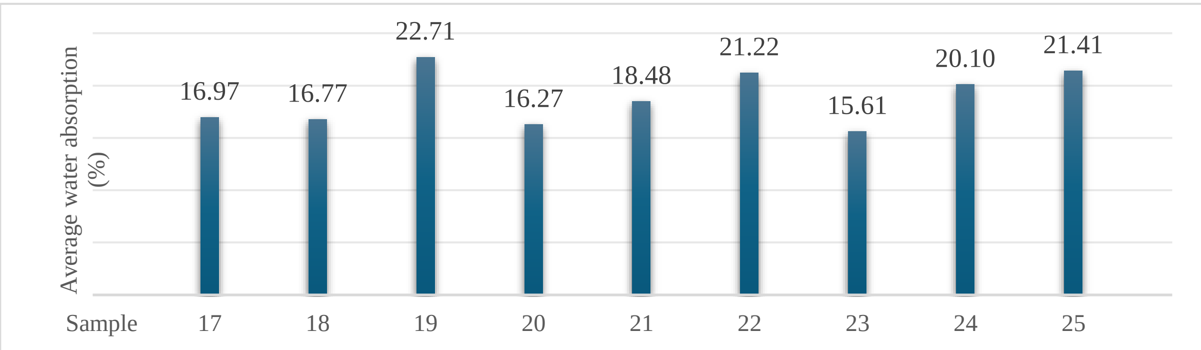


Figure 71. The average values of the samples, in the e water absorption (%)

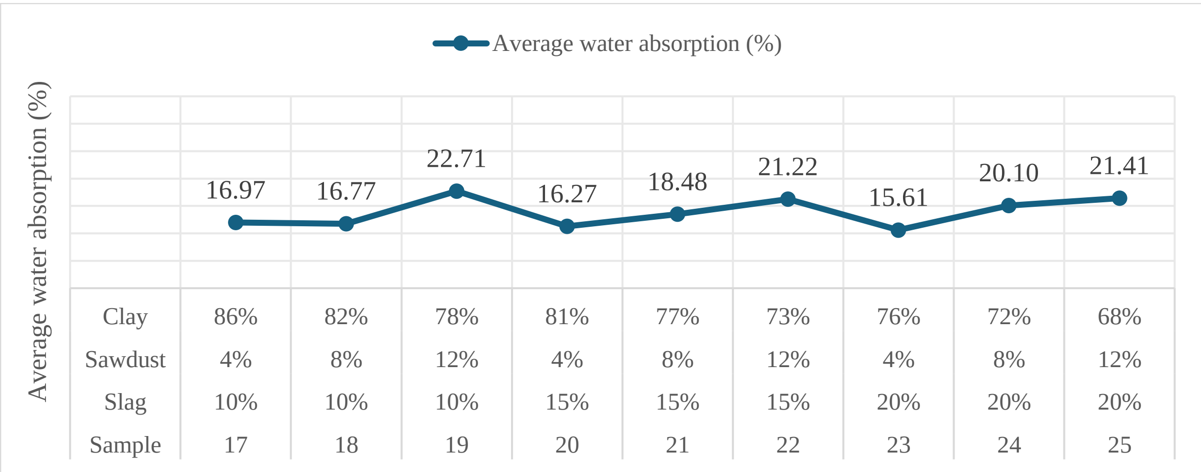


Figure 72. The ratio of clay, sawdust and slag in (%) comparing the values of water absorption in each sample

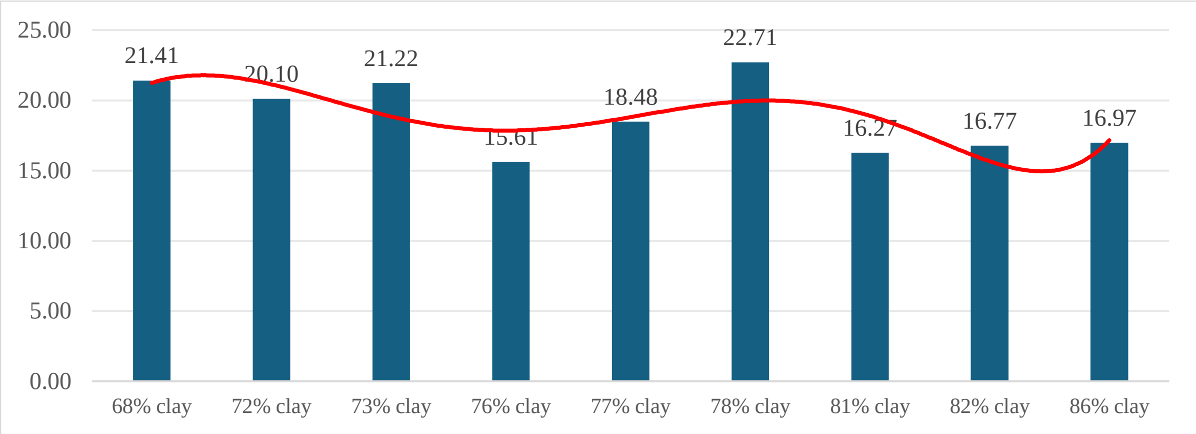


Figure 73.Average water absorption (%) in relation to clay (%)

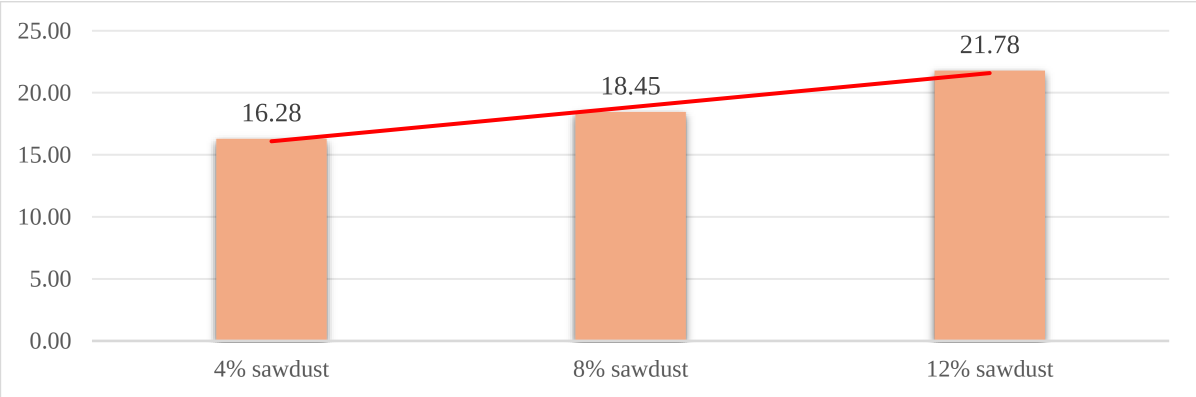


Figure 74. Average water absorption (%) in relation to sawdust (%)

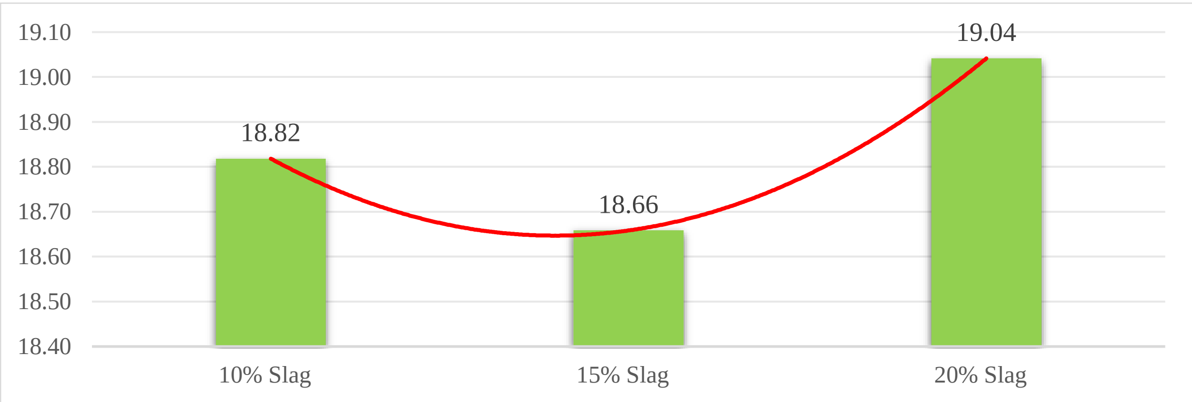


Figure 75.Average water absorption (%) in relation to slag (%)

5.5.3 Interpretation of results

According to the results shown, the minimum water absorption is 15.60%, while the maximum is 22.71%. It is observed that sample "23 $_{76\text{-}4\text{-}20}$" with 76% clay, 4% sawdust% and 20% slag has the lowest water absorption value of 15.60%, while the mixture "19 $_{78\text{-}12\text{-}10}$" with: 78% clay, 12% sawdust and 10% slag, has the highest water absorption value of 22.71%. This indicates that the low percentage of sawdust affects low water absorption. And as the slag content increases, the water absorption value also increases.

According to the European standards EN 771-1:2011 and BS 3921:1985 [160], for clay bricks, to properly balance the permeability and durability of the wall, water absorption provides general norms ranging up to 12%, while for some types of bricks, water absorption can be up to 20%, this value was also suggested according to manuals for brick production using the "hand making" technique [161], [160], [99] .

5.6 Experiment IV – Durability, Freezing and thawing cycles

This experiment is about evaluating the durability and resistance of a material to temperature changes. During this experiment, the external environmental conditions are simulated, with which the material must cope with low temperatures and under the influence of high temperatures. After this experiment, the structure of the bricks is visually checked if cracks have appeared in it, their mass is measured and the change in compressive strength is also measured. After these experiments, it is assessed whether the material is suitable for outdoor use and whether it can withstand weather cycles. The experiments were carried out in laboratory ambient conditions at temperature: 20 +-2 ℃, relative humidity 50% and according to European standards EN 771-1:2011 [161] and EN 772-22:2018 [180].

According to the standards, it is required to perform an average of 25 to 100 freeze-thaw cycles depending on the external conditions and the degree of exposure. In our case, 50 freeze-thaw cycles are performed, 13 days is the duration of the test in question (4 cycles within one day, a total of 50 cycles / 4 days = 12.5 days ~ 13 days). The test product in question, according to its function for use in the facade of the building, according to *Eurocode 6* (EN 1996-2:2006) [182] is classified in the MX 3.1 group.

The testing of this experiment went through these steps:

- At the beginning of the experiment, the brick samples are immersed in water for 24h at a temperature of +20℃ (due to saturation of the samples, water absorption).
- Then the cycle begins: the brick samples are placed in a refrigerator at a temperature of -20℃ for 4h, Fig.76.
- The next phase of the cycle: the samples are immersed in water under ambient conditions at a temperature of +20℃ ± 2 ℃ and remain for 2h, Fig.77.
- After the completion of 50 freezing and thawing cycles, the bricks are placed in an oven for drying at a temperature of +80℃ for 48h. This phase is carried out to achieve material stability and water evaporation, Fig.78.

- After the drying process in the oven, the bricks are checked for damage such as: deterioration in the structure, degradation of the brick surface, loss of color, fig.79.
- Then mass measurement is made, to determine the loss in mass caused by the freezing and thawing cycles, Fig 80.
- And then the samples in question are subjected to the compressive strength test, to determine how much there is a loss of bearing capacity.

Figure 76. Placing the bricks in the refrigerator at a temperature of -20 °C

Figure 77. Placing the bricks in water at a temperature of +20°C

5.6.1 Results

After this experiment, during the visual observation of the samples that have been subjected to freezing and thawing cycles, cracks are observed in the brick structure, as well as the outer surface of the samples are damaged and peeled/scraped. While there is no change in the color. These changes in the brick structure are shown in the attached photos (fig.88).

Figure 78. Drying temperatures in the oven after freezing and thawing cycles, at a temperature of +80°C

Figure 79. Damage to brick surfaces after freezing and thawing cycle

Figure 80. Measuring the mass of bricks after the oven drying process, different samples

During this experiment, the possibility that after the water evaporation process, i.e. during the drying process under the influence of air flow, the appearance of salt on the surface was possible. Which could also affect the fading of the color of the product (such a phenomenon could damage the aesthetic appearance and damage the structure), but at the end of this experiment such a process did not occur. Based on the standard EN 772-22:2018 [180], which provides the specifics of the implementation of the standard of freezing and thawing cycles, while the allowed limit of mass loss after the cycles is not specified, but based on other standards such as: ASTM C67-19 [190], the mass loss for clay bricks should not exceed 3% of the initial weight of the material. From the result of the values achieved, it is seen that sample "18" has the lowest value of 0.67% of mass loss, while sample "23" has the highest value of 2.61% of mass loss. To show these results obtained, Table 11 and the accompanying diagrams Fig.81, Fig.83, Fig.84, Fig.85, are attached. While in the diagram Fig.82, a summary report of freezing and thawing is given.

Table 11. Results after freezing and thawing cycles

Sample	Sample	Clay (%)	Sawdust (%)	Slag (%)	Gross dry mass (g)	Weight loss after 50 cycles (%)	Mass loss after freezing and thawing cycles (%)	Average loss in mass after cycles (%)
17	17-1	86	4	10	1660.7	1634.70	1.59	1.64

	17 -2				1734.5	1700	2.03	
	17-3				1738.7	1672	3.99	
	17-4				1770.9	1757	0.79	
	17 -5				1729.3	1712.2	1.00	
	17-6				1748.1	1740.3	0.45	
18	18-1	82	8	10	1634.6	1623.00	0.71	0.67
	18-2				1718.8	1707	0.69	
	18-3				1720.6	1705	0.91	
	18-4				1707.8	1690	1.05	
	18-5				1597.1	1594.1	0.19	
	18-6				1613.8	1606.3	0.47	
19	19-1	78	12	10	1549.1	1528	1.38	1.18
	19-2				1582.1	1566.9	0.97	
	19-3				1576.9	1551.8	1.62	
	19-4				1585.6	1568.2	1.11	
	19-5				1587.9	1570.9	1.08	
	19-6				1615.3	1601.0	0.89	
20	20-1	81	4	15	1797.2	1773.00	1.36	1.33
	20-2				1844	1812	1.77	
	20-3				1824.4	1796	1.58	
	20-4				1848.8	1818	1.69	
	20-5				1755.7	1743.8	0.68	
	20-6				1745.5	1730.2	0.88	
21	21-1	77	8	15	1719.7	1713.10	0.39	1.13
	21-2				1737.6	1697	2.39	
	21-3				1718.8	1692	1.58	
	21-4				1738.4	1717	1.25	
	21-5				1685.8	1676.3	0.57	
	21-6				1695.1	1684.8	0.61	
22	22-1	73	12	15	1691.2	1636.7	3.33	2.57
	22-2				1700.2	1676.5	1.41	
	22-3				1629.8	1581.9	3.03	
	22-4				1636.2	1603.6	2.03	
	22-5				1652.1	1589.8	3.92	
	22-6				1740	1710.6	1.72	
23	23-1	76	4	20	1811.00	1795.90	0.84	2.61
	23-2				1856.2	1817	2.16	
	23-3				1873.2	1815	3.21	
	23-4				1873.8	1824	2.73	
	23-5				1877	1810.4	3.68	
	23-6				1818.5	1764.4	3.07	
24	24-1	72	8	20	1763.7	1754.10	0.55	1.11
	24-2				1718	1690	1.66	
	24-3				1748.2	1733	0.88	
	24-4				1753.8	1722	1.85	
	24-5				1728.7	1712.9	0.92	
	24-6				1675.4	1662	0.81	
25	25-1	68	12	20	1709.6	1688.6	1.24	1.85
	25-2				1682.5	1633.9	2.97	
	25-3				1636.5	1614.1	1.39	
	25-4				1697.8	1667.1	1.84	
	25-5				1683.8	1658.3	1.54	
	25-6				1707.1	1672	2.10	

5.6.2 Comparison of the results

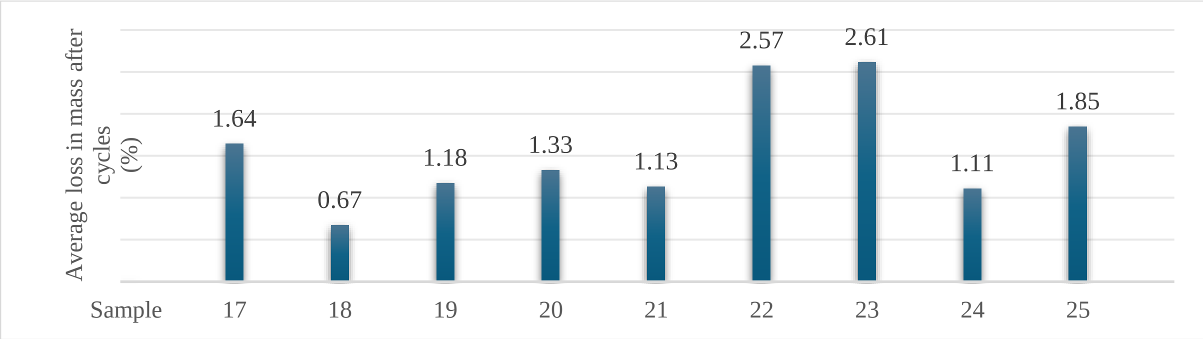


Figure 81. The average values of the samples, in the mass loss (%) after freezing and thawing

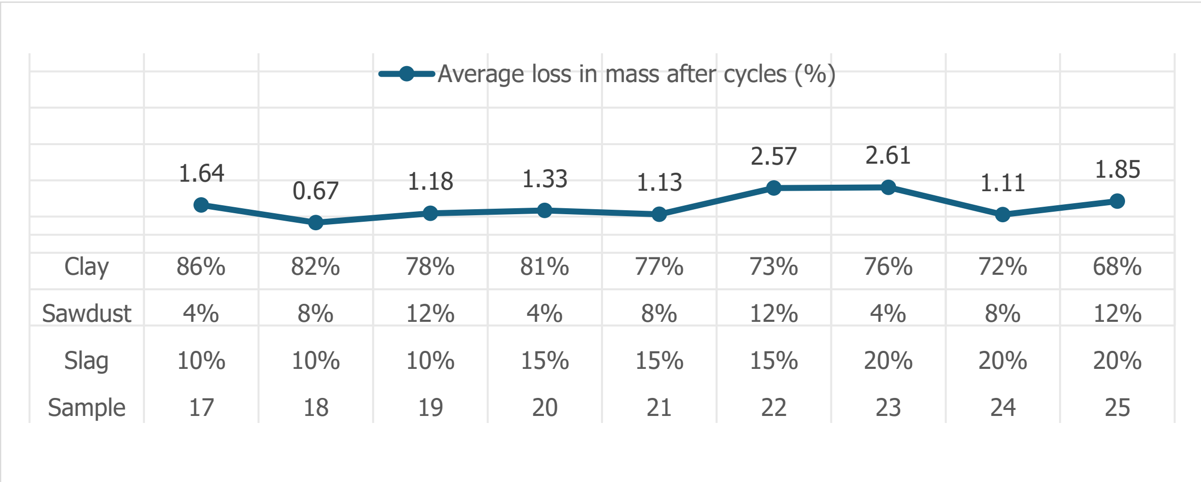


Figure 82. The ratio of clay, sawdust and slag in (%) comparing the values of loss in mass (%) after freezing and thawing cycles in each sample

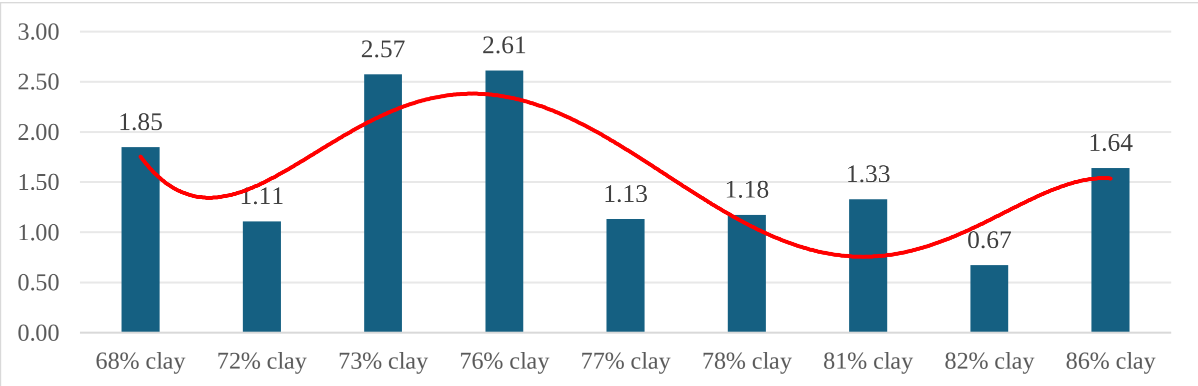


Figure 83. Average in mass loss (%) after freezing and thawing in relation to clay (%)

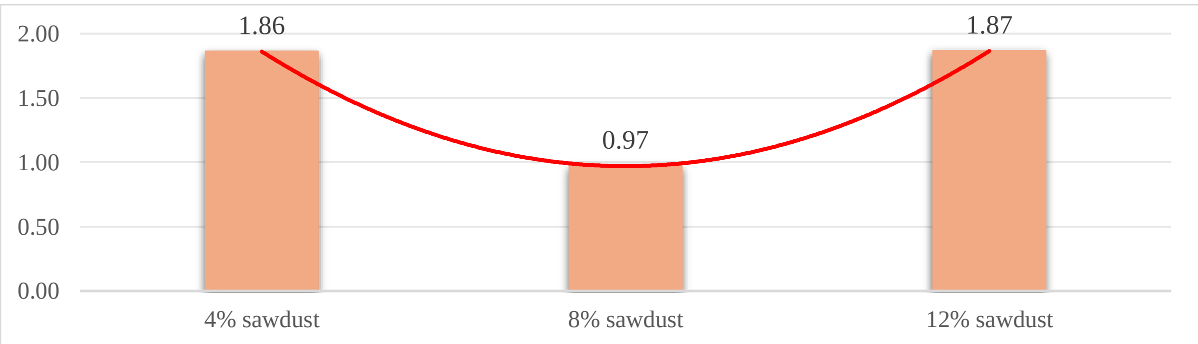


Figure 84. Average in mass loss (%) after freezing and thawing in relation to sawdust (%)

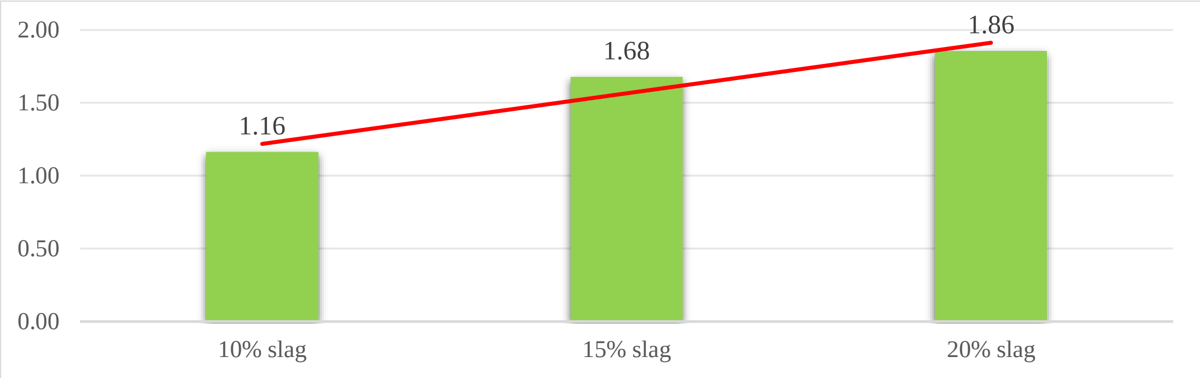


Figure 85. Average in mass loss (%) after freezing and thawing in relation to slag (%)

5.6.3 Interpretation of results

From these results it is observed that the high participation of slag in the research material, affects the mass loss of the product and can also be explained by the fact that the slag material affects the compaction of the product, the loss of porosity. While the participation of clay, depending on the combination with other carrier materials, has a variable curve in water absorption values.

Sample "18 $_{82\text{-}8\text{-}10}$" has the lowest mass loss value of 0.67%, while sample "23 $_{76\text{-}4\text{-}20}$" has the highest mass loss value of 2.61%. The explanation of these values can be interpreted when the samples in question are subjected to the compressive strength test, after freezing and thawing cycles. The results of freezing and thawing in summary form are presented in Fig.82.

5.7 Experiment V - Compressive strength in dry state condition

After the freeze-thaw cycle experiment, the product is tested for compressive strength according to EN 772-1:2011+A1:2015 standards [177]. According to this standard, bricks showing values ≥ 10 MPa belong to the "first category" this means that the bricks can be used in applications for structural load-bearing walls. While the "second category" ≥ 5 MPa, the bricks can be used for walls that do not carry large loads. Bricks with the designations "17" to "25" were subjected to this test. Each set of bricks consists of three test samples. A sample is formed by two bricks bonded together with a common mortar. The properties of the mortar are specified in the standard EN 998-2:2016 [185] and BS 5628-3:2001 [188], according to which this mortar contains a mixture of Portland cement 42.5N and sand in a ratio of 1:1 (cement: sand). Such a procedure for applying compressive strength to the joint of two bricks is used to demonstrate the behavior and loads that will occur in real conditions on the facade of buildings. The samples during testing must have a flat upper and lower surface, because when tested, their surface must fit well with the instrument plate, for reasons of transmitting forces evenly throughout the test sample. The flat surface is achieved by processing the brick faces with mortar. The procedure is carried out in this form: the lower surface of the brick is treated and left to stand for 14 days, Fig.86, Fig.87.

Figure 86. Preparation of the lower surfaces of the brick, to match the instrument plate

Figure 87. The concentration of the mortar in the brick per day to achieve strength according to the standards

After this time, two bricks are joined together with a bonding mortar and left to stand for drying for another 20 days. Then the upper surface of the sample is treated with mortar and left to stand for another 14 days until the mortar dries, Fig.88.

After these steps, the bricks are subjected to compressive strength testing in the laboratory, in the instrument: “Pilot Pro, EN Automatic Compression Tester for Cubes, Cylinder and Block [191]. Also, there were discussions held in the laboratory before starting the compressive strength testing, Fig.89.

Figure 88. Preparation of the upper surface of the bricks and observing the condition of the bricks during the drying time of the varnish

Figure 89. Discussions held in the laboratory before starting the compressive strength testing

The sample must fit into the instrument on two metal discs (conductive parts of the instrument) for the purpose of transmitting the load uniformly throughout the sample and at the same time this is also the reason for the pre-treatment of the outer surfaces of the sample with varnish. The instrument used can exert a force of up to 500kN. The instrument “Pilot Pro, EN Automatic Compression Tester for Cubes, Cylinder and Block”, exerts load on a sample until its breaking point. The instrument records on the monitor the maximum force reached in the sample, Fig. 90, Fig.91.

Figure 90.Instrument for measuring compressive strength "Pilot Pro, EN Automatic Compression Tester for Cubes, Cylinder and Block

Figure 91. Execution of the fracture process in samples in the laboratory with the help of the instrument and The state of the bricks after the breaking process

5.7.1 Results

In the following, Table 12 is attached and it is noted that sample number “23 $_{76-4-20}$” compared to the other samples has higher results of compressive strength 7.6 MPa, while sample number “22 $_{73-12-15}$” has the lowest value of compressive strength 3.72 MPa. To better show this relationship, the attached graphs are presented below, Fig.92 - Fig.93. While in the diagrams Fig.94, Fig.95, Fig.96, an overview of the ratio of the constituent materials of the samples with the values of compressive strength obtained is given.

Table 12. The result of the samples for the compressive strength test

Sample	Sample	Samples in composition	Clay (%)	Sawdust (%)	Slag (%)	Force (kN)	Compressive strength (MPa)	Compressive strength average (MPa)
17	17 -I	17/1	86	4	10	138	7.77	6.90
		17/2						
	17-II	17/3				121.4	6.63	
		17/4						
	17-III	17/5				115.6	6.31	
		17/6						
18	18-I	18/1	82	8	10	122.4	6.83	6.90
		18/2						
	18-II	18/3				115.5	6.27	
		18/4						
	18-III	18/5				140.3	7.62	
		18/6						
19	19-I	19/1	78	12	10	77.9	3.98	4.27
		19/2						
	19-II	19/3				83.3	4.25	
		19/4						
	19-III	19/5				86.8	4.58	
		19/6						
20	20-I	21/1	81	4	15	107.3	5.88	6.30
		21/2						
	20-II	21/3				116.3	6.38	
		21/4						
	20-III	21/5				121.8	6.64	
		21/6						
21	21-I	21/1	77	8	15	94.8	5.01	5.45
		21/2						
	21-II	21/3				99.8	5.28	
		21/4						
	21-III	21/5				114.5	6.05	
		21/6						
22	22-I	22/2	73	12	15	80.9	4.25	3.72
		22/3						
	22-II	22/1				59.6	3.12	
		22/4						
	22-III	22/5				72.6	3.78	
		22/6						
23	23-I	23/1	76	4	20	112.2	6.13	7.60
		23/2						
	23-II	23/3				143.4	7.88	
		23/4						
	23-III	23/5				160.4	8.78	
		23/6						
24	24-I	24/1	72	8	20	82.4	4.450	4.31
		24/2						
	24-II	24/5				69.7	3.630	
		24/3						
	24-III	24/4				92.3	4.860	
		24/6						
25	25-I	25/6	68	12	20	61.7	3.25	3.76
		25/5						
	25-II	25/2				76.1	4.11	
		25/1						
	25-III	25/3				74.1	3.94	
		25/4						

5.7.2 Comparison of the results

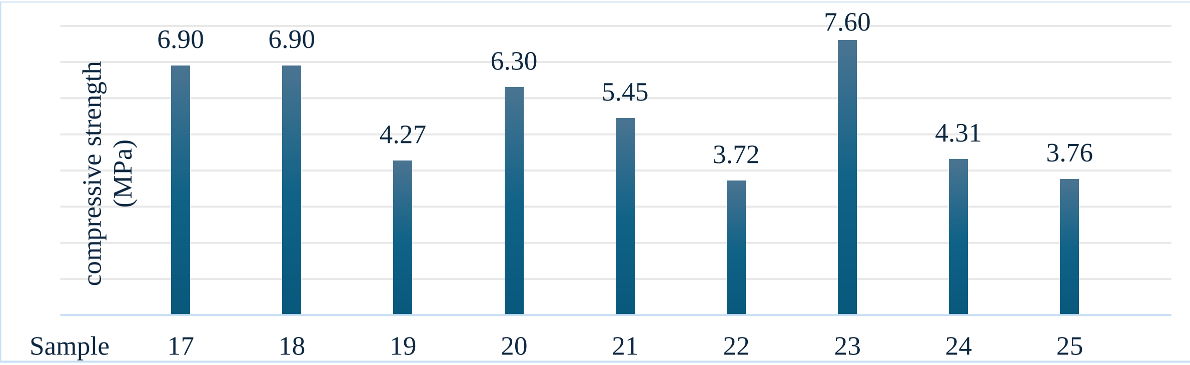


Figure 92. Average values of compressive strength (MPa) for each sample

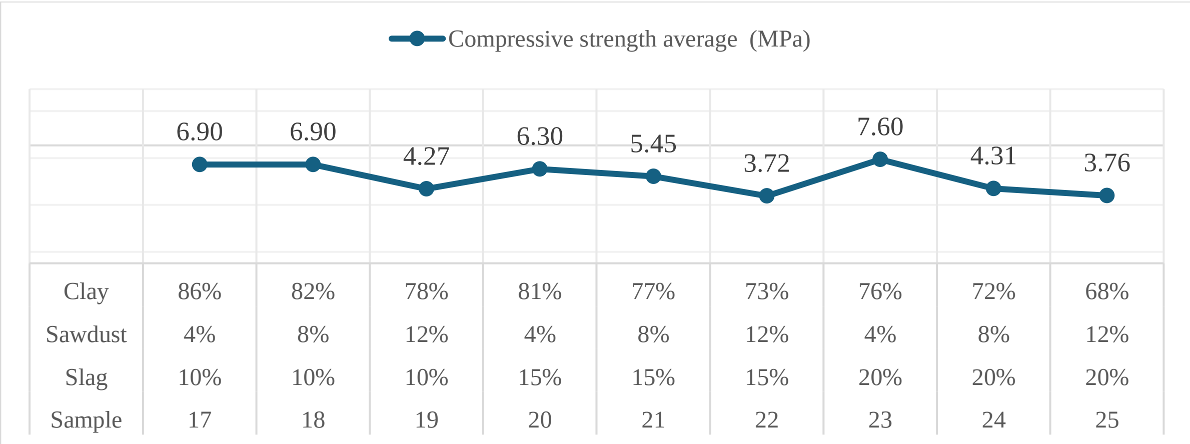


Figure 93. The ratio of clay, sawdust and slag in (%) comparing the values of compressive strength (MPa)

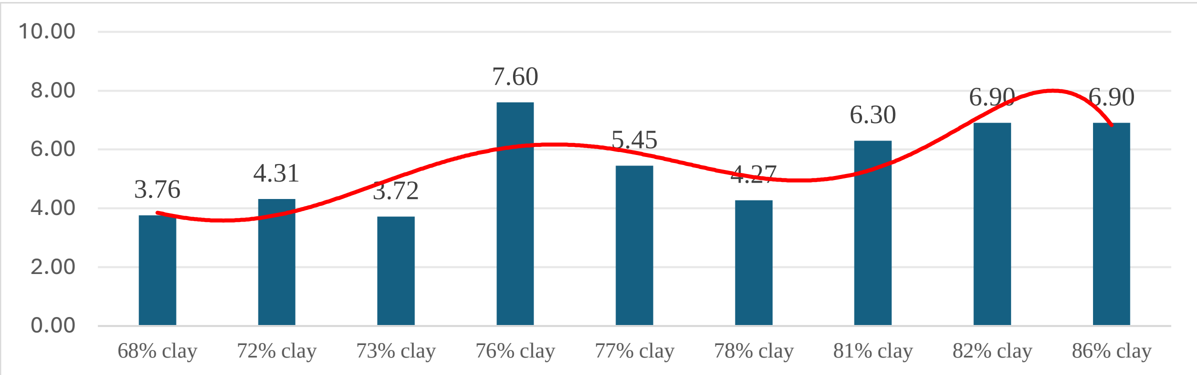


Figure 94. Compressive strength (MPa) in relation to clay (%) content in the product

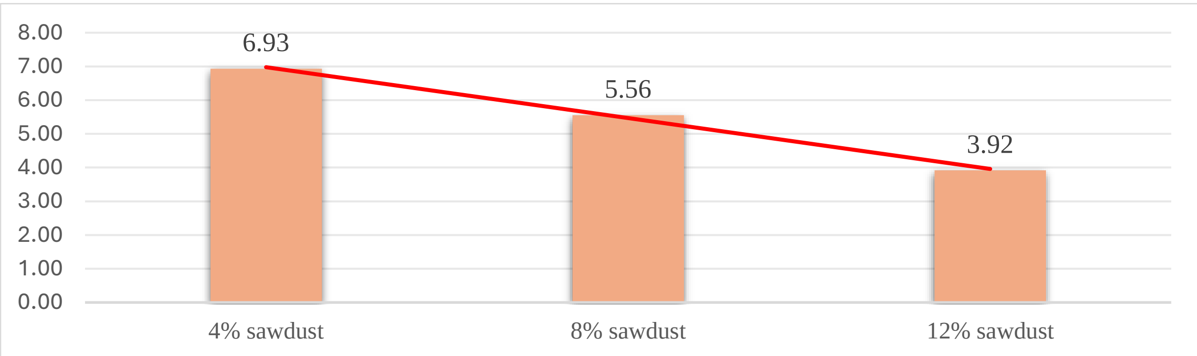


Figure 95. Compressive strength (MPa) in relation to sawdust (%) content in the product

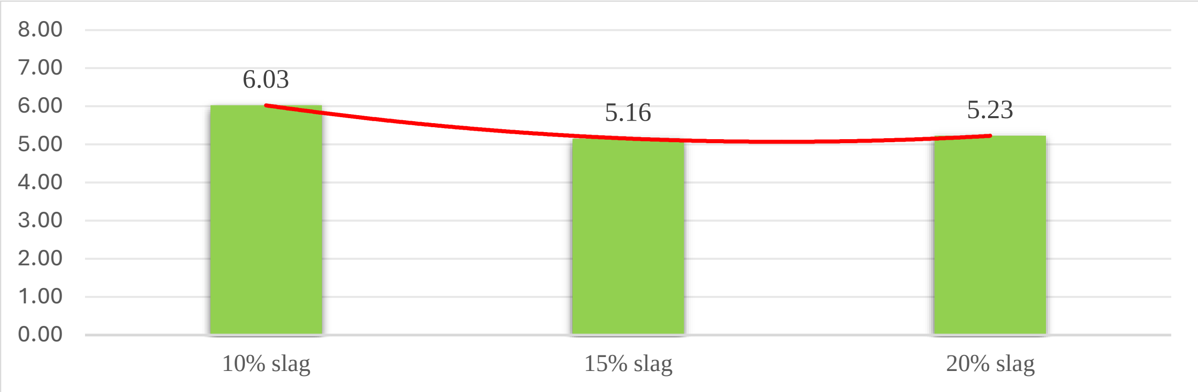


Figure 96. Compressive strength (MPa) in relation to slag (%) content in the product

5.7.3 Interpretation of results

Based on the standard EN 772-1:2011+A1:2015 and BS 5628-1:1992, bricks that show values ≥ 5 MPa belong to the "second category" this means that the bricks can be used in applications that do not carry large loads. In our testing, the highest value of compressive strength is 7.6 MPa obtained from the sample "23 $_{76\text{-}4\text{-}20}$", while the lowest compressive strength is 3.72 MPa. obtained from the sample "22 $_{73\text{-}12\text{-}15}$".

Sample "23 $_{76\text{-}4\text{-}20}$" which has the highest value of compressive strength has the lowest participation of sawdust 4% and the highest participation of slag 20%. While sample "22 $_{73\text{-}12\text{-}15}$" with the lowest value of compressive strength has in its composition the highest value of sawdust 12%. This shows that the low percentage of sawdust material, and the high percentage of clay affect the compressive strength value. While the presence of slag material affects a small decrease in the compressive strength value, it can also be understood that the combination of slag with other strength materials keeps the compressive strength value constant.

5.8 Experiment VI - Compressive strength, condition after freeze thaw cycles

In addition to testing samples for compressive strength in the normal state, it is also necessary to know the value of the compressive strength after freezing and thawing cycles of the samples, to understand whether the samples have maintained their mechanical properties after the cycles. This procedure is required to be carried out because during the cycling process, internal stresses are created in the product that affect the reduction of its stability, causing cracks in the product structure, loss of overall mass and eventual changes in dimensions. And such testing provides information about the lifespan of the material, under the influence of the external environment of extreme conditions and under the influence of external forces. The test is carried out according to the standards of EN 772-1:2011+A1:2015 [177] and EN 772-22:2018 [180]. The samples of our research product, which have undergone the process of freezing and thawing cycles, are now subjected to the compressive strength test with the help of the instrument “Pilot Pro, EN Automatic Compression Tester for Cubes, Cylinder and Block”, the processing of the surfaces of the samples is done according to European standards, applying the same technique as for testing the samples in normal condition. The mortar is prepared according to the standards: EN 998-2:2016 [185] , BS 5628-3:2001 [188] and BS 3921:1985 [160], according to which this mortar contains a mixture of Portland cement 42.5 N and sand in a ratio of 1:1 (cement : sand), Fig.97. With this mortar, the external contacting surfaces of the brick are treated and left to stand for a period of 14 days, then after this period of time, the two bricks are joined together with mortar and left to stand for a period of 20 days, Fig.98.

Figure 97.The process of preparing the mortar for brick bonding

Figure 98. Processing the exterior surfaces of bricks, preparation for compressive strength testing

5.8.1 Results

After reaching the strength of the sample processing mortar, the brick samples are subjected to the compressive strength test in the instrument “Pilot Pro, EN Automatic Compression Tester for Cubes, Cylinder and Block”, the process is presented in the attached Fig.99. After the completion of the testing process, the compressive strength values are recorded, and the values achieved are presented in the following table, Table 12. While showing the ratio of the results obtained from the experiment in question, diagrams are presented for each tested sample, Fig.100 , Fig.101 and the average value of compressive strength after freezing and thawing cycles. While in the diagrams Fig.104, Fig.106, the ratio of the constituent materials of the samples to the values of compressive strength is provided, this overview is better understood in the summary diagram in Fig.102, Fig.103.

Figure 99.The process of testing the strength of samples in the instrument

Table 13.The result of the samples for the compressive strength test after freezing and thawing cycles

	Sample	Samples in composition	Clay (%)	Sawdust (%)	Slag (%)	Mass loss after freezing and thawing cycles (%)	Compressive strength after freezing and thawing cycles (MPa)	Average compressive strength, after freezing and thawing cycles (MPa)	Compressive strength reduction (%)
17	17-I	17\1	86	4	10	1.64	6.59	6.64	3.86
		17\5							
	17-II	17\6					6.14		
		17\4							
	17-III	17\3					7.18		
		17\2							
18	18-I	18\1	82	8	10	0.67	5.2	6.14	11.02
		18\6							
	18-II	18\5					6.2		
		18\3							
	18-III	18\4					7.03		
		18\2							
19	19-I	19\1	78	12	10	1.18	4.10	4.04	5.31
		19\2							
	19-II	19\3					4.18		
		19\4							
	19-III	19\5					3.85		
		19\6							
20	20-I	20\1	81	4	15	1.33	6.07	6.27	0.51
		20\2							
	20-II	20\3					7.09		
		20\4							
	20-III	20\5					5.65		
		20\6							
21	21-I	21\1	77	8	15	1.13	4.84	4.96	8.99
		21\2							
	21-II	21\3					4.42		
		21\4							
	21-III	21\5					5.62		
		21\6							
22	22-I	22\1	73	12	15	2.57	2.82	3.40	8.60
		22\2							
	22-II	22\3					3.25		
		22\4							
	22-III	22\5					4.13		
		22\6							

23	23-I	23\1	76	4	20	2.61	6.55	6.59	13.29
		23\2							
	23-II	23\3					7.59		
		23\4							
	23-III	23\5					5.63		
		23\6							
24	24-I	24\1	72	8	20	1.11	5.32	3.88	10.07
		24\2							
	24-II	24\3					2.68		
		24\4							
	24-III	24\5					3.63		
		24\6							
25	25-I	25\1	68	12	20	1.85	3.02	3.24	13.94
		25\2							
	25-II	25\3					2.66		
		25\4							
	25-III	25\5					4.04		
		25\6							

5.8.2 Comparison of the results

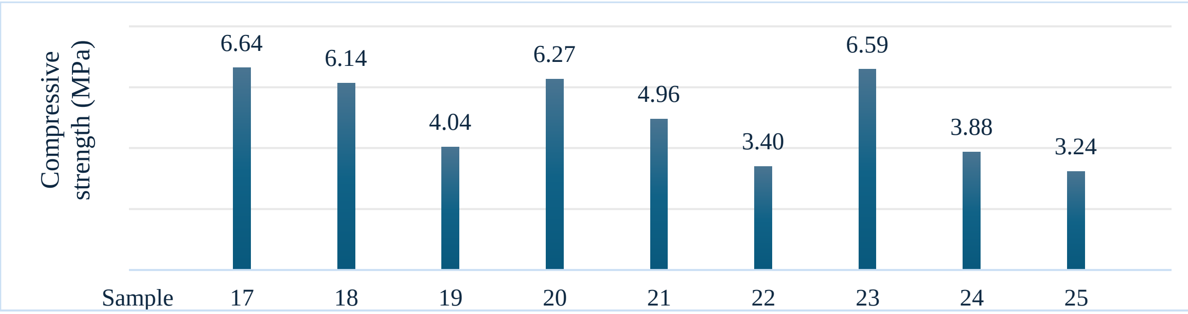


Figure 100. Average values of compressive strength (MPa) for each sample

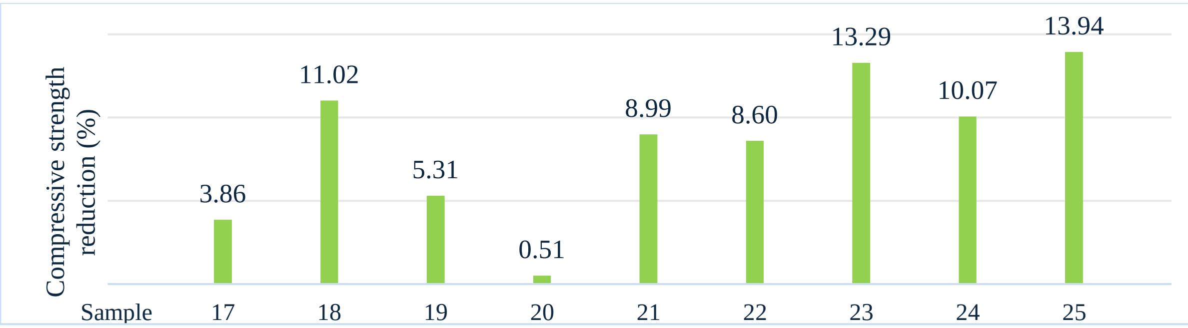


Figure 101.Average values of compressive strength reduction (%) for each sample

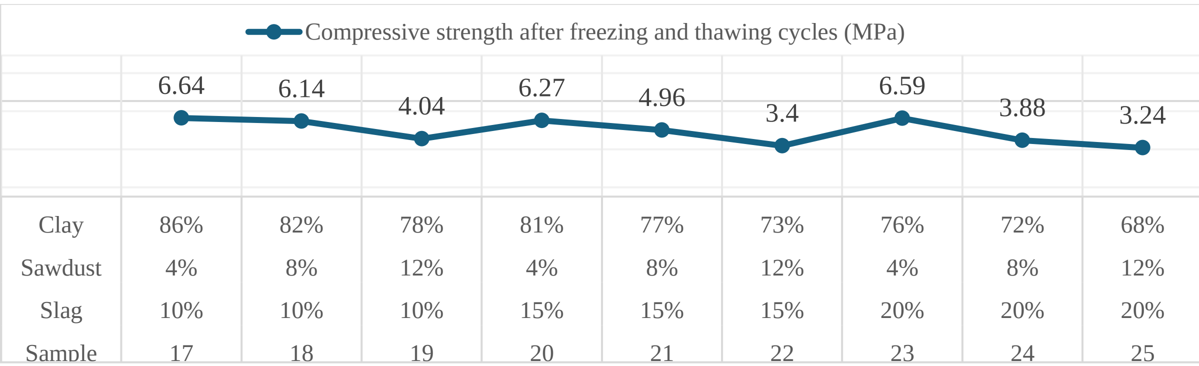


Figure 102. The ratio of clay, sawdust and slag in (%) comparing the values of compressive strength (MPa) after freezing and thawing cycles

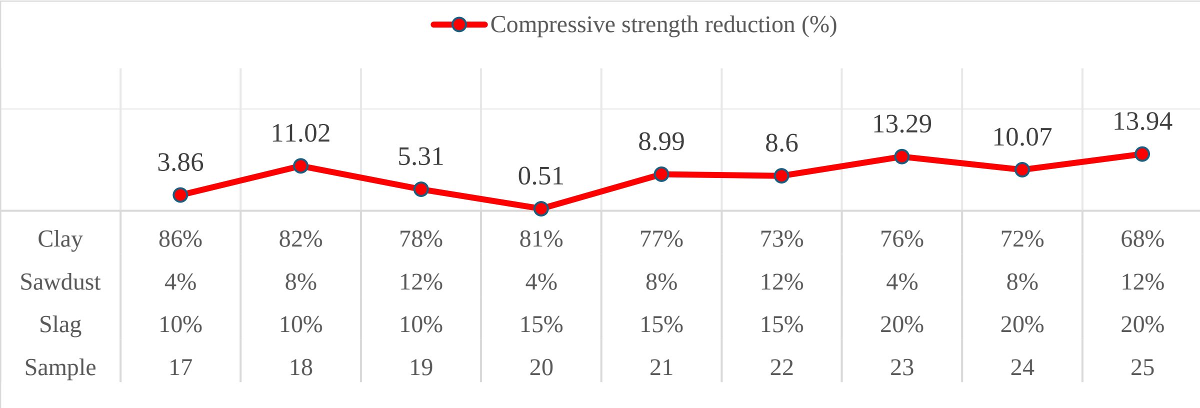


Figure 103.The ratio of clay, sawdust and slag in (%) comparing the values of compressive strength reduction (%) after freezing and thawing cycles

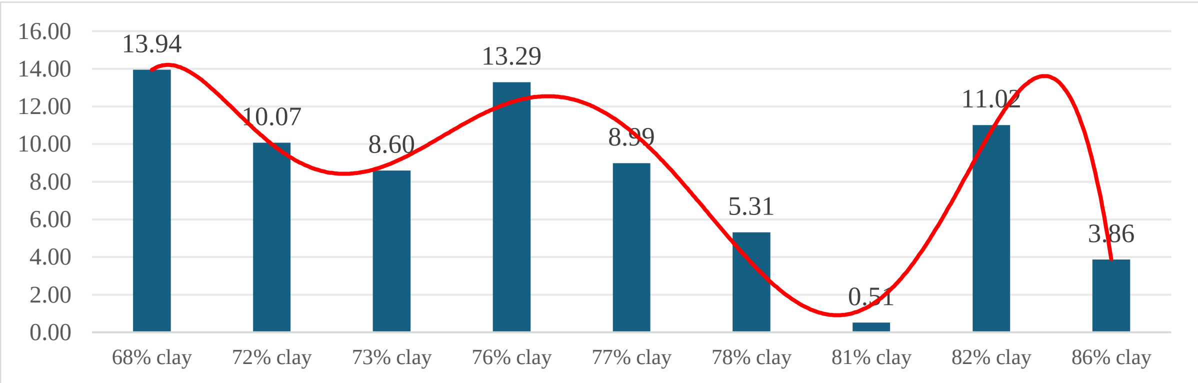


Figure 104. Compressive strength reduction (%) after freezing and thawing cycles in relation to clay (%)

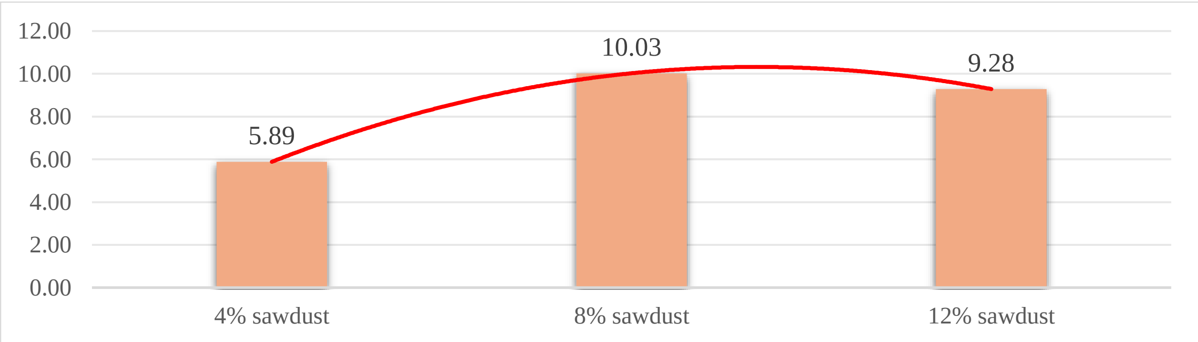


Figure 105. Compressive strength reduction (%) after freezing and thawing cycles in relation to sawdust (%) content in the product

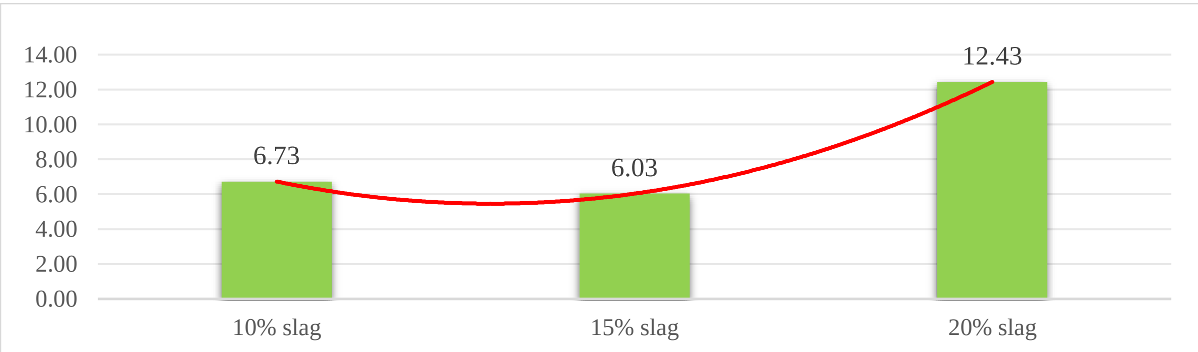


Figure 106. Compressive strength reduction (%) after freezing and thawing cycles in relation to slag (%) content in the product

5.8.3 Interpretation of results

From the values obtained in this experiment of compressive strength after freezing and thawing cycles, it is observed that sample “17 $_{86\text{-}4\text{-}10}$” has the highest value of compressive strength 6.64 MPa, while sample “25 $_{68\text{-}12\text{-}20}$“ has the lowest value of compressive strength 3.24 MPa. Comparing the results of this experiment with the initial results of the compressive strength of the normal state, it can be concluded that the sample “17 $_{86\text{-}4\text{-}10}$” has the smallest reduction in compressive strength of 3.86%, while the sample “25 $_{68\text{-}12\text{-}20}$“ has a largest reduction in compressive strength of 13.94% .

From these results it can be seen that in samples in which the participation of sawdust and slag increases, this affects the increase in the reduction of compressive strength.

These low results, compared to the initial compressive strength results measured before the cycles, are due to the subjection to freezing and thawing cycles. During these cycles, the samples undergo physical and chemical changes in their structure. Regarding this phenomenon, there are studies by others, case study clay in combination with other materials [192] [193]. In samples that have a low slag content, the presence of slag in them can improve the microstructure of the samples, making the product more resistant to extreme temperature cycles; this microstructure parameter also affects the pozzolanic reactivity of the slag in combination with clay, [194], [195], [196].

5.9 Experiment VII - Thermal conductivity

Achieving good thermal performance, meaning low thermal transmittance, is related to the thermal insulating ability of the materials used on the facade of the building. Within the framework of the thermal insulating ability of a material in thermal calculation practice, we distinguish these measurement units: the thermal conductivity λ (W/m·K), the thermal transmittance U (W/m^{2}K), the thermal resistance R (m^{2}K/W), $R=1/U$.

In our case, the target for the research product is thermal conductivity λ (W/m·K), which will be tested in two locations, in the laboratory of the Faculty of Civil Engineering in Skopje and in the laboratory of the Faculty of Mechanical Engineering in Pristina. While this chapter will explain the testing of the experiments carried out in Skopje.

5.9.1 The method of the experiment at the Faculty of Civil Engineering in Skopje

To measure the thermal conductivity λ (W/m·K) at the Faculty of Civil Engineering in Skopje, the instrument that will carry out these tests "Heat Flow Meter HFM 436", requires the processing of samples with dimensions 300 mm x 300 mm x 30 mm, because the internal space of the instrument in which these tests will be carried out has such dimensions. The processing of samples with these dimensions is carried out in the outdoor environment, at a temperature of 21-22°C and air humidity of 70%.

The technique of mixing the materials, the method of pouring the material into the mold, the standing of the samples in natural conditions under the influence of air currents, sending them to the factory for drying and firing, all these techniques are the same, used for the preliminary samples tested in the experiments explained in the above chapters. After receiving them from the factory, the samples were kept for 14 days in ambient conditions at a temperature of 20 +-2 °C, and a relative humidity of 50%. After this period, the samples were sent to the Civil Engineering Laboratory in Skopje for testing, Fig.107. The samples that were sent for testing in Skopje are: “19 $_{78\text{-}12\text{-}10}$“, “22 $_{73\text{-}12\text{-}15}$“, “25 $_{68\text{-}12\text{-}20}$“, such selection of samples because they were ready for testing compared to the other samples. The samples sent for testing are from three groups in total. Each group contains three samples for testing, forming a total of 9 samples.

Figure 107. a) Sample in laboratory’s, b) Instrument Heat Flow Meter HFM 436

After being sent to the laboratory of the Faculty of Civil Engineering in Skopje, the bricks were subjected to thermal testing in the apparatus. The apparatus used for the thermal experiment is known as the Heat Flow Meter HFM 436 [197], (fig.b.134), which generates data in accordance with the standards set by ASTM C518 [198], ISO 8301:1991 [199], and EN 12667:2001 [200]. The materials that can be tested in this apparatus are diverse, ranging from materials such as: vacuum, insulation panels, polystyrene, fibreboards, oils, fibre insulation, wood, polymers and other thermal insulation materials with thermal conductivity no greater than λ= 0.5 (W/m·K). The "Heat Flow Meter HFM 436" instrument works in this way: a sample measuring 30x30x2cm is placed inside the instrument's interior. After closing the instrument door, through software commands and digital instructions, the heat flux begins to pass from the upper plate through the test brick to the lower plate, which is connected to the cooling system, Fig.108.

After a time interval, which varies from one and a half to three hours, depending on the stabilization of the λ value (W/m·K) and the test sample, these conductivity values are recorded in the Q-Lab program. The Q-Lab program is an integral part of the HFM instrument in which the samples are tested for thermal conductivity coefficient. This program generates the results obtained for each test sample. This information will be attached in the following chapters.

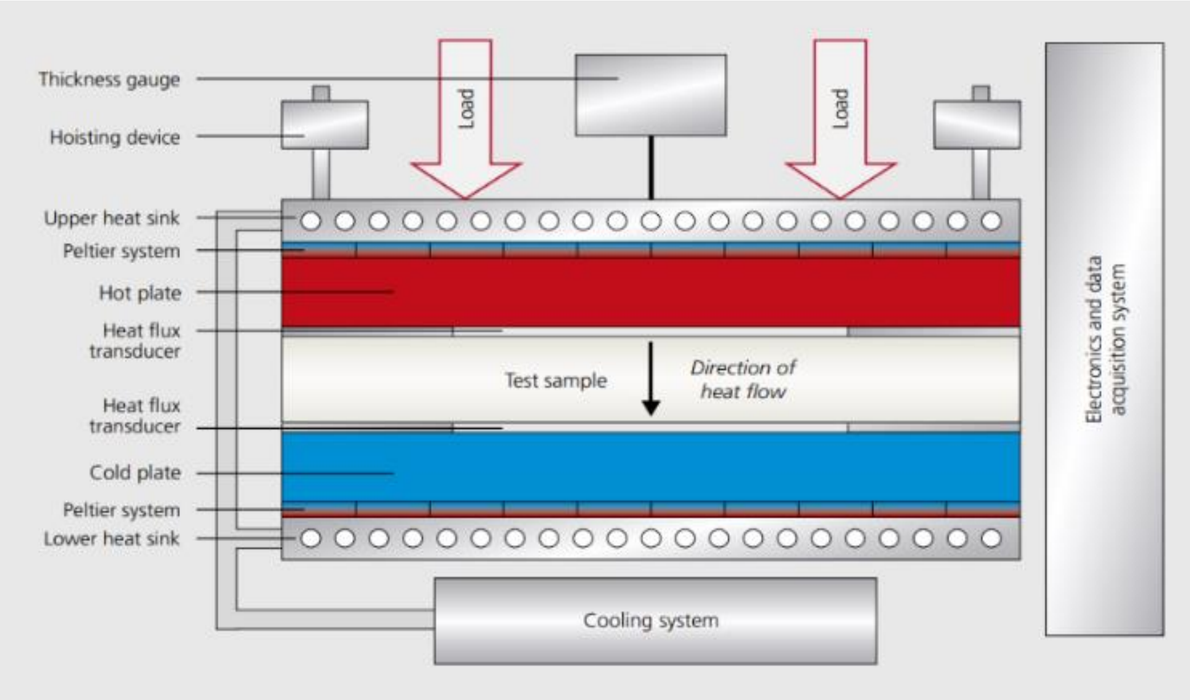


Figure 108. Schematic design of the HFM 436/3/1 Lambda Source *[197]*

5.9.2 Results

The thermal conductivity λ (W/m·K) varies from λ = 0.14 (W/m·K) to λ = 0.18 (W/m·K). These values were generated by the program in a time of one and a half to three hours. From the obtained results, it is observed that the time of generation of thermal conductivity varies, depending on the density of the material, the percentage of combined materials, and how the instrument manages to generate and consume temperature. The following data are presented in Table 14. The information generated by the software for sample "19" is presented in Fig.109, Fig.110, Fig.111, and the same technical procedure was applied to the other test samples.

Table 14. The result of samples in the laboratory for the thermal conductivity

Thermal conductivity in Skopje (W/m K)											
Sample	Sample name	Clay (%)	Sawdust (%)	Slag (%)	Mass (g)	Volume (cm3)	Density (g/cm3)	Average density (g/cm3)	Thermal conductivity in Skopje (W/m K)	Time for testing (h)	Thermal conductivity average (W/m K)
19	19-1	78	12	10	3941	2977	1.324	1.33	0.1592	2:08	0.148
	19-2				3910	2977	1.313		0.1446	1:09	
	19-3				4092	3050	1.342		0.1400	1:34	

22	22-1	73	12	15	4425	3070	1.441	1.45	0.1581	2:51	0.152
	22-2				4455	3070	1.451		0.1543	2:56	
	22-3				4442	3070	1.447		0.1421	2:43	
25	25-1	68	12	20	4427	3070	1.442	1.49	0.1468	1:46	0.165
	25-2				4726	3070	1.539		0.1816	2:34	
	25-3				4451	2977	1.495		0.1674	2:34	

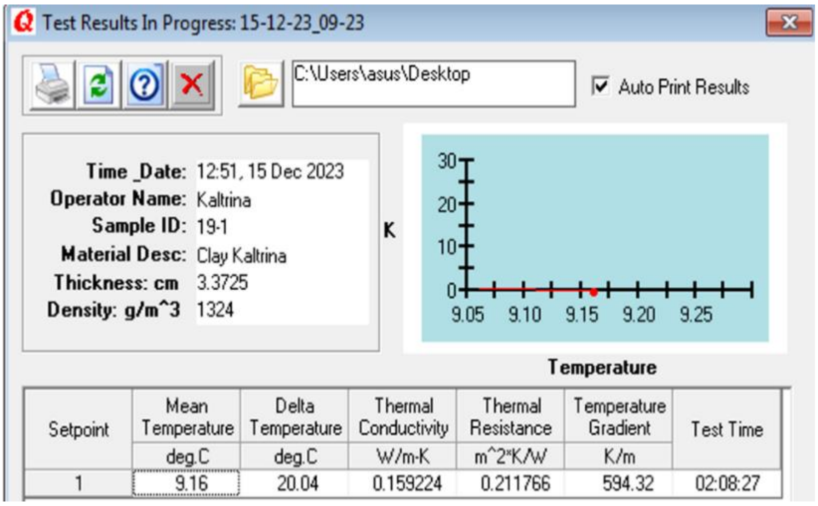


Figure 109. Output results generated with the software

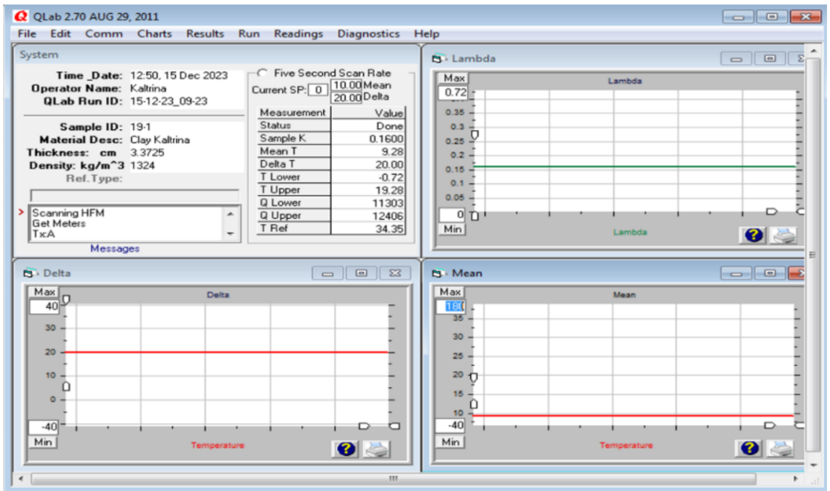
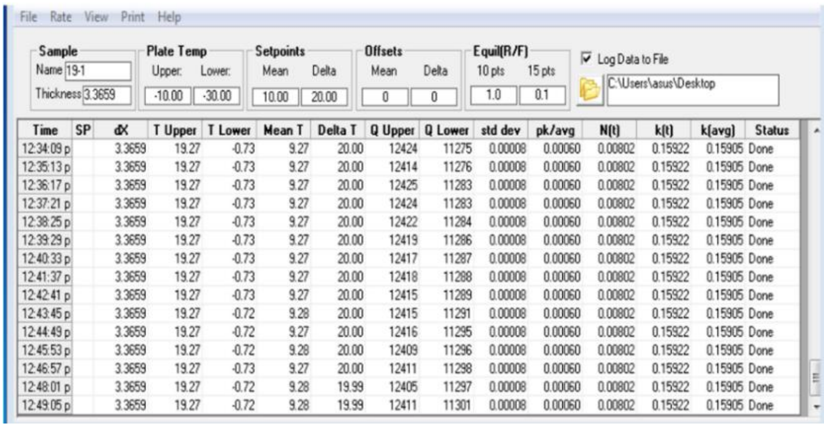


Figure 110. Values generated with the software



Time	SP	dX	T Upper	T Lower	Mean T	Delta T	Q Upper	Q Lower	std dev	pk/avg	N(t)	k(t)	k(avg)	Status
12:34:09 p		3.3659	19.27	-0.73	9.27	20.00	12424	11275	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:35:13 p		3.3659	19.27	-0.73	9.27	20.00	12414	11276	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:36:17 p		3.3659	19.27	-0.73	9.27	20.00	12425	11283	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:37:21 p		3.3659	19.27	-0.73	9.27	20.00	12424	11283	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:38:25 p		3.3659	19.27	-0.73	9.27	20.00	12422	11284	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:39:29 p		3.3659	19.27	-0.73	9.27	20.00	12419	11286	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:40:33 p		3.3659	19.27	-0.73	9.27	20.00	12417	11287	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:41:37 p		3.3659	19.27	-0.73	9.27	20.00	12418	11288	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:42:41 p		3.3659	19.27	-0.73	9.27	20.00	12415	11289	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:43:45 p		3.3659	19.27	-0.72	9.28	20.00	12415	11291	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:44:49 p		3.3659	19.27	-0.72	9.27	20.00	12416	11295	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:45:53 p		3.3659	19.27	-0.72	9.28	20.00	12409	11296	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:46:57 p		3.3659	19.27	-0.73	9.27	20.00	12411	11298	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:48:01 p		3.3659	19.27	-0.72	9.28	19.99	12405	11297	0.00008	0.00060	0.00802	0.15922	0.15905	Done
12:49:05 p		3.3659	19.27	-0.72	9.28	19.99	12411	11301	0.00008	0.00060	0.00802	0.15922	0.15905	Done

Figure 111. Values generated with the software

The results of testing three different samples, with different clay and slag contents, where the slag varies between 10%, 15% and 20%, in relation to the thermal conductivity λ (W/m·K), are presented in Fig.112, Fig.113, Fig.115, Fig.116, Fig.117. Fig.114 shows the ratio of the value to the percentage participation of the materials that make up the samples.

5.9.3 Comparison of the results

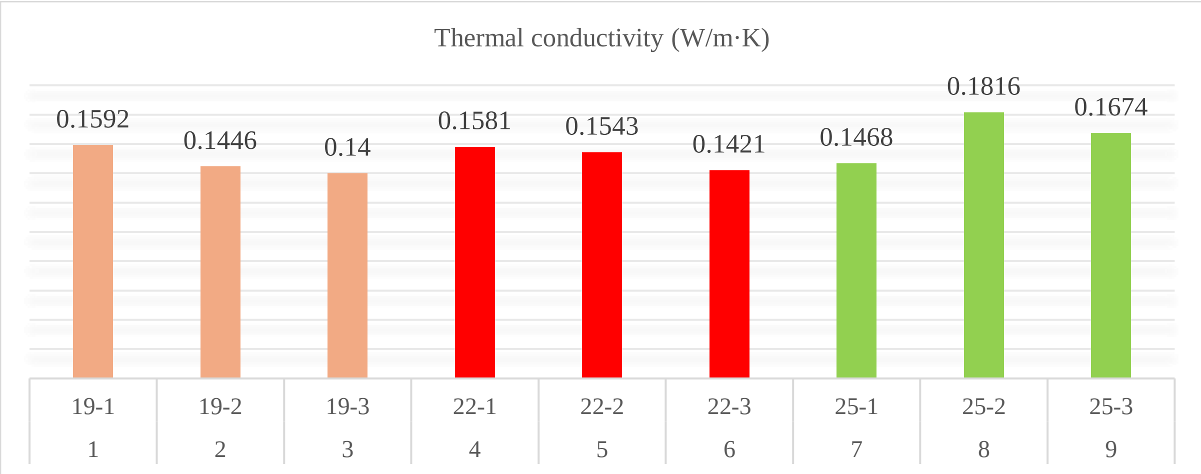


Figure 112. Comparison of the thermal conductivity (W/m·K) for samples of groups "19", "22", "25"

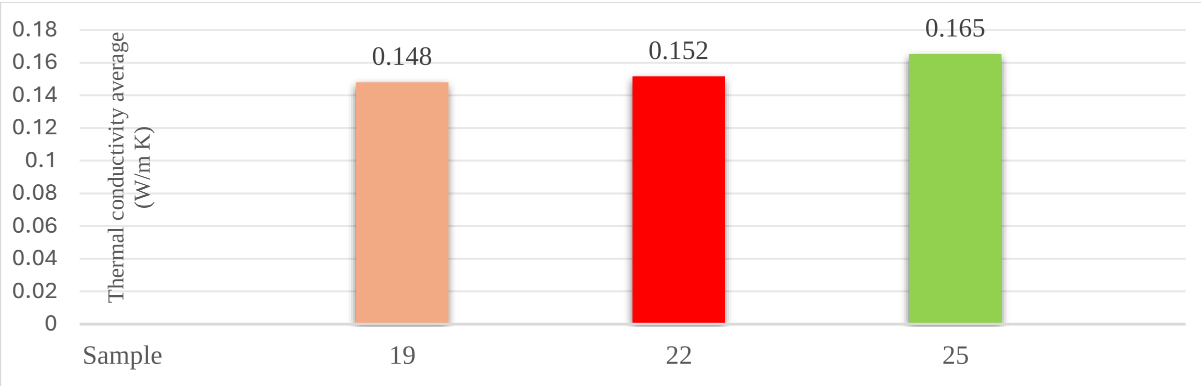


Figure 113. Average values of the thermal conductivity (W/m·K) for the three samples "19", "22", "25"

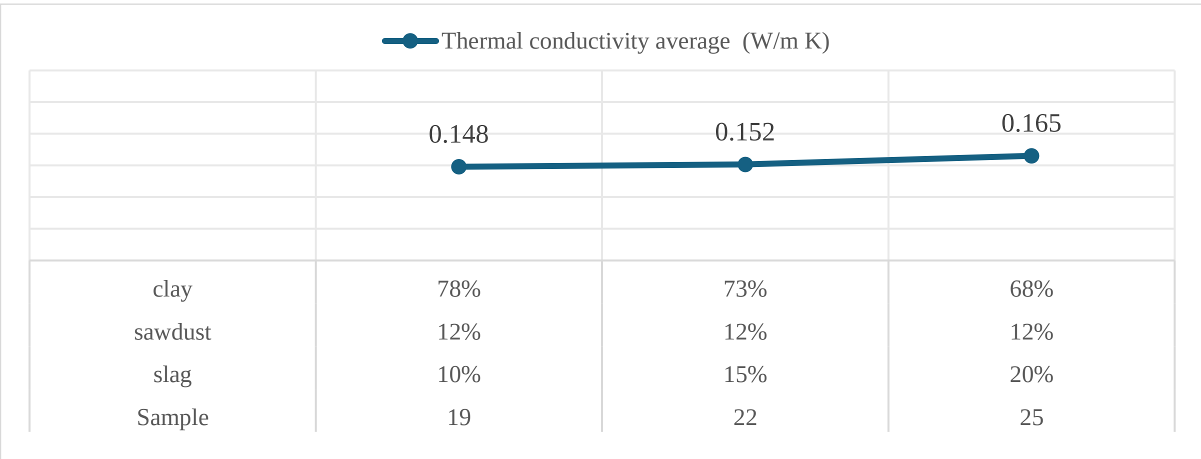


Figure 114. The ratio of clay, sawdust and slag in (%) comparing the thermal conductivity (W/m·K)

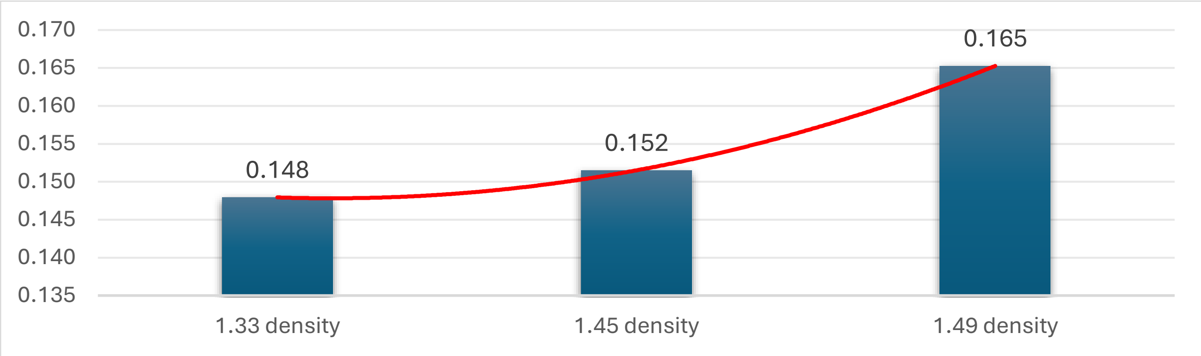


Figure 115. Thermal conductivity (W/m·K) in relation to density (g/cm) in the product

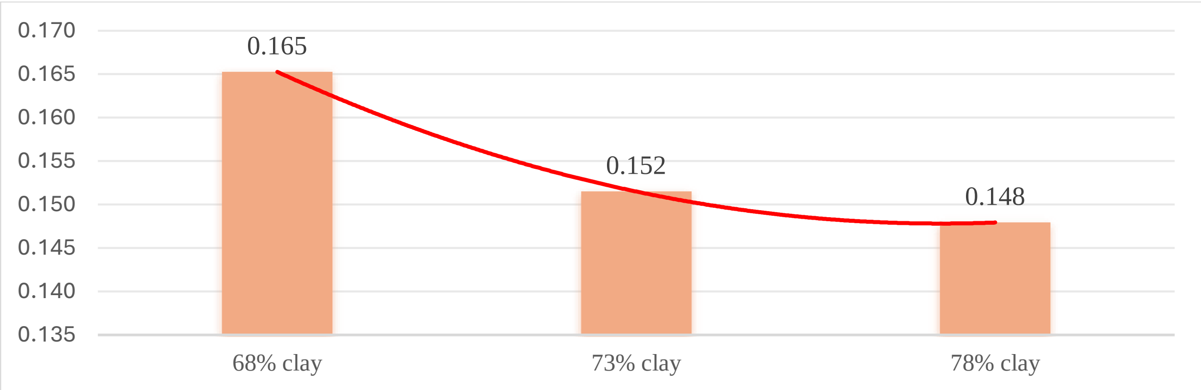


Figure 116. Thermal conductivity (W/m·K) in relation to clay (%) content in the product

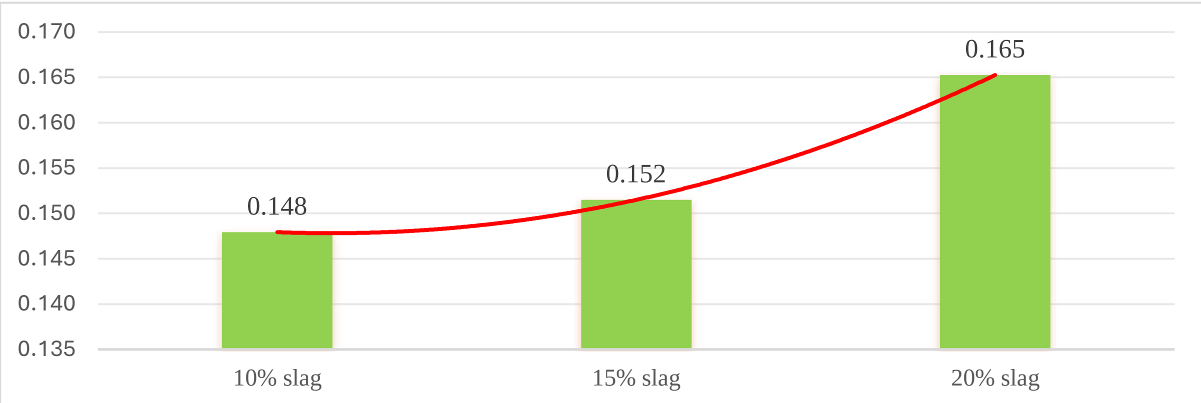


Figure 117.Thermal conductivity (W/m·K) in relation to slag (%) content in the product

5.9.4 Interpretation of results at the Faculty Skopje

In conclusion, it can be said that samples with low density show lower thermal conductivity. While the comparison of these thermal conductivity results for the test samples is shown in Fig.115. Based on these obtained results, it can be said that the value of the thermal conductivity λ=0.148 (W/m·K) of sample "19 $_{78\text{-}12\text{-}10}$", is the best thermal value for this group of test samples compared to the values of the other samples that are tested. While the sample "25 $_{68\text{-}12\text{-}20}$" "has the lowest thermal conductivity value from this group of samples λ=0.165 (W/m·K).

From these results it can be said that low density affects a lower result thermal conductivity. While the greater presence of clay in percentage affects the reduction in the coefficient of thermal conductivity, while the small presence of slag affects a higher result of thermal conductivity. The average value of the coefficient of the test sample “$19_{78\text{-}12\text{-}10}$“ when compared with the thermal coefficient of ordinary clay brick, which is 0.82 W/m·K [201], shows a significant difference in this area.

5.10 The method of the experiment at the Faculty of Mechanical Engineering in Pristina

The samples that will be tested at the Faculty of Mechanical Engineering in Pristina are: “$17_{86\text{-}4\text{-}10}$“, "$18_{82\text{-}8\text{-}10}$", "$20_{81\text{-}4\text{-}15}$", "$21_{77\text{-}8\text{-}15}$", "$23_{76\text{-}4\text{-}20}$", "$23_{72\text{-}8\text{-}20}$".

The processing of these samples is done in dimensions: 250 x 250 x 60 mm, because the space for testing the sample in this instrument corresponds to such dimensions. Each set of samples contains 3 samples, a total of 18 specimens for testing. The method of their processing in the outdoor field is the same as the processing of other samples, which are tests for other physical and mechanical properties of the product, described in the above chapters. That is, the external conditions are: temperature of 21-22°C and air humidity of 70%. While the molds are made of pressed MDF wood with the required dimensions: 250x250x60mm. After reaching a solid state of the samples and releasing moisture from the influence of air flow, after this process the samples are sent to the kiln for deep drying and firing at a temperature of 900 ℃. After this process, the samples are left to stand in laboratory conditions for 14 days at a temperature of 20 +-2 ℃, and a relative humidity of 50%. The instrument that will perform these tests is called: “WL 376 Thermal conductivity of building materials”, Fig.118.

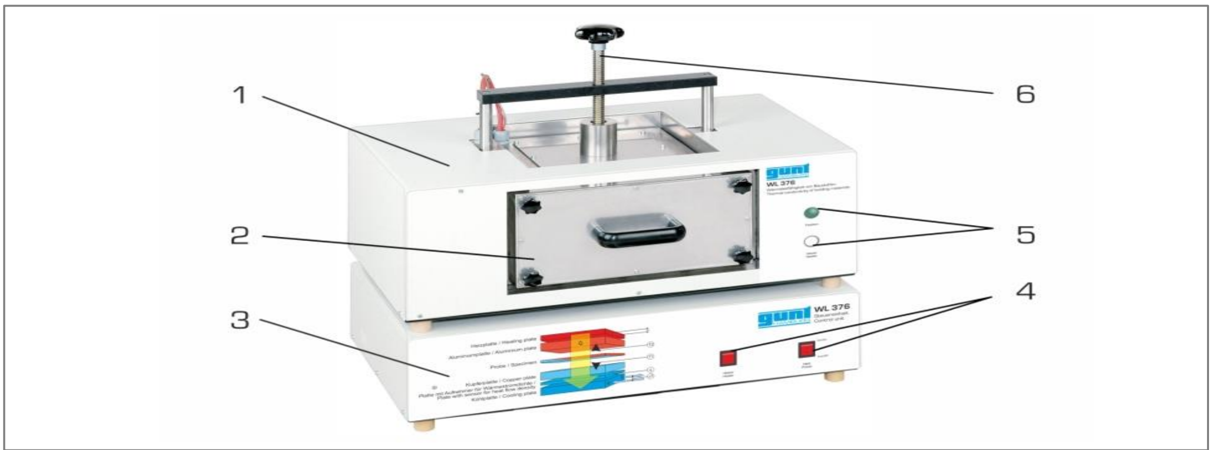


Figure 118. Instrument WL376 Thermal Conductivity of building materials, 1. Insulating housing, 2 covers for sample chamber, 3 control unit, 4 main switch and heater switch, 5 indicator lights, 6 contact spindle *[202]*

This instrument tests the thermal conductivity of various materials in accordance with the German standards Deutsches Institut für Normung DIN 52612: 1984 [202], [203].The operation of this instrument is as follows: The space where the materials are tested is an insulated space and consists of two plates. The upper plate is passed by the high temperature from the electric heater towards the test sample, while the lower plate has a low temperature cooled with the help of circulating water, Fig.119, Fig.120.

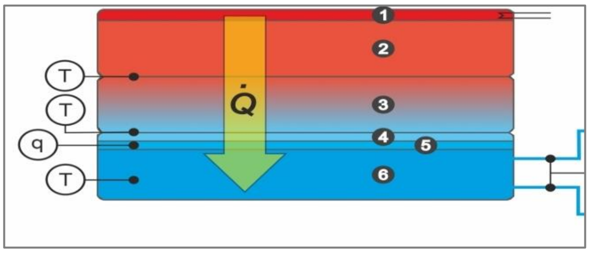


Figure 119. Heating plate, 2 hot plate, 3 sample, 4 copper plate, 5 plate with heat flux density sensor, 6 cold plate; *[202]*

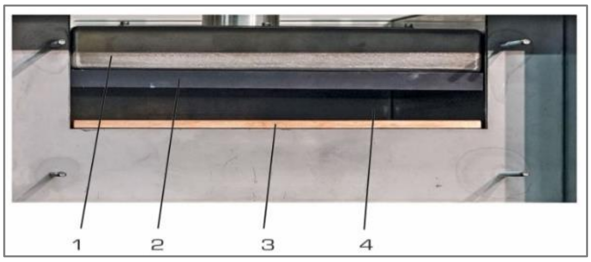


Figure 120. View into the opened sample chamber, 1 hot plate insulation, 2 hot plate, 3 copper plate, 4 sample space *[202]*

In the upper part of the instrument there is a device for clamping the plates and the product together, in order to ensure pressure between these plates and the product. Through the instrument's sensors, the temperature of the water at the inlet and outlet is measured, as well as the temperature in the center of the instrument's plates, these temperature values are recorded in the software connected to the PC. These sensors also measure the density of the heat flux that passes through the sample being tested [202].

Figure 121. Instrument WL 376 in the laboratory, and its parts

Figure 122.Data generation in software

In Fig.121 the way of placing the sample in the instrument for testing is presented. The program in which the data is generated is "WL 376 Thermal Conductivity of Building Materials" it is the same as the basic instrument, Fig.122. The duration of the tests was from one and a half hours to three hours and forty minutes, depending on the density and stabilization of the heat flux.

5.10.1 Results

The attached Table 15 shows the results obtained at the end of the process of this experiment. The table also shows the percentages of the materials in the research product, density, volume, and testing time. The samples, after drying and firing in the kiln, have resulted in shrinkage (changes in their dimensions), which results in different volumes of the samples.

Table 15. Data table for thermal conductivity

Sample	Sample name	Clay (%)	Saw dust (%)	Slag (%)	Mass (g)	Volume (cm3)	Density (g/cm3)	Average density (g/cm3)	Thermal conductivity in Skopje (W/m K)	Time for testing (h)	Thermal conductivity average (W/m K)
17	17-1	86	4	10	5639	3584.96	1.573	1.6	0.1443	2:00	0.141
	17-2				5428	3599.53	1.508		0.1345	3:30	
	17-3				5588	3393.55	1.647		0.1435	1;30	
18	18-1	82	8	10	5094	3630.96	1.403	1.4	0.1353	2:57	0.128
	18-2				5061	3675.36	1.377		0.1223	3:00	
	18-3				4888	3599.53	1.358		0.1253	2:14	
20	20-1	81	4	15	5571	3477.51	1.602	1.6	0.1319	2:02	0.139
	20-2				5682	3645.72	1.559		0.1435	2:02	
	20-3				5705	3630.96	1.571		0.1405	2:20	
21	21-1	77	8	15	5531	3645.72	1.517	1.5	0.1341	2:55	0.132
	21-2				5300	3660.48	1.448		0.1344	2:20	
	21-3				5221	3690.24	1.415		0.1268	3:40	
23	23-1	76	4	20	5978	3720.06	1.607	1.6	0.1364	3:10	0.132
	23-2				5763	3645.72	1.581		0.1338	3:20	
	23-3				5794	3630.96	1.596		0.1253	3:16	
24	24-1	72	8	20	5132	3720.06	1.380	1.4	0.1225	3:20	0.127
	24-2				5295	3599.53	1.471		0.1175	3:43	
	24-3				5337	3584.96	1.489		0.1398	3:09	

5.10.2 Comparison of the results

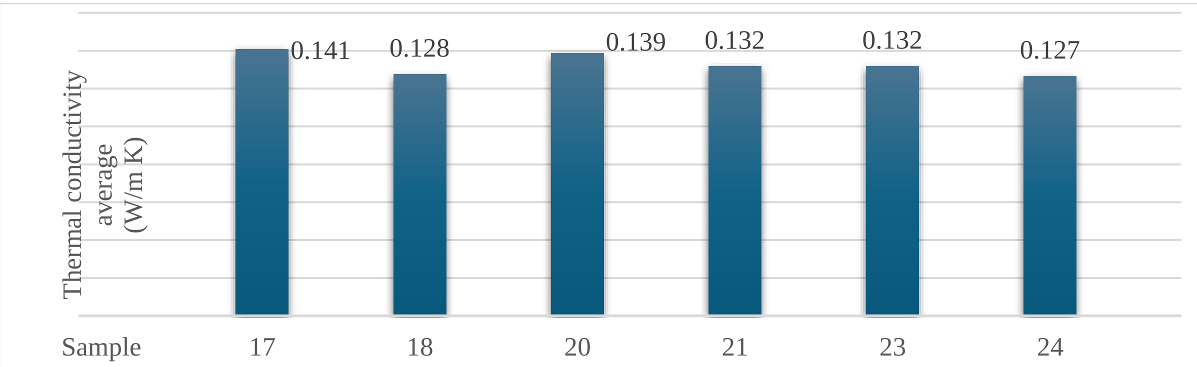


Figure 123. Average values of the thermal conductivity (W/m·K) for the six samples

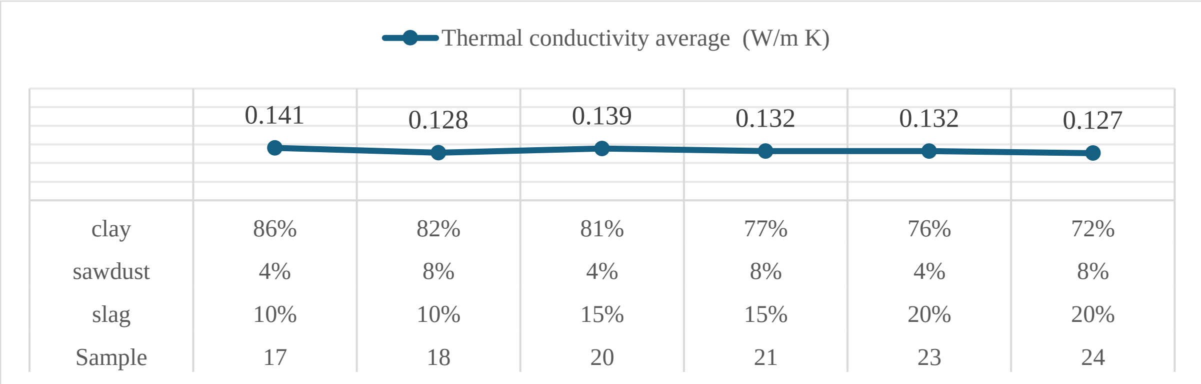


Figure 124. The ratio of clay, sawdust and slag in (%) comparing the thermal conductivity (W/m·K)

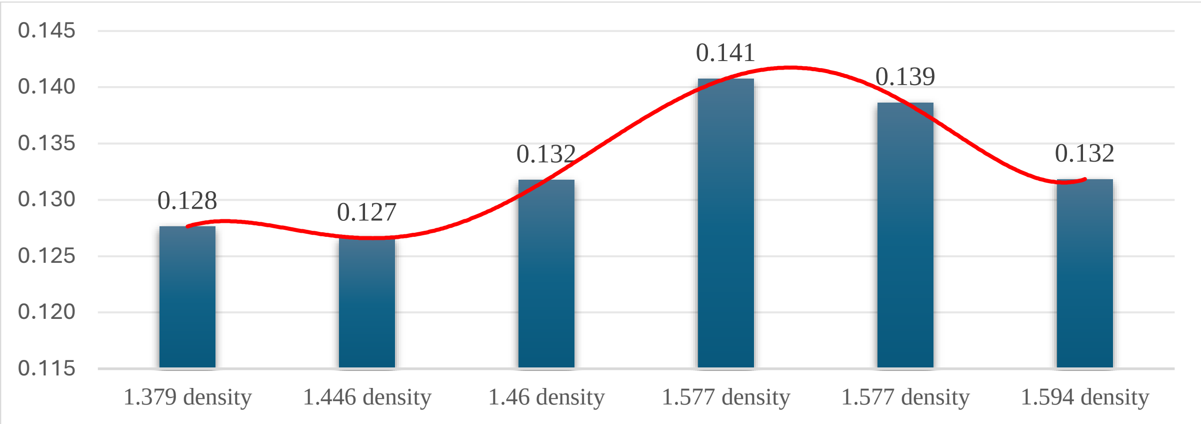


Figure 125.Thermal conductivity (W/m·K) in relation to density (g/cm) in the product

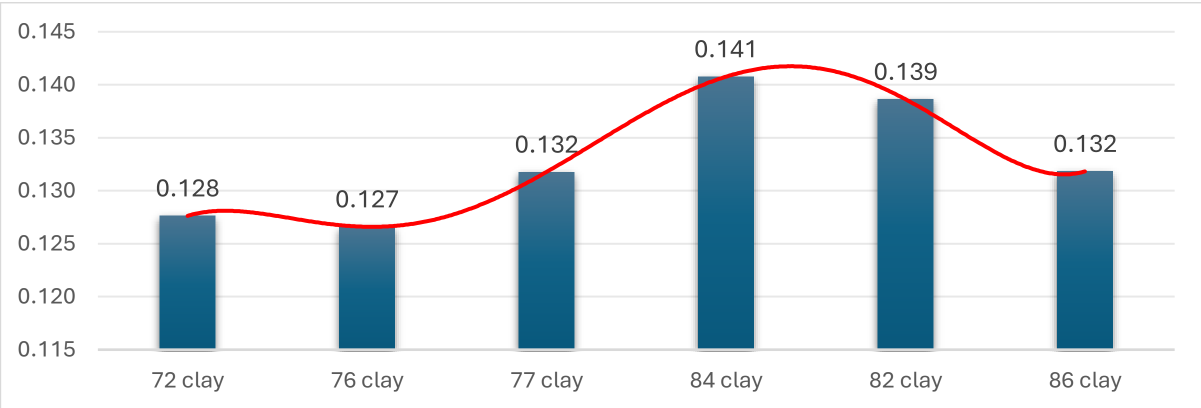


Figure 126.Thermal conductivity (W/m·K) in relation to clay (%) content in the product

Figure 127. Thermal conductivity (W/m·K) in relation to sawdust (%) content in the product

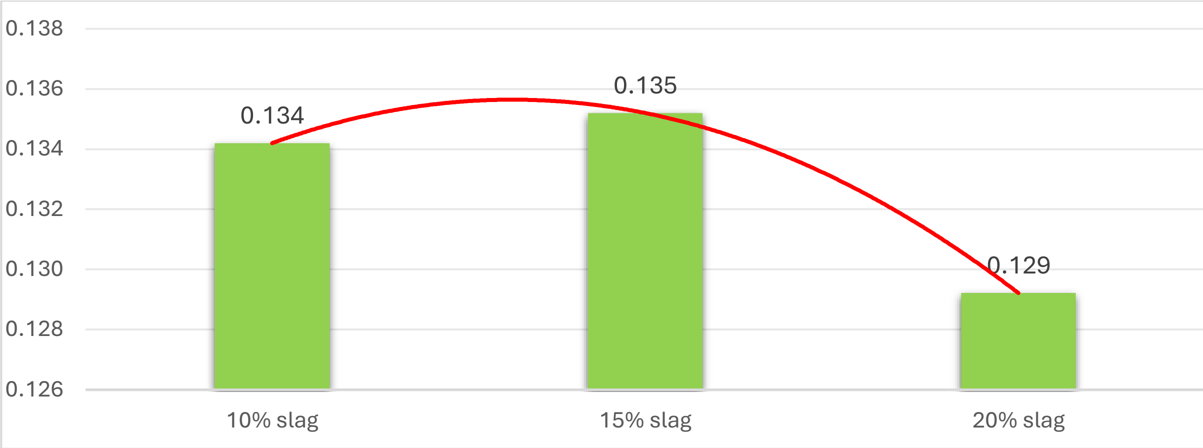


Figure 128.Thermal conductivity (W/m·K) in relation to slag (%) content in the product

5.10.3 Interpretation of results at the Faculty Pristina

The presentation of the graphs in the above chapters provides a clearer picture of the behavior of the samples that have been subjected to this experiment. In the attached figures Fig.123, Fig.124, the values of the thermal conductivity for each test sample are given. While in Fig.125-Fig.128, the ratio of the thermal conductivity coefficient to the density, the ratio with the constituent materials clay sawdust and slag is given.

Based on experimental analyses, the product with a higher percentage of clay results in higher values of the thermal conductivity. The presence of slag keeps the thermal conductivity coefficient constant. While the presence of sawdust in the material affects the decrease in the values of thermal conductivity. In the case of increasing the density, it can be said that it affects the increase in the values of thermal conductivity (W/m·K).

The combination of sawdust with 8% in relation to the participation of other materials shows these coefficient results: “18 $_{82\text{-}8\text{-}10}$“ λ=0.128 (W/m·K) and “24 $_{72\text{-}8\text{-}20}$“ λ=0.127 (W/m·K) . These two samples for coefficient are distinguished from the other samples, for the same density and the same amount of sawdust material. While the samples that have the highest density, have higher thermal conductivity values than the other samples.

5.10.4 Interpretation of the two groups of results achieved at the Faculty of Skopje and Pristina

From the results obtained for thermal conductivity (W/m·K) in both devices:

- "Heat Flow Meter HFM 436"
- “WL 376 Thermal conductivity of building materials”

From the final results Table 16 it is observed that the sample “24 $_{72\text{-}8\text{-}20}$ “ has the lowest value of thermal conductivity λ=0.127 (W/m·K). While the sample “25 $_{68\text{-}12\text{-}20}$ “, has the highest value of thermal conductivity λ=0.165 (W/m·K).

From these results it is observed that the optimized presence of the combination of clay with 72%, sawdust material with 8% and with the participation of slag 20%, offers better results of thermal conductivity.

While the result of sample “24 $_{72\text{-}8\text{-}20}$“ is close to the result of sample “18 $_{82\text{-}8\text{-}10}$“ with the value λ=0.128 (W/m·K). This result shows that the presence of lower clay is indicative of the lower value of thermal conductivity (W/m·K).

Table 16. Data table for thermal conductivity for all samples

Sample	Clay (%)	Sawdust (%)	Slag (%)	Average density (g/cm3)	Thermal conductivity average (W/m K)
17	86	4	10	1.58	0.141
18	82	8	10	1.38	0.128
19	78	12	10	1.33	0.148
20	81	4	15	1.58	0.139
21	77	8	15	1.46	0.132
22	73	12	15	1.45	0.152
23	76	4	20	1.59	0.132
24	72	8	20	1.45	0.127
25	68	12	20	1.49	0.165

6. MINI WALLS EXPERIMENT

After the analysis and testing of the brick samples were completed, the results obtained were compared with each other and the sample was selected which met the standards for use in the building envelope, according to the standards EN 771-1:2011 [161], EN 772-1:2011 [177], and their standard series. From the results obtained for each tested sample, the average of samples “$17_{86-4-10}$”, “$18_{82-8-10}$” , “$19_{78-12-10}$” , “$20_{81-4-15}$“, “$21_{77-8-15}$“, “$22_{73-12-15}$“, “$23_{76-4-20}$“, “$24_{72-8-20}$“, “$25_{68-12-20}$“, was taken, and is presented in the attached table, Table 17.

Table 17. Overview of the average values for each sample

The mean of the calculated values for each set of samples						
Sample	Water absorption	Mass loss after 50 cycles, freezing and thawing cycles	Compressive strength, normal state (MPa)	Compressive strength after 50 cycles, freezing and thawing (MPa)	Compressive strength reduction (%)	Thermal conductivity (W/m K)
17	16.16%	1.64%	6.90	6.64	3.86	0.1408
18	16.76%	0.67%	6.90	6.14	11.02	0.1276
19	18.50%	1.18%	4.27	4.04	5.31	0.1479
20	15.42%	1.33%	6.30	6.27	0.51	0.1386
21	17.40%	1.13%	5.45	4.96	8.99	0.1318
22	17.49%	2.57%	3.72	3.40	8.60	0.1515
23	14.93%	2.61%	7.60	6.59	13.29	0.1318
24	18.84%	1.11%	4.31	3.88	10.07	0.1266
25	17.63%	1.85%	3.77	3.24	13.94	0.1653

From these results, sample number “$18_{82-8-10}$” is selected, and is considered the most suitable set considering the thermal conductivity coefficient. This selection orients us to the compressive strength and the low percentage of mass loss of the sample after 50 cycles of freezing and thawing. Therefore, in the following we will present a recapitulation of sample “$18_{82-8-10}$” and its selection properties:

- The water absorption of 16.76% is within the standard values for traditional brick: 5-20%, (if the brick is used in combination with plaster in the work of building envelopes/facades).
- The mass loss percentage of 0.67%.
- The compressive strength is 6.9 MPa. Out of the three categories of brick classification, from first to third, according to EN 771-1:2011, this value places the brick category ≥ 5 MPa, meaning that the bricks can be used in applications that do not carry heavy loads.
- The reduction of compressive strength after cycles: 0.76%.
- Thermal conductivity 0.1276 (W/m K), which for common bricks averages 0.8 (W/m K) [204].

6.1 Experiment VIII - Testing of bonding mortar for the work of mini walls

After the experimental tests of the bricks are completed, it is planned to work on mini walls from the research product. Therefore, it is planned to work on 3 mini walls to reach a conclusion regarding the mechanical behavior of the walls under the influence of the instrument for measuring compressive strength. By testing the mini walls, the results can be compared, an average value can be achieved, and a basic statistical analysis can be performed.

Before working on the mini walls, it is necessary to select the bonding mortar for bonding the bricks together. Therefore, based on the purpose of this work, which is "research for a product from bio and recycled materials", the Mape-Antique Strutturale NHL mortar is selected. Such a mortar has good compatibility with natural biomaterials, at the same time the purpose of this mortar is for use in the restoration of historic buildings and is certified by EPD (Environmental Product Declaration) [205]. The mortar in question "Mape-Antique Strutturale NHL" is based on natural hydraulic lime and Eco-Pozzolan, it is considered an environmentally friendly mortar, suitable for ecological constructions [205]. While according to the specifications of such mortar, in use the thickness of this mortar varies from 10mm-40mm [206]. To use the mortar in the work of mini walls, the flexural strength and compressive strength of the binder mortar are tested in advance, according to standard EN 1015-11:2019 [184]. These tests are carried out in two time periods, after 7 days and after 28 days. The mortar is prepared and initially 6 samples are worked in steel molds with dimensions 160mm x 40mm x 40mm Fig.129. Three of these samples are left to dry for 7 days, their mass is measured and then subjected to testing.

Figure 129. The working process of processing Mape plaster

While three other samples are left to dry for 28 days, after this time they are measured Fig.130, and then subjected to experimental tests: flexural strength and compressive strength.

The realization of these tests is done with the help of the instrument: Uniframe Universal Electromechanical Teasters 50-100 kN [207]. This instrument helps in the mechanical testing of various building and structural materials, which is equipped with an electromechanical system that enables the measurement of forces up to F=50-100kN, Fig.130. The device in question works in testing experiments in tension, compression, flexural and shear, and enables the presentation of the results on the monitor attached to the instrument. In the flexural strength test, the sample is loaded at three points until the failure of the capacity. Then the compressive strength is determined in the other two parts of the sample obtained from the flexural strength, in the two supporting plates 40x40mm above and below, Fig.131.

Figure 130. The process of testing samples for flexural strength and for compressive strength

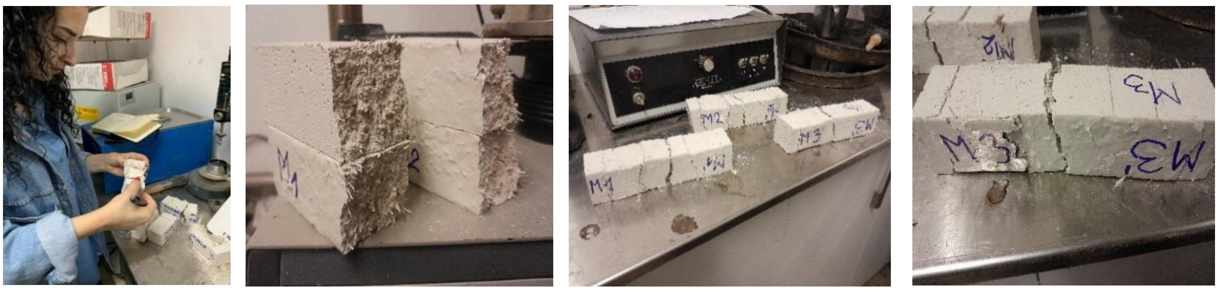


Figure 131. The state of the samples after the experiments

6.1.1 Results

The results obtained during the measurements of the samples on the electronic scale are placed in Table 19, which will be attached below. Also, the results obtained after 7 days and after 28 days for flexural strength and for compressive strength are reflected in Fig.132- Fig.135. While in Fig.136, the ratio of the values of bending strength to compressive strength for two time periods is presented. The values obtained from these experiments serve to give an overview of the behavior of the mortar to the subsequent mechanical actions of the mini walls.

Table 18.The result of the Mape plaster after the end of the experiments

<table>
<tr><th colspan="12">The result after 7 days</th></tr>
<tr><th>Sample</th><th>Dim. (A) mm</th><th>Dim. (B) mm</th><th>Dim. (C) mm</th><th>Mass (g)</th><th>Density (g/cm3)</th><th>Strength (kN)</th><th>Flexural strength (MPa)</th><th>Flexural strength (MPa)</th><th>Max. strength (kN)</th><th>Max. strength (kN)</th><th>Compressive strength (MPa)</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">160</td><td rowspan="2">40</td><td rowspan="2">40</td><td rowspan="2">458.03</td><td rowspan="2">1.789</td><td rowspan="2">0.793</td><td rowspan="2">1.487</td><td rowspan="6">1.665</td><td>11.295</td><td rowspan="6">11.227</td><td rowspan="6">7.02</td></tr>
<tr><td>10.872</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">160</td><td rowspan="2">40</td><td rowspan="2">40</td><td rowspan="2">460.03</td><td rowspan="2">1.797</td><td rowspan="2">1.007</td><td rowspan="2">1.886</td><td>11.313</td></tr>
<tr><td>11.452</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">160</td><td rowspan="2">40</td><td rowspan="2">40</td><td rowspan="2">454.96</td><td rowspan="2">1.777</td><td rowspan="2">0.866</td><td rowspan="2">1.623</td><td>10.94</td></tr>
<tr><td>11.487</td></tr>
<tr><td colspan="12"></td></tr>
</table>

<table>
<tr><th colspan="12"></th></tr>
<tr><th colspan="12">The result after 28 days</th></tr>
<tr><th>Sample</th><th>Dim. (A) mm</th><th>Dim. (B) mm</th><th>Dim. (C) mm</th><th>Mass (g)</th><th>Density (g/cm3)</th><th>Strength (kN)</th><th>Flexural strength (MPa)</th><th>Flexural strength (MPa)</th><th>Max. strength (kN)</th><th>Max. strength (kN)</th><th>Compressive strength (MPa)</th></tr>
<tr><td rowspan="2">4</td><td rowspan="2">160</td><td rowspan="2">40</td><td rowspan="2">40</td><td rowspan="2">432.38</td><td rowspan="2">1.689</td><td rowspan="2">1.13</td><td rowspan="2">2.118</td><td rowspan="6">2.275</td><td>13.51</td><td rowspan="6">13.934</td><td rowspan="6">8.71</td></tr>
<tr><td>14.089</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">160</td><td rowspan="2">40</td><td rowspan="2">40</td><td rowspan="2">427.10</td><td rowspan="2">1.668</td><td rowspan="2">1.343</td><td rowspan="2">2.518</td><td>14.838</td></tr>
<tr><td>14.792</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">160</td><td rowspan="2">40</td><td rowspan="2">40</td><td rowspan="2">432.07</td><td rowspan="2">1.688</td><td rowspan="2">1.165</td><td rowspan="2">2.19</td><td>13.596</td></tr>
<tr><td>12.78</td></tr>
</table>

7.1.2 Comparison of the results

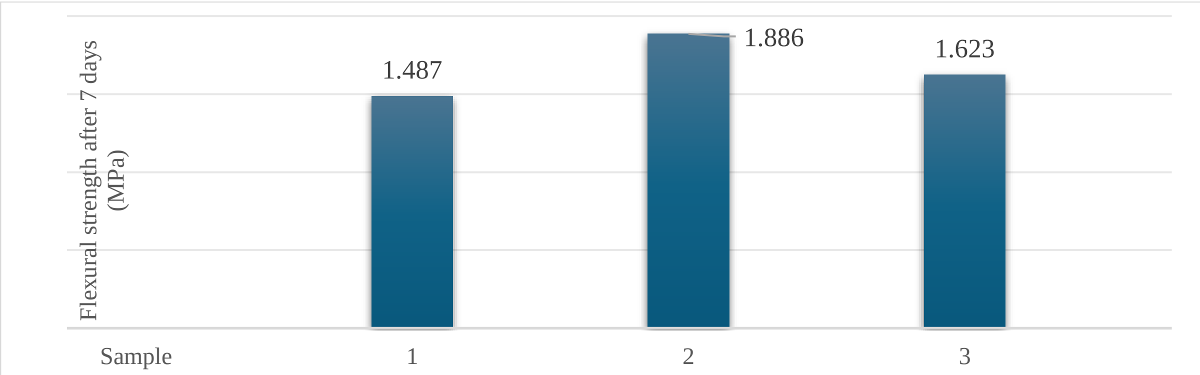


Figure 132. Flexural strength (MPa) results after 7 days

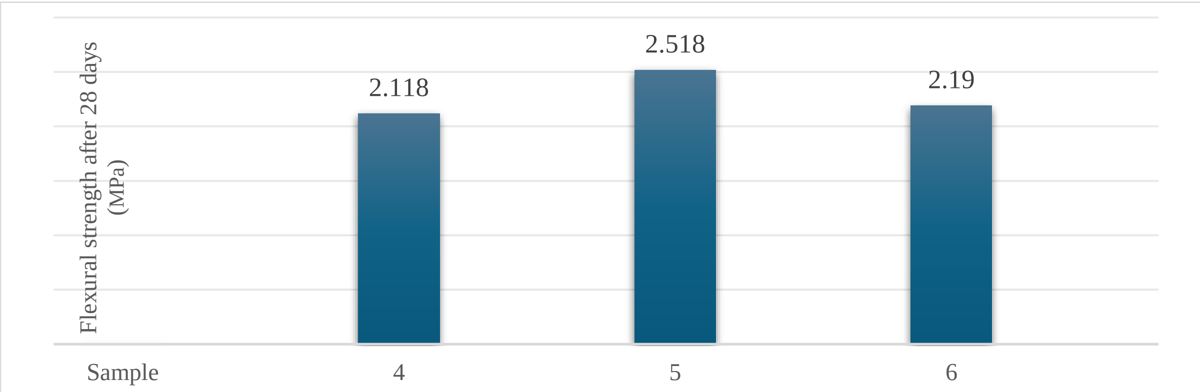


Figure 133. Flexural strength (MPa) results after 28 days

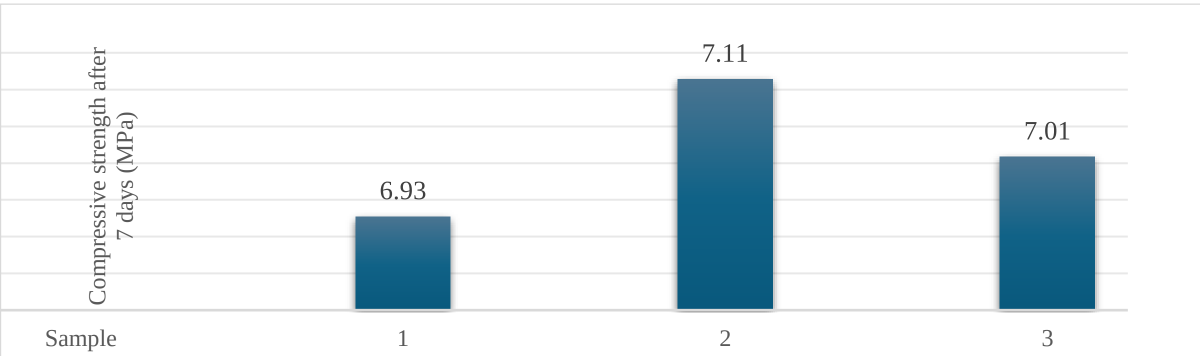


Figure 134. Compressive strength (MPa) results after 7 days

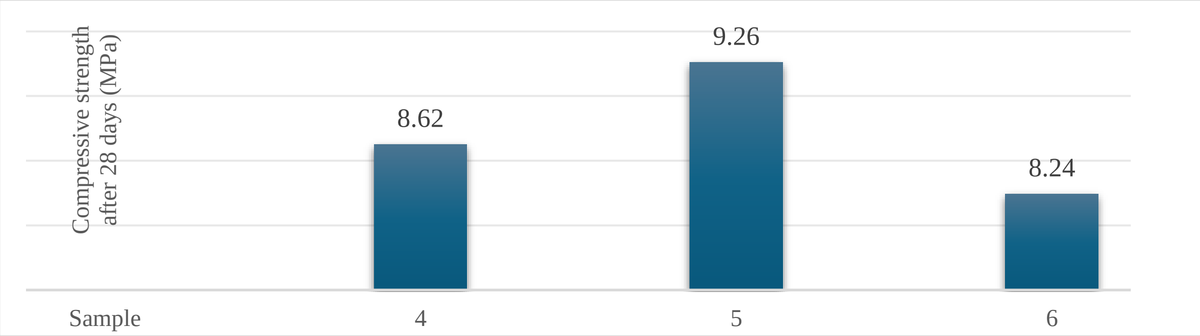


Figure 135. Compressive strength (MPa) results after 28 days

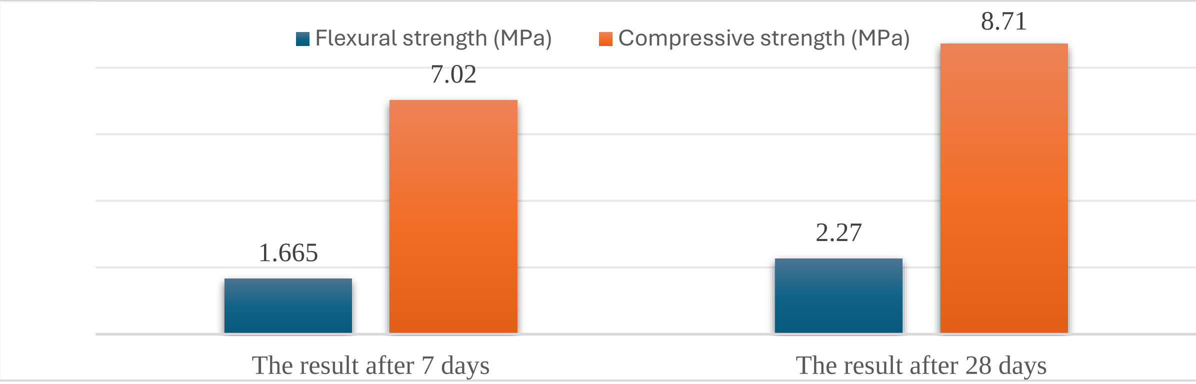


Figure 136. Comparison of sample values after 7 days and after 28 days, for flexural strength (MPa) and compressive strength (MPa).

The preparation of the mortar was done according to standard EN 1015-11:2019 [184]. And according to this standard, the mortars used for construction refer to the requirements from class M1 (>1N/mm2) to class Md (>25 N/mm2), the values are shown in Fig.132- Fig.136. While according to the standards BS EN 1052-1:1998 [183], the allowed value of compressive strength for the mortar used in the wall starts from the value M1. Based on the values of the results obtained from the experiments carried out in the laboratory, the results rank the tested mortar in the category M9 (≥1 N/mm2), and CS IV (≥ 6MPa), suitable for use in the envelope of buildings [205] [185] [208].

6.2 Preparation of three mini walls

The assignment of the brick sample number "18 $_{82\text{-}8\text{-}10}$" was made with the aim of working three mini-walls with this type of brick. The work of three mini-walls is done to demonstrate the connectivity of the bricks among themselves, to test the modulus of elasticity and the bearing capacity of the mini-walls. Three samples represent an effective compromise between accuracy and available resources. Also, according to standard EN 1052-1:1998 [183], to test the compressive strength for masonry specimens, it is recommended to test at least three samples. The set of bricks "18 $_{82\text{-}8\text{-}10}$" was made in the field under the same conditions as the other bricks of the past. First, the ingredients were mixed according to the recipe of sample "18 $_{82\text{-}8\text{-}10}$", then the obtained mass was poured into the mold, processed in the mold and then the molds were removed. This sample formed from the mold remained in the outdoor environment until the brick was formed as a solid mass and capable of being transported to the factory. The bricks were heating and firing in the factory and after 14 days they were sent to the laboratory for the work of the walls, Fig.137.

Figure 137. Bricks in the laboratory for the work of mini walls

The laboratory conditions during the work on the mini walls are the same as those used in other preliminary experiments on the test bricks. The mini-walls were manufactured according to standard BS EN 1052-1:1998 [183] and according to Eurocode 6 EN 1996-1-1:2005 [181], the mini-walls were made with dimensions 40x35x10cm, (fig.181), in the lower and upper part of their structure, metal plates were placed for the purpose of achieving the compatibility of the plates of the apparatus when the elastic modulus measurements are made. These tiles have dimensions: 36x10x2cm. The three mini-walls were built within one day, and the process of building the walls is shown in Fig.138 - Fig.142. The mortar used in the masonry of the mini-walls is Mape-Antique Strutturale NHL [206] which has been tested in previous experiments.

Figure 138. Arranging the space in the laboratory for starting the work on the mini walls and preparation of bonding mortar for mini wall

Figure 139. Working on rows of mini walls

Figure 140. Completion of the mini wall work

Figure 141. Checking some details of the mini walls being worked on

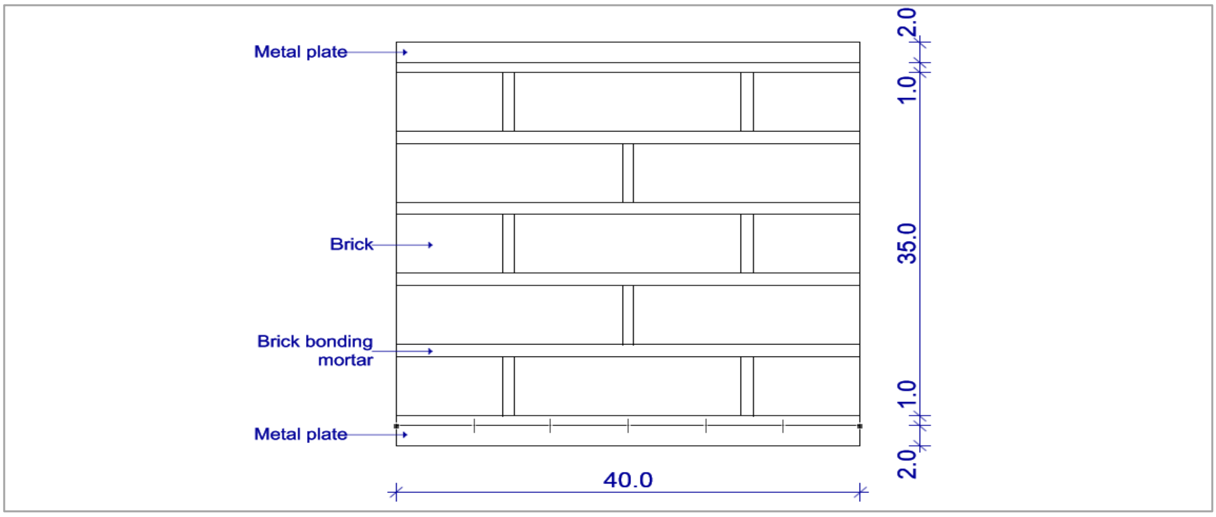


Figure 142. Schematic representation of the mini wall worked in the laboratory

6.3 Experiment IX - The behavior of the masonry wall under the load applications

The mini-walls were placed in laboratory conditions at 20 ± 2°C and 50% relative humidity, which is within the specifications of the bonding mortar required for the drying of Mape-Antique Structural NHL mortar used in the bonding of bricks for mini-walls [206]. After hardening process, the mini walls were subjected to tests for measuring the strength in vertical compression, which were carried out in two apparatuses. In the first step of applied loads, the mini-wall samples were loaded to forces of up to 125 kN, while in the other equipment the mini-walls were subjected to forces of up to 500 kN. The use of these two devices was made to complete the operational finalizations of the mini-walls against the mechanical forces acting, starting from the appearance of the first cracks in the mini-wall until their complete destruction, that is, the loss of bearing capacity. And this could be achieved with the help of these two devices which will be described below:

a) Apparatus for measuring the modulus of elasticity of mini walls (appearance of first cracks in mortar and bricks), the device connected to the monitoring apparatus “Stand-alone Control Console.
b) Apparatus for measuring the bearing capacity of mini walls (up to the destruction of mini walls).

The development of experiments and measurements regarding the fulfillment of quality requirements, sample preparation, standard laboratory conditions, test equipment, test methods, have been developed within the relevant standards for testing masonry walls made of bricks with mortar. The standards used in this experiment are : EN 772-1:2011+A1:2015 [177], BS EN 1052-1:1998 [183], BS 5628-1:1992 [186], Eurocode 6 (EN 1996-1-1:2005) [181].

6.3.1 Method

The apparatus used for this experiment is called “High Stiffness Flexural Frame”, Fig.a.143, it works according to international standards, depending on the test being performed [209], in our case the test will be performed according to standard BS EN 1052-1:1998 [183]. This apparatus is connected to the accompanying instrument “Stand-alone Control Console” [210] , Fig.c.143, and to the computer, which through the software “MCC8 Multitest Program”, Fig.d.143, generates force action diagrams in the mini wall. The companion device “Stand-alone Control Console” or otherwise called “Automax Pro-M”, serves to receive information from the main device and its automatic visual transmission to the software program “MCC8 Multitest Program” [211], this device can also provide the determination of the modulus of elasticity for the tested samples [210].

Figure 143. High Stiffness Flexural Frame, Stand-alone Control Console and software MCC8 Multitest Program

After adjusting the equipment procedures, placing the mini wall in the space provided for testing, and placing the LVDT displacement device on the test mini wall, then through the MCC8 Multitest Program software, the acting force F is given to the mini wall, Fig.144, Fig. 145. For each specified time interval, the possibility of cracks appearing in the mini wall is checked, by checking in parallel the diagram formed in the software.

Figure 144. Preparation of wall "1" for testing, High Stiffness Flexural Frame apparatus

Figure 145.Observation of the experiment during the loads transmitted to the mini wall

The fixed distance of the displacement measurements on the mini wall is 70mm (this also serves for the subsequent calculation of the modulus of elasticity from the ratios of the deformation values and the stress values obtained, specifically the elastic relegion part).

6.3.2 Analysis of results

Under the influence of forces, first cracks begin to appear in the mortar, then cracks appear in the bricks, all of these under the influence of the forces F (kN) recorded in the device. The same procedure and situations occur for the three mini walls. All of these are graphically demonstrated by the diagrams attached below, which were generated by the MCC8 Multitest Program software. After processing these tests and obtaining the results, the force $F_{i\,max}$ (kN) is divided by the cross-sectional area of the test mini wall A which is (400x100mm) and we obtain the value of the compressive strength f_i (MPa), formula (2) [183]. This serves us in the subsequent calculations of the modulus of elasticity for the three mini walls.

$$f_i = F_{i\,max} \,/\, A_i \qquad (N/mm^2) \qquad (2)$$

The elastic modulus of an object is defined as the slope of its stress-strain curve, Fig.146, in the elastic deformation region, which is also known as Young's modulus [212].

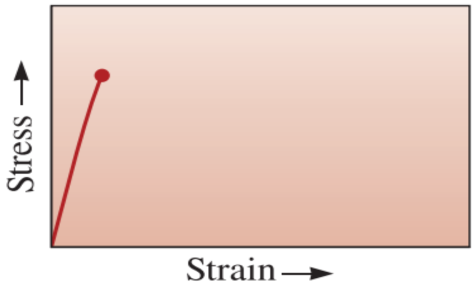


Figure 146. Tensile stress–strain curves for ceramics, glasses and concrete. *[212]*

The modulus of elasticity as a parameter indicates the ability of a material to deform elastically under the action of loads and then its ability to return to its previous state when it is no longer subjected to loads. This parameter serves to indicate the stiffness of the material, in our case it serves to indicate the stiffness of the mini walls that are examined.

The calculation of the Young's modulus of elasticity, E, during this research was carried out with the well-known formula Hooke's Law: ***E*** **modulus of elasticity =** ***б*** **slope stress strain curve /** ***e*** **elastic region** [212], formula (3).

While the coefficient of the elastic region is expressed in the formula: ***ε*** **engineering strain =** ***Δl*** **deformation from the curve /** ***l*** **0 fixed distance** [212], formula (4).

$$E = 6 / \varepsilon \qquad \text{(MPa)} \tag{3}$$

$$\varepsilon = \Delta\, l \,/\, l_0 \tag{4}$$

Using these calculations, for each mini wall the coefficient of the modulus of elasticity is found and presented in the attached tables. Ratio stress /strain is result from the values of the force acting on the wall at the time of the appearance of cracks, the value of deformation from curve is read from the values generated by the software in relation to the force acting, while fixed distance is the distance between two fixed points during the testing of the mini walls, in our case l_0=70mm.

In the absence of values obtained from testing according to the standard EN 1052-1:1999, according to Eurocode 6 (EN 1996-1-1:2005) [181] the value of the modulus of elasticity coefficient *E* can also be determined with empirical data from the characteristic strength of the mini wall ***fk*** (MPa), Fig.147, formula (5). Which is multiplied by the adopted coefficient K = 1000 (value recommended by Eurocode 6), formula (5) and the calculation of the Characteristic compressive strength of masonry f_k according to EN 1052-1:1998 using the force acting on the wall f or smallest compressive strength of an individual masonry specimen $f_{i,min}$, formula (6).

$$E = K\ x\ f_k \qquad \textit{(MPa)} \tag{5}$$

$$f_k = f/1.2 \ \ or \ \ f_k = f_{i,min} \qquad \textit{(MPa)} \tag{6}$$

But while the development of laboratory experiments has been carried out in accordance with the standard BS EN 1052-1:1998 [183], under continuous verification of the process, using equipment dedicated to these experiments, providing concrete results, therefore in further analyses of this research regarding the modulus of elasticity will continue according to the values obtained in the laboratory.

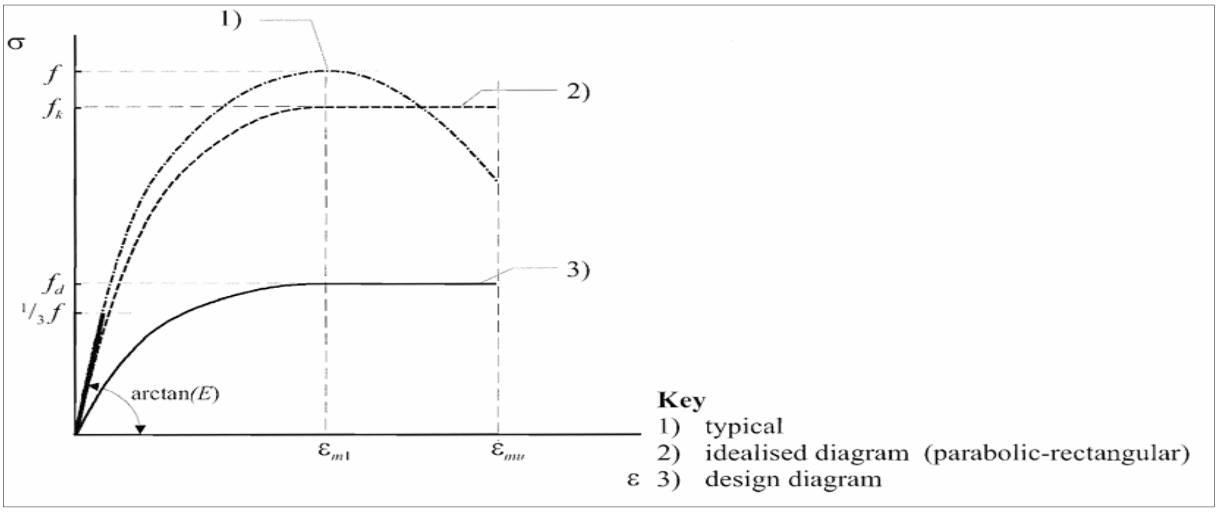


Figure 147. Stress-strain relationship for masonry in compression Eurocode 6 (EN 1996-1-1:2005) *[181]*

6.3.3 Mini wall "1" results

During the continuous monitoring of the mini wall in the High Stiffness Flexural Frame device, to verify eventual cracks in mortar and bricks, the state is also checked in the software "MCC8 Multitest Program", in which the generation of curves is controlled with the gradual increase of force. During this time, it is observed that under the action of force *F*=75kN the first crack begins to appear in the mortar connecting the mini wall, with values of deformation in the curve 0.1205 (mm), Fig.148, Fig.149. While the first crack in the brick appears under the action of force *F*=120kN with values of deformation in the curve 0.14mm, Fig.150. These results are generated and obtained by the software program from these values the modulus of elasticity E is also obtained for each case, Table 20. Other cracks in the mortar appear during the process. While in Fig.150-Fig.154, the diagrams generated by the software regarding the behavior of the wall and the ratio: of stress to deformation, the ratio of strain to deformation and the ratio of stress to strain are presented.

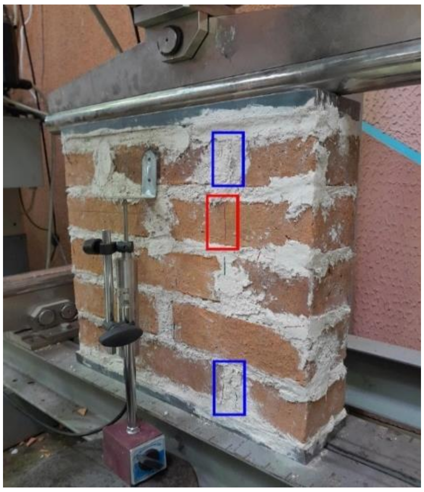


Figure 148. Mini wall “1” , the crack in the bonding plaster (blue) and in the brick (red).

Figure 149. The crack in the bonding mortar, mini wall “1”

Figure 150. Cracks in the brick, *mini wall “1”*

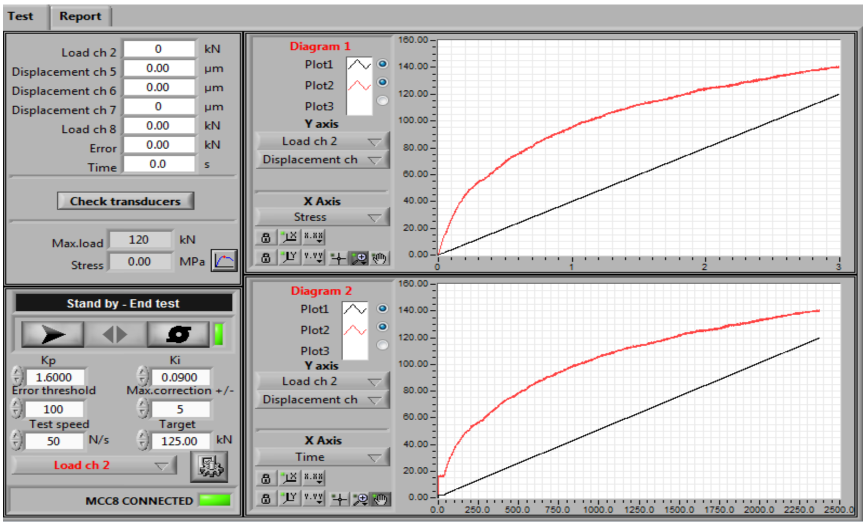


Figure 151.Generating diagrams from the software for min wall ”1”.
The upper curve shows strain on the X axis and force and deformation on the Y axis,
The lower curve shows time on the X axis and force and deformation on the Y

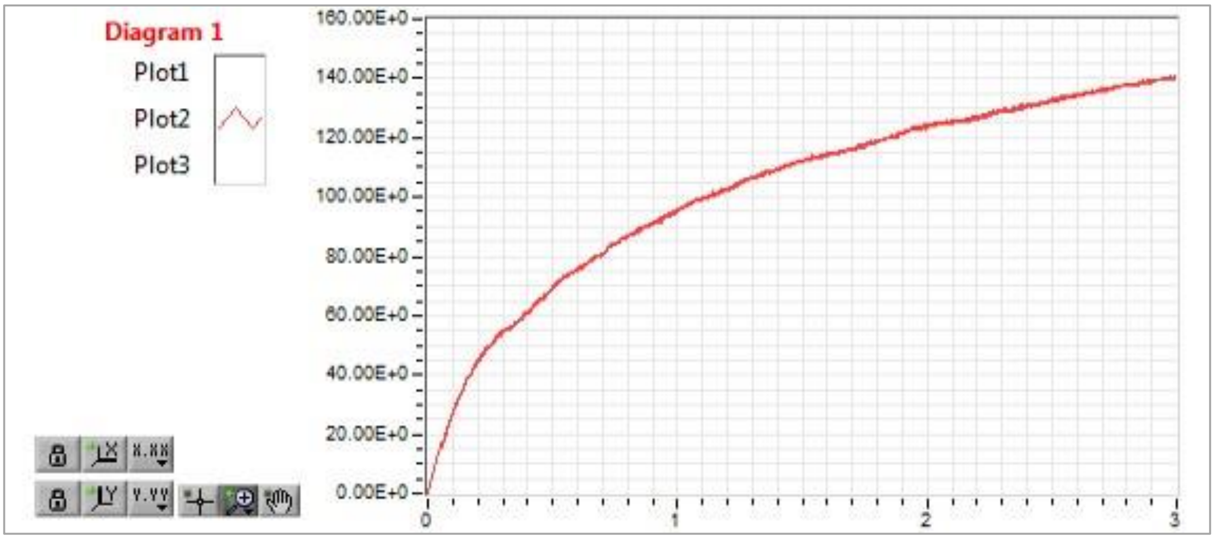


Figure 152. Diagram for mini wall “1”, strain (axis x), deformation (axis y)

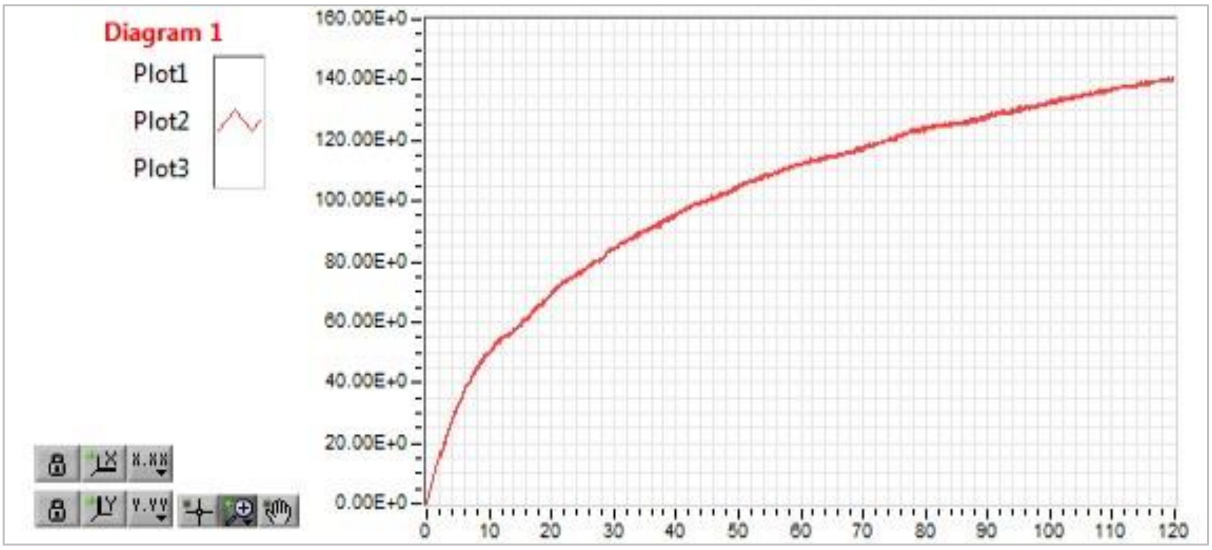


Figure 153. Diagram for mini wall “1”, force (axis x), deformation (axis y)

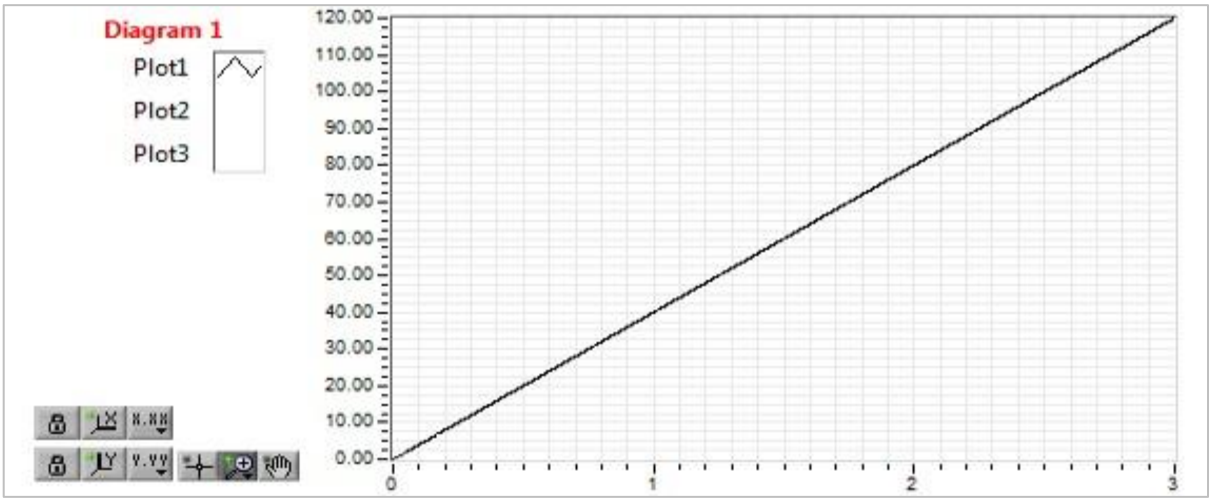


Figure 154. Diagram for mini wall “1”, strain (axis x), force (axis y)

Table 19. Values obtained for mini wall "1"

Mini wall "1"	Force F (kN)	Stress σ (MPa)	Deformation from the curve Δl (mm)	Engineering strain e	Modulus of elasticity E (MPa)
Crack in bonding mortar	75	1.875	0.1205	0.00172	1088.85
Crack in the brick	120	3	0.14	0.002	1500

6.3.4 Mini wall “2” results

For the mini wall “2” under the action of force F=40 kN the first crack begins to appear in the connecting mortar of the mini wall, with deformation values of 46.9mm, Fig.155, Fig.156. While the first crack in the brick appears under the action of force F=100kN with deformation values of 95.6 (mm), Fig.157. These results are generated and obtained by the software program, and from these values the modulus of elasticity is also obtained for each case, Table 21. Other cracks appear during the process, these are evidenced in the wall structure with a marker and are shown in the photos attached in the Annex. While in Fig.158 - Fig.161, the diagrams generated by the software are presented regarding the behavior of the wall and the ratio of: stress to deformation, strain to deformation ratio and stress to strain ratio.

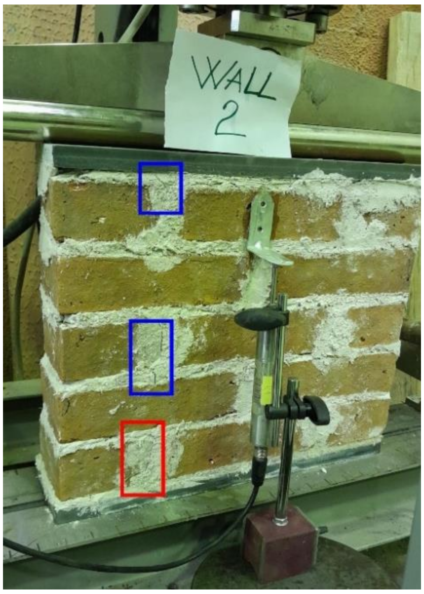


Figure 155. Mini wall “2”, the crack in the bonding plaster (blue) and in the brick (red).

Figure 156. The crack in the bonding mortar, mini wall “2”,

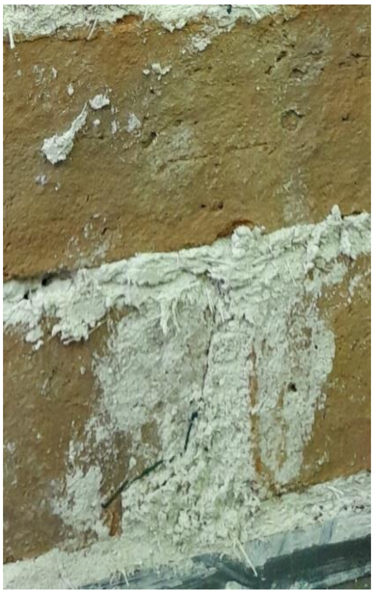


Figure 157. The crack in the brick, mini wall “2”.

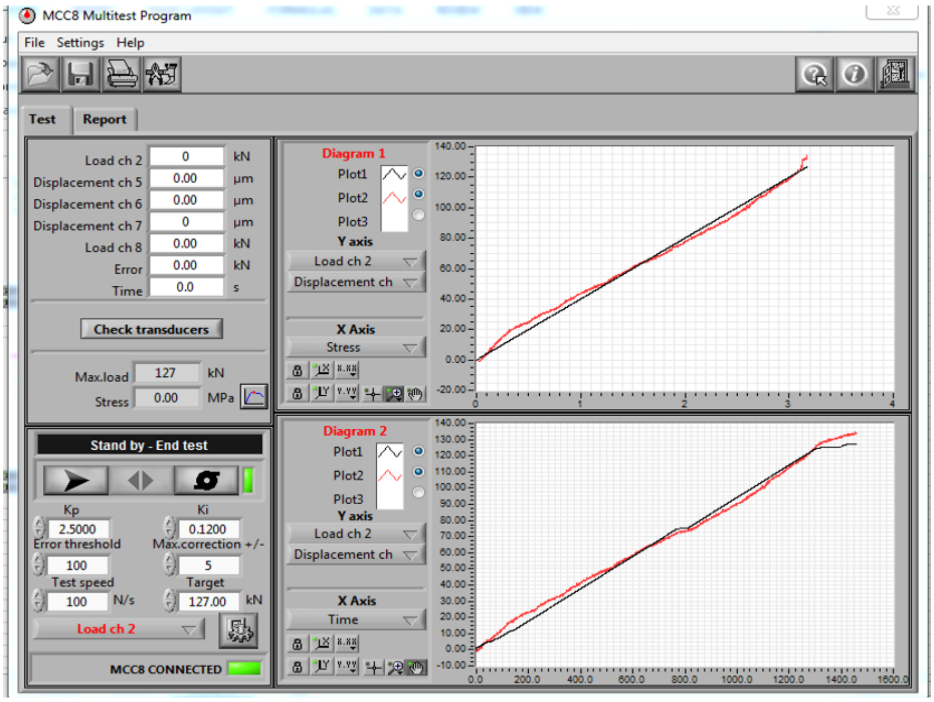


Figure 158.Generating diagrams from the software for min wall ”2”.
The upper curve shows strain on the X axis and force and deformation on the Y axis,
The lower curve shows time on the X axis and force and deformation on the Y axis,

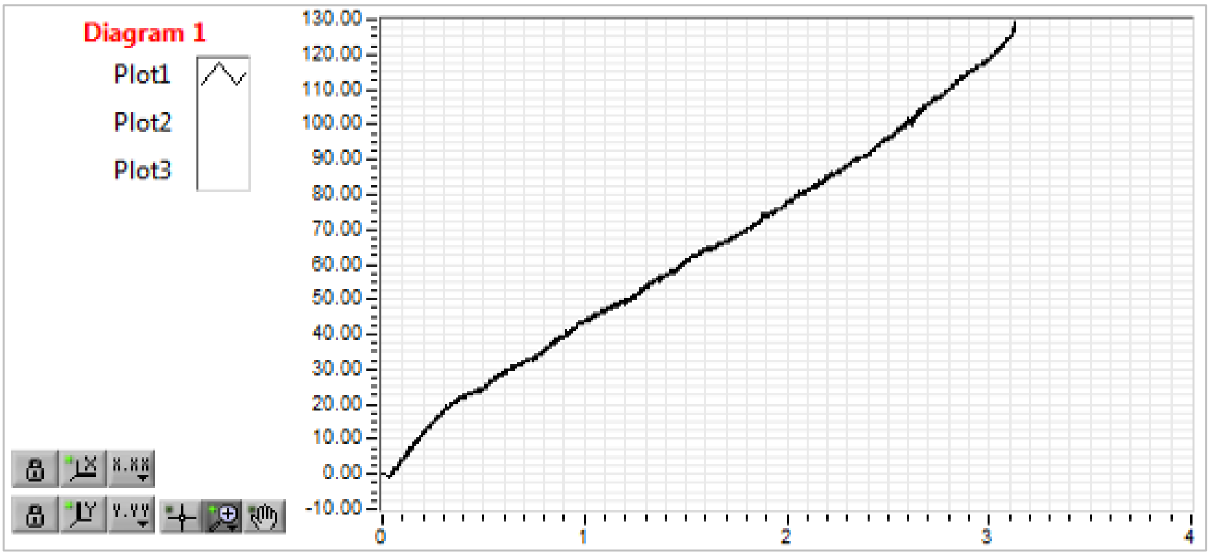


Figure 159. Diagram for mini wall “2”, strain (axis x), deformation (axis y)

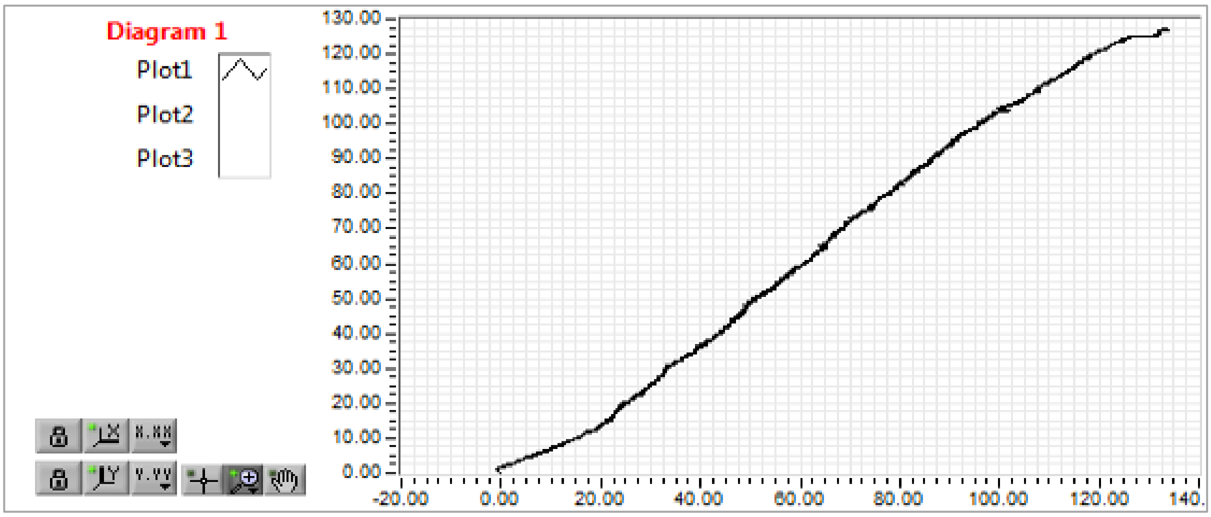


Figure 160. Diagram for mini wall “2”, force (axis x), deformation (axis y)

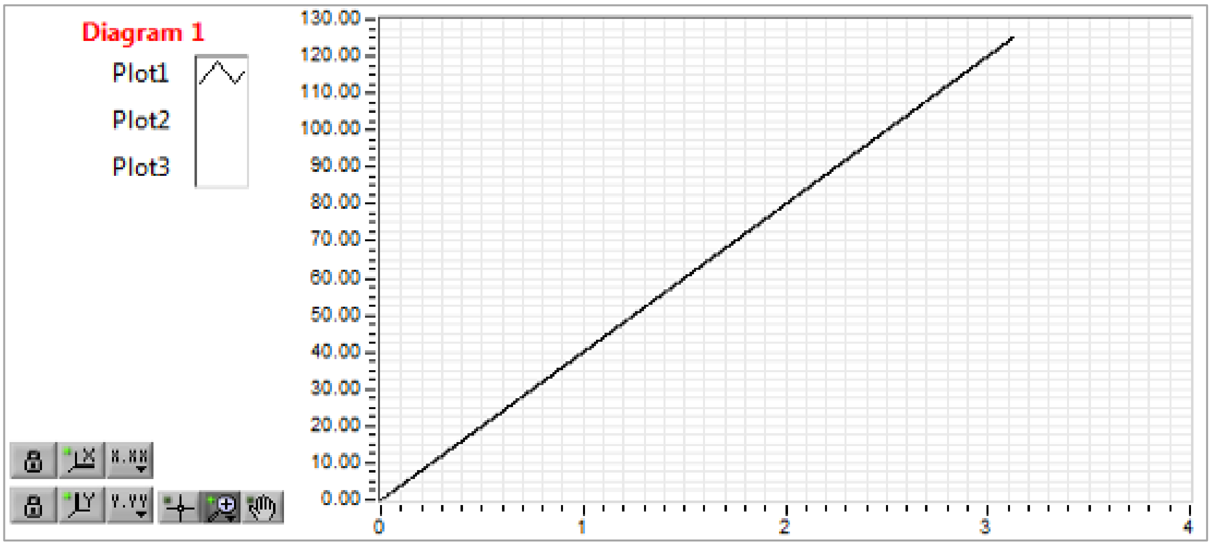


Figure 161. Diagram for mini wall “2”, strain (x), force (y)

Table 20. Values obtained for mini wall "2"

Mini wall "2"	Force F (kN)	Stress σ (MPa)	Deformation from the curve Δl (mm)	Engineering strain e	Modulus of elasticity E (MPa)
Crack in bonding mortar	40	1	0.0438	0.00062	1595.62
Crack in the brick	100	2.5	0.0961	0.00137	1820.45

6.3.5 Mini wall “3” results

For the mini wall “3” under the action of force F=65kN the first crack begins to appear in the connecting mortar of the mini wall, with deformation values of 0.0566mm, Fig.162, Fig.163. While the first crack in the brick appears under the action of force F=107kN with deformation values of 0.0873mm, Fig.164. These results are generated and obtained by the software program, Table 22. And from these values the modulus of elasticity is also obtained for each case, Table 22. Other cracks appear during the process, these are evidenced in the wall structure with a marker and are shown in the photos attached in the Annex. While in Fig.165 - Fig.168, the diagrams generated by the software are presented regarding the behavior of the wall and the ratio of: stress to deformation, strain to deformation ratio and stress to strain ratio.

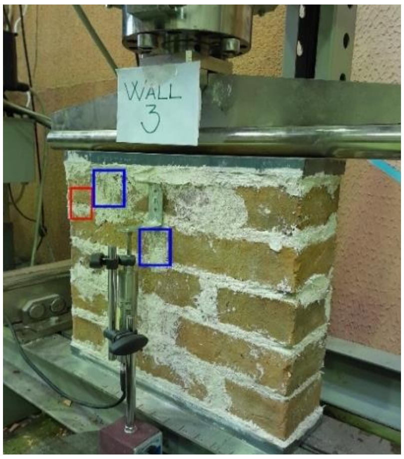


Figure 162. Mini wall “3”, the crack in the bonding plaster (blue) and in the brick (red).

Figure 163. Cracks in the bonding mortar mini wall “3”,

Figure 164. The crack in the brick, mini wall “3”,

Table 21. Values obtained for mini wall "3"

Mini wall "3"	Force F (Kn)	Stress σ (MPa)	Deformation from the curve Δl (mm)	Engineering strain e	Modulus of elasticity E (MPa)
Crack in bonding mortar	65	1.625	0.0556	0.00079	2042.55
Crack in the brick	107	2.675	0.0873	0.00124	2143.42

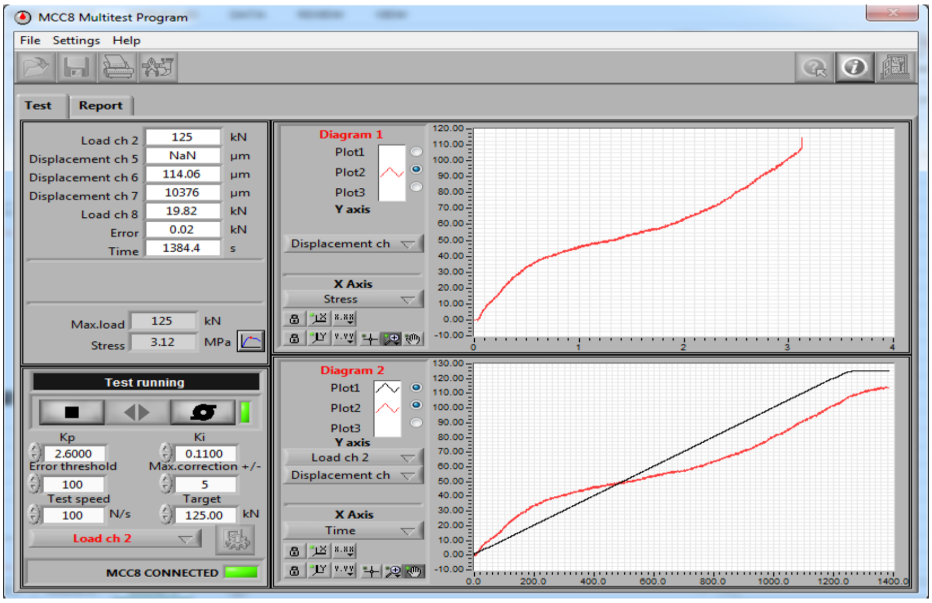


Figure 165.Generating diagrams from the software for mini wall ”3”.
The upper curve shows strain on the X axis, and deformation on the Y axis
The lower curve shows time on the X axis, and force and deformation on the Y axis,

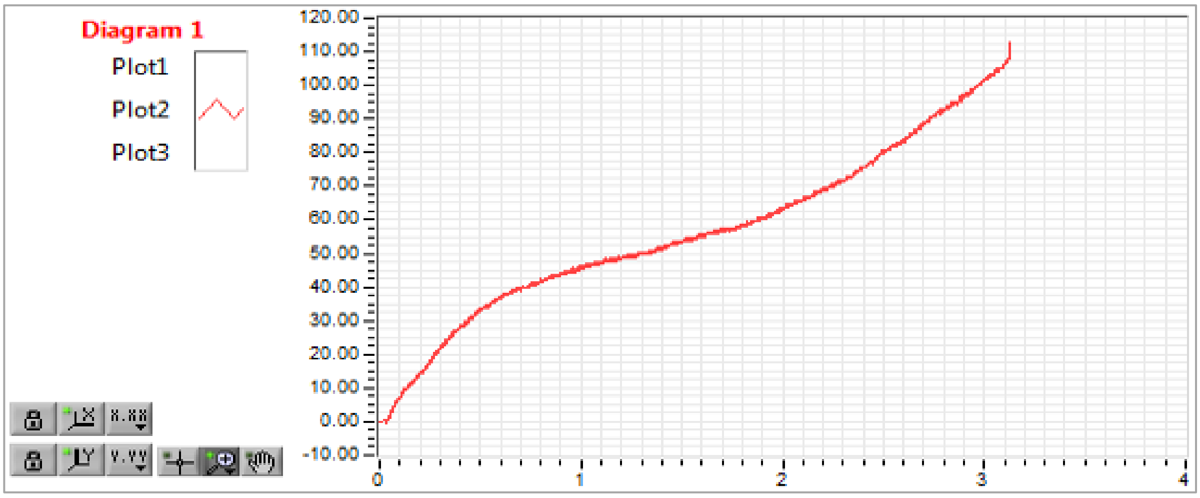


Figure 166. Diagram for mini wall “3”, strain (axis x), deformation (axis y)

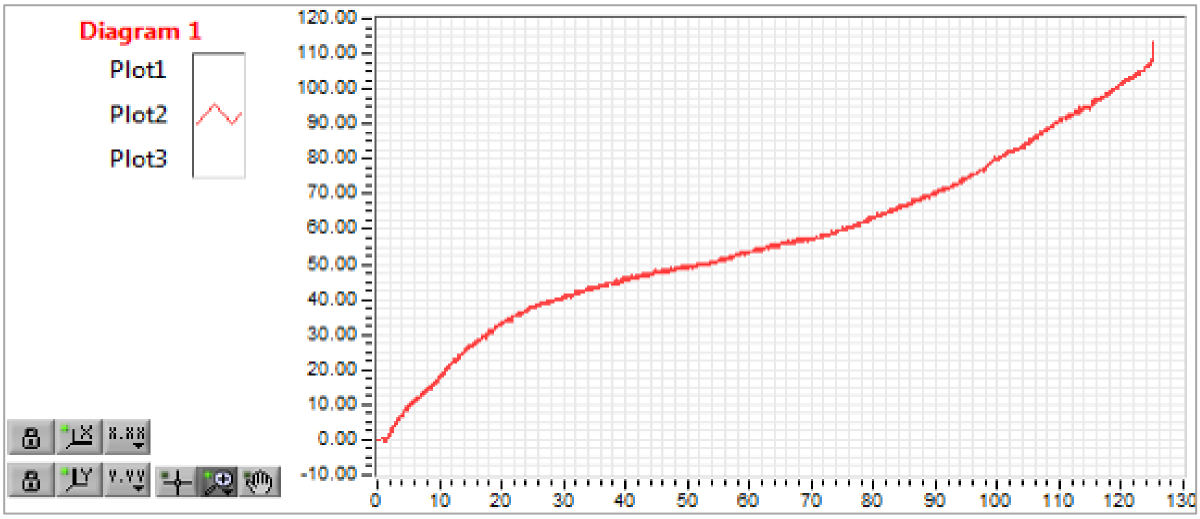


Figure 167. Diagram for mini walls “3”, force (axis x), deformation (axis y),

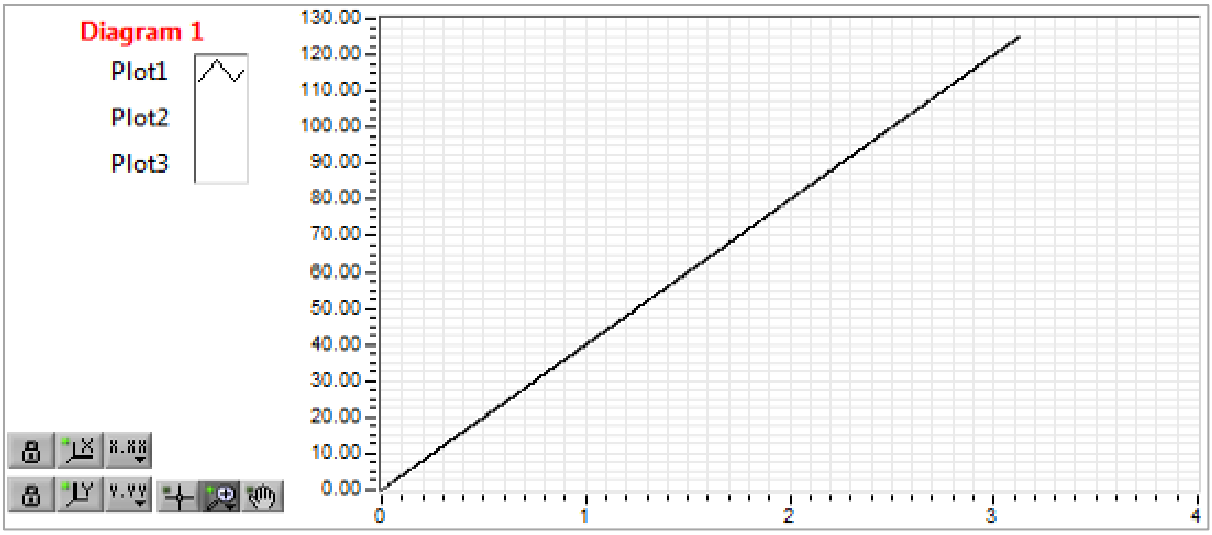


Figure 168.Diagram for mini wall "3", strain (axis x), force (axis y)

7.3.6 Cracking in the bonding mortar on the three mini walls

Table 22. The summary of the values of the results of the cracking in the bonding mortar on the three mini walls

3 Mini walls	Force *F* (kN)	Stress σ (MPa)	Deformation from the curve Δl (mm)	Engineering strain *e*	Modulus of elasticity *E* (MPa)
Crack in bonding mortar in "mini wall "1"	75	1.875	0.00172	0.00172	1088.85
Crack in bonding mortar in "mini wall "2"	40	1	0.00062	0.00062	1595.62
Crack in bonding mortar in "mini wall "3"	65	1.625	0.00079	0.00079	2042.55
Average	60	1.50	0.0010	0.00104	1575.67

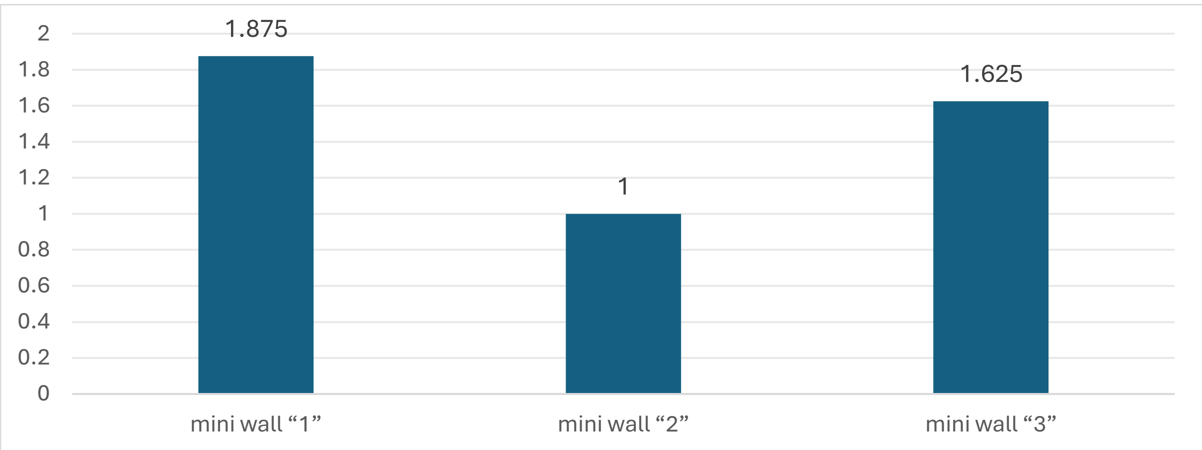


Figure 169. Stress (MPa) values obtained at three mini walls

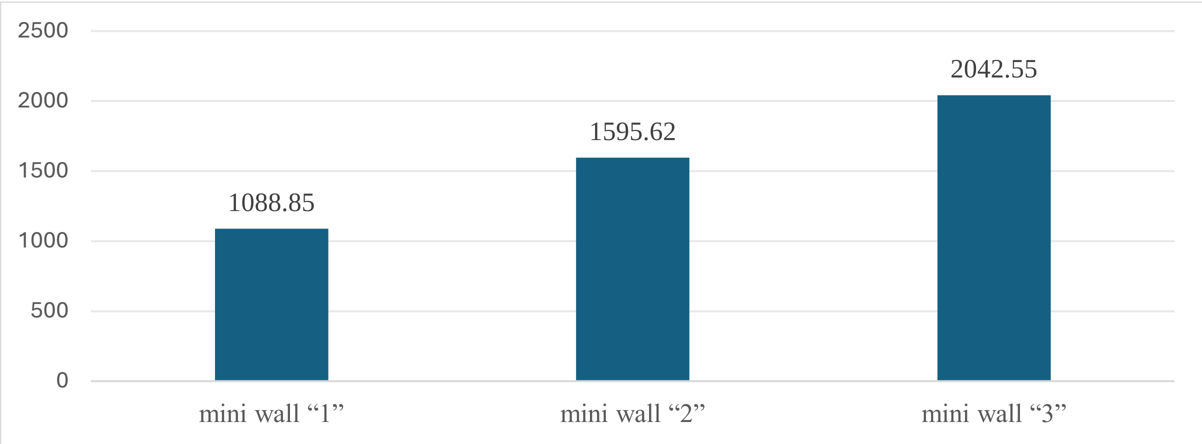


Figure 170. Modulus of elasticity (MPa) obtained at three mini walls

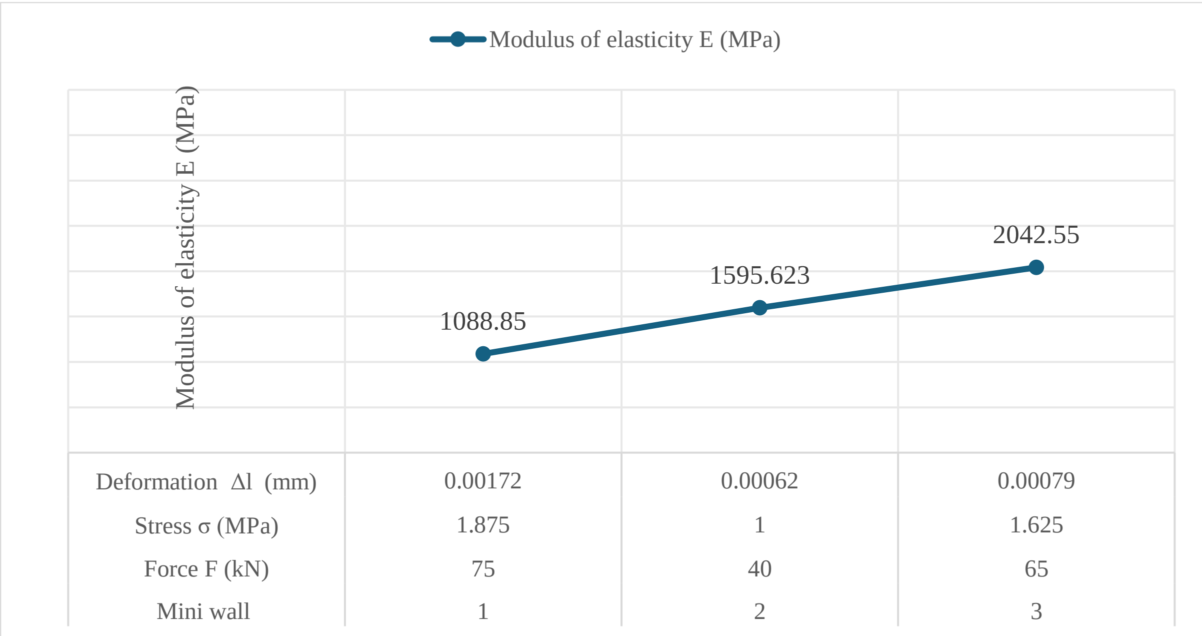


Figure 171. The ratio of modulus of elasticity, comparing the other values in each sample of mini wall.

6.3.7 Cracking in the brick on the three mini walls

Table 23.The summary of the values of the results of the cracking of the brick on the three mini walls

3 Mini walls	Force F (kN)	Stress σ (MPa)	Deformation from the curve Δl (mm)	Engineering strain ε	Modulus of elasticity E (MPa)
Crack at the brick mini wall “1”	120	3	0.002	0.002	1500
Crack at the brick mini wall “2”	100	2.5	0.00137	0.00137	1820.45
Crack at the brick mini wall “3”	107	2.675	0.0873	0.00124	2143.42
Average	109.00	2.73	0.0302	0.00154	1821.29

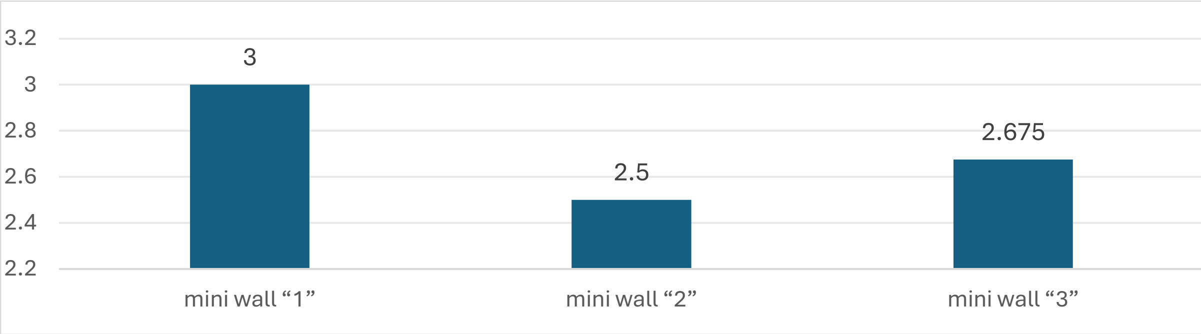


Figure 172. Stress (MPa) values obtained at three mini walls

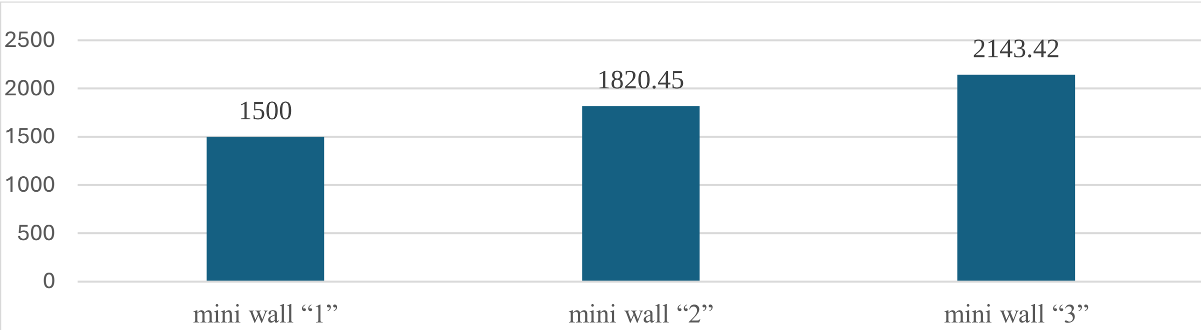


Figure 173. Modulus of elasticity (MPa) obtained at three mini walls

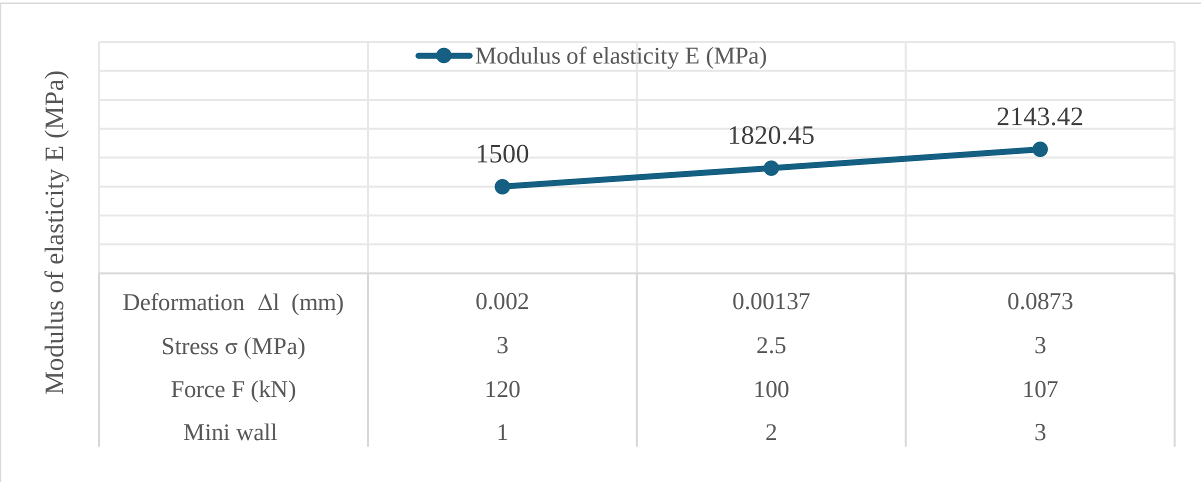


Figure 174. The ratio of modulus of elasticity, comparing the other values in each sample of mini wall

6.3.8 Interpretation of results

During the laboratory experiments for this research, the average results of the modulus of elasticity for bricks were obtained as: E= 1821.28 MPa, while for mortar E =1575.67 MPa. The percentage difference between the two values of the modulus of elasticity is 13.49%. In the diagrams attached above Fig.172, Fig.173, an overview of the stress-modulus ratio of the wall is given with a focus on cracks caused in the mortar. While Fig.174 an overview of the stress-modulus ratio of the wall is given with a focus on cracks caused in the bricks.

Looking at the summary of the results attached in Table 23 and Table 24, it is observed that the modulus of elasticity E (MPa) is related to the force F (kN) and the stress σ (MPa). This means that with the increase of the force F and the stress σ, according to the values read in the curve, the modulus of elasticity *E* (MPa) also increases. This direct relationship between these two values is important for the analysis of materials and for the design of positions in the facades, which promise to withstand loads and improve the performance in construction. This also reflects "The elastic modulus is roughly proportional to the compressive strength of the masonry assemblage" [213]. The photo obtained during the implementation of this experiment, for three mini walls are attached in the annex A.1 section at the end of this doctoral thesis.

6.4 Experiment X- Bearing capacity – Compressive Strength

The next experiment for the three mini walls concerns the "Hydraulic compression testing machine" apparatus. The operating mode of this apparatus during the testing of the samples is attached Fig.175 and Fig.176. This apparatus has a bearing force acting on the samples, up to 500kN [214] [215]. The space in which the mini wall is placed is 40x32x52cm. This laboratory experiment is carried out according to the standards BS EN 1052-1:1998 [183] and BS 5628-1:1992 [186]. In this apparatus, to obtain the final result of the bearing capacity, the three mini walls have been tested. The obtained result of the maximum force *F* is read in the accompanying "pneumatic controller" apparatus, Fig.c.176.

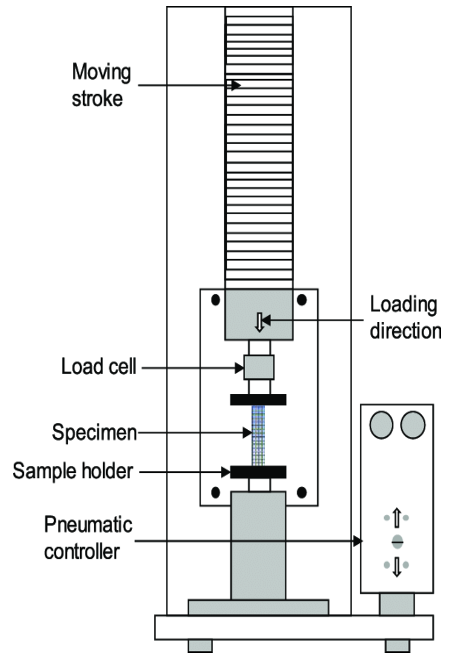


Figure 175.The working scheme of the device "Hydraulic compression testing machine" *[216]*

This transmission apparatus has two barometer devices, which indicate the gradual increase of the force up to the maximum value that the samples can withstand. Also in this device, the value of the force *F* transmitted to the samples is increased and decreased manually through valves.

Figure 176. Hydraulic compression testing machine, a) the entire instrument b) testing equipment c) pneumatic controller

6.4.1 Results

The mini walls are prepared for testing, the equipment is checked beforehand, and testing begins. It is gradually observed that cracks appear in the mini wall, continuing until the mini wall loses its bearing capacity. To generate the results for the three mini walls, the maximum bearing capacity values for each mini wall are obtained from the "Hydraulic compression testing machine" apparatus, which is read on the barometer. The process is also recorded on video and all the changes that the wall undergoes under the influence of compressive strength are observed.

7.4.2 Mini wall "1" result

Figure 177. The mini wall "1" before the start of testing and after testing

Table 24.Bearing capacity score for mini wall "1"

Mini wall "1"	Force *F* (kN) failure load	Compressive strength *Rm* (MPa)
Loss of bearing capacity of the mini wall	240	6

The cracks caused in the mini wall “1” during the test are shown in Fig.177. The values read by the barometer of the device are shown in Table 25, and from these values obtained it can be said that the mini wall “1” reaches the bearing capacity up to the value *F* =240 kN or *Rm* =6 MPa. After this value the bearing capacity of the mini wall is lost. The cracks caused by the action of the force *F* are observed in the lateral parts of the mini wall “1”.

6.4.3 Mini wall “2” results

Figure 178. The mini wall "2” before the start of testing and after testing

Table 25. Bearing capacity score for mini wall 2"

Mini wall “2”	Force *F* (kN) failure load	Compressive strength *Rm* (MPa)
Loss of bearing capacity of the mini wall	190	4.75

The cracks caused in the mini wall “2” during the test are shown in Fig.178. The values read from the barometer of the device are shown in Table 26, and from these values obtained it can be said that the mini wall “2” reaches the bearing capacity up to the value *F* =190 kN or *Fm* =4.75MPa. After this value the bearing capacity of the mini wall is lost. The cracks caused by the action of the force *F* are observed in the lateral and frontal parts of the mini wall “2”.

6.4.4 Mini wall “3” results

Figure 179.The mini wall "3” before the start of testing and after testing

Table 26. Bearing capacity score for mini wall "3"

Mini wall "3"	Force *F* (kN) failure load	Compressive strength *Rm* (MPa)
Loss of bearing capacity of the mini wall	190	4.75

The cracks caused in the mini wall "3" during the testing are shown in Fig.179. The values read from the barometer of the device are shown in Table 27, and from these values obtained it can be said that the mini wall "3" has the bearing capacity up to the value F =190 kN or Fm =4.75MPa. After this value the bearing capacity of the mini wall is lost. The cracks caused by the action of the force F are observed in the lateral parts of the mini wall "3". View of the three mini walls after the completion of the experimental testing process, Fig. 180, Fig.181.

Figure 180.The final state of the three mini walls after test

Figure 181. The condition of the walls after examinations, some of their details in the structure

7.4.5 Comparison of the results

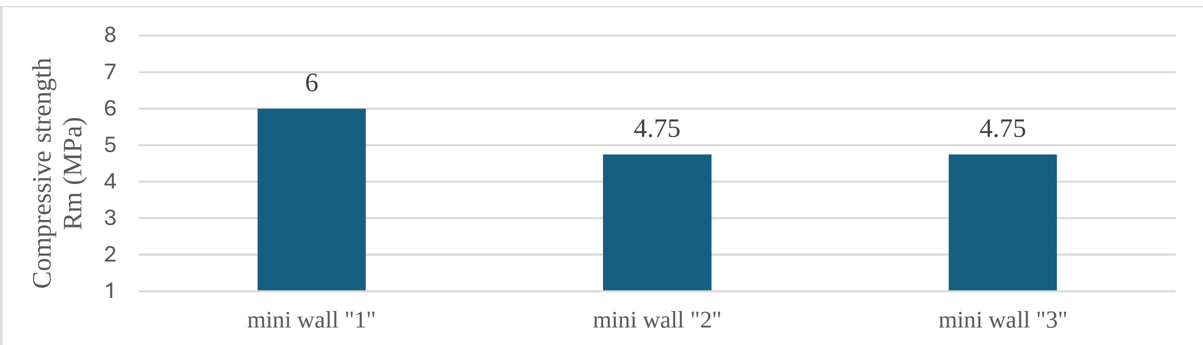


Figure 182.The ratio of the force values with the stress caused in the mini walls

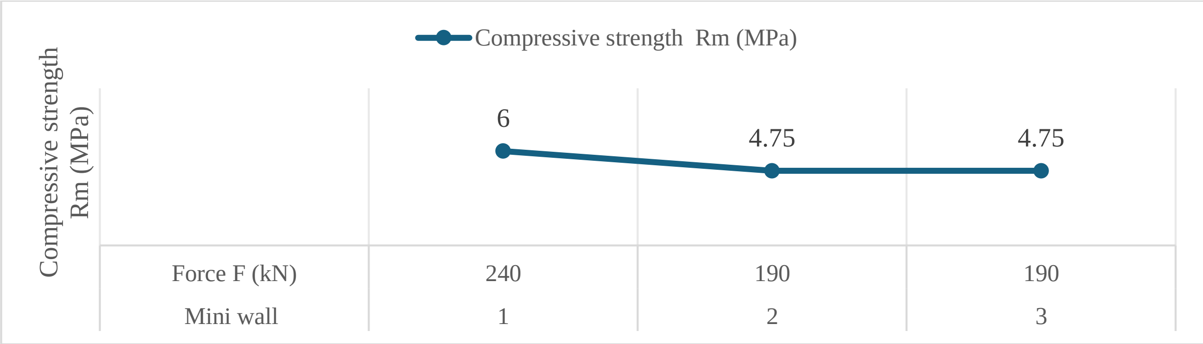


Figure 183.The ratio of stress, comparing the other values in each sample of mini wall

Table 27. Average minimum scores from the last test

Mini wall	Force *F* (kN) failure load	Compressive strength *Rm* (MPa)
Loss of bearing capacity mini wall "1"	240	6
Loss of bearing capacity mini wall "2"	190	4.75
Loss of bearing capacity mini wall "3"	190	4.75
Average	206.67	5.17

7.4.6 Interpretation of results

The largest cracks are observed in the mini wall “3” while the smallest ones are observed in the wall “1”.

In the diagrams Fig.182 and Fig.183, the ratio of the acting force in the mini walls to the compressive strength is presented. While from the summary of the values of the maximum acting forces *F* presented in Table 28, the average of the maximum acting force *F* reached in the mini walls is found, which is *F* =206.67 kN and compressive strength *Rm* =5.17 MPa. And it is observed that the mini wall “1” has resulted in having the greatest bearing capacity.

The cracks caused at the edges of the three mini walls are as a result of the special types of these walls, which are different from the standard prototype of the walls and also as a result of the specific materials used in the research into bricks.

From the results obtained for testing the three mini walls for the modulus of elasticity and bearing capacity, it can be said that the values obtained are promising for a more advanced development towards sustainable architecture with a focus on the building facade.

Based on the standards BS 5628-1:1992 [186], the minimum compressive strength for walls made of clay bricks is specified to be *F*=5MPa. The development of experiments related to the bearing capacity, the average of the values of compressive strength for the three tested mini walls which were obtained *Fm* =5.17 MPa, shows that it reaches the standard.

And according to standards BS EN 1052-2:1998 [183], the MAPEI mortar with which the mini walls were made, the allowable resistance range of the mortar with which the masonry is tested, in our research case, correspond to each other. Other images of the loss of bearing capacity in the three mini-walls during the implementation of the Bearing capacity – Compressive Strength experiment, with the help of the “Hydraulic compression testing machine”, are attached in annex A.1, in the last part of the doctoral thesis.

6. GENERAL KNOWLEDGE FROM DOCTORAL RESEARCH

The main knowledge and main contributions from doctoral research, achieved by the elaboration of all the above chapters include: the context, the importance of the study, the methods used, the results and the academic contribution. All these elaboration points are related to the theme of this research: “Comparative experimental research of innovative sustainable ceramic building material for facades”. The graphical representation of this research is made in Fig.184, attached below. And Meetings held with professors on research and experimental achievements Fig.185.

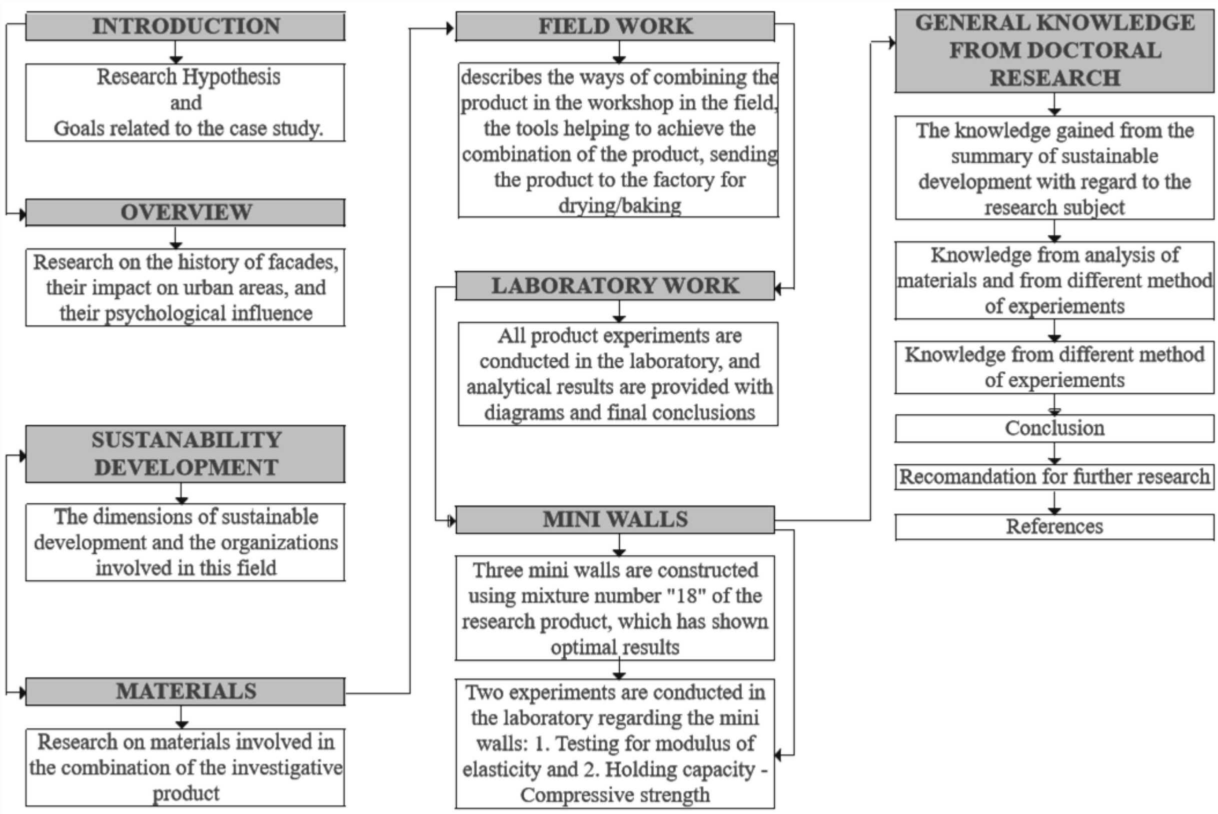


Figure 184. Graphical summary of the research in the thesis

Figure 185. Meetings held with professors on research and experimental achievements

Just as the approach to this research began, from the elaboration of sustainable development in the context of building engineering and architecture, so will the knowledge achieved in this research. The connection of sustainable development with the social, economic and ecological dimension, in our case targeted the building envelope and energy performance. This targeting filtered the potential materials for use in the building envelope. These materials referred to bio and recycled materials. Depending on the objectives and policies of global energy performance, methodologies, legislation, the scope of the research focused on some bio and recycled materials, which were selected for combination and creation of the product with application on the facade of buildings. Afterwards, this obtained product has been analyzed with the help of experiments according to European standards for the potential possibility of using this material on the facade of buildings. And depending on these results, a conclusion and recommendation should be reached for the research conducted regarding the product in question.

From these analyses and experiments described above, it can be said that the product in question has the potential for recycling of the constituent materials after the end of its use in the facade. In this case, we have the possibility of recycling the clay material and the slag material which are constituent parts of this product. These materials can continue to be used further in some other construction field, thanks to the physical, mechanical and chemical properties which they possess as materials. But for the possibility of further use and recycling of this product, other processing methods are needed.

7.1 The knowledge gained from the summary of sustainable development with regard to the research subject

Sustainable development in the context of civil engineering and architecture is based on energy performance which is directly related to comfort, human well-being and harmony with nature. These sustainable development objectives are merged into three dimensions: ecological, economic and social. From these dimensions it can be understood that sustainable development is defined as the demand to balance economic, environmental and social demands. This approach refers to the use of bio and recycled materials which reduce environmental impact and promote sustainable buildings.

Sustainable development, being the objective of many global campaigns, has influenced the raising of human awareness of the importance of using sustainable materials in the facade of buildings. This has also been evidenced by the global increase in investments in technology and construction industries with an approach to energy performance. Campaigns for economic financing of building performance have also had an impact on raising human awareness of energy performance. Economic grants have also had an impact, as have economic incentives for the execution of buildings if bio and recycled materials are used. And as a result, all of these also affect the cheaper financial bills for energy consumption.

7.2 Knowledge from analysis of materials

Sustainable materials applied to the facade of buildings can integrate sustainable development standards by reducing and improving energy performance. These materials can reduce environmental impact because by relying on resource recycling, they can reduce global pollution. At the same time, this approach improves comfort in the interior spaces of buildings and can promote the development of the sustainable materials industry. The materials applied in this research fulfill the "17 Sustainable Development Goals", in these points: 7,9,11,12,13,15, which have been mentioned earlier in this research in the Sustainable Development chapter. These points are related to the promotion of sustainable practices in construction and architecture, emphasizing the importance of innovative materials that support economic development and environmental protection. These goals of these measures, from the research of the materials of this dissertation, it can be said that the materials: clay, sawdust and slag, in combination with each other aim at preserving land ecosystems, reducing land degradation, supporting an architecture, urbanism, that is friendly to the environment and the community in general.

The union of these materials with each other can also be considered an attempt to create a balance between the three dimensions: ecological, environmental and social, to build a better and greener future.

7.3 Knowledge from different methods of experiments

The knowledge gained in the field from material research provides a critical overview of the properties of the materials, which are demonstrated and verified in laboratory tests to assess their performance over time. These laboratory tests, for this product mix, have enabled the identification of optimal mixing ratios and possible limitations in each category of experiments. The use of different experimental methods in the laboratory, based on European standards, has identified the possible potential of the product in different situations. The experiments reveal that these natural and recycled components affect energy efficiency, the structural behavior of the material, the development of innovations for sustainable materials, the creation of standards and policies to promote sustainable construction.

- **Dimension:** shows and reflects the influence of materials on the shrinkage of the dimensions of the product. In bricks that have mainly higher clay content in combination with small sawdust content, there were differences in shrinkage. This shrinkage varies in each brick. In general, if we look at the percentage of dimensions, the smallest shrinkage occurred in sample "19 $_{78\text{-}12\text{-}10}$" "a" =6.97%, in dimension "b" = 6.08%, in dimension "c" = 7.82 %. While the largest shrinkage occurred in samples "17 $_{86\text{-}4\text{-}10}$", "a" =9.02 %, in dimension "b" = 9.59 %, while in dimension "c" = 12.74 % .
- **Bulk density**: reflects the important indicator regarding the density and response of the product to loads. From the results of the brick samples, it can be seen that the presence of slag components affects the increase in the density of the brick samples, while the presence of sawdust affects the low density of the samples. The lowest density was achieved by sample "19 $_{78\text{-}12\text{-}10}$" ρ=1.37 g/cm3, while the highest density was achieved by sample "23 $_{76\text{-}4\text{-}20}$" ρ =1.73g/cm3.
- **Water absorption:** provides information on the performance of the product in humid conditions, in assessing the stability of materials to the water factor and the impact of water on the product in the long term. The results obtained after the experiment show that sample "23 $_{76\text{-}4\text{-}20}$" has the lowest water absorption value of 15.60%, while mixture "19 $_{78\text{-}12\text{-}10}$" has the highest water absorption value of 22.71%. This indicates that the low percentage of sawdust affects low water absorption.
- **Freezing and thawing cycles:** this experiment has proven the stability of materials in extreme conditions, at low and high temperatures. And with this experiment, the evaluation of the product's ability to maintain and preserve its structure after several freeze and thaw cycles has been proven. From the results of the values achieved, it is seen that sample "18 $_{82\text{-}8\text{-}10}$" has the lowest value of 0.67% of mass loss after the cycles, while sample "23 $_{76\text{-}4\text{-}20}$" has the highest value of 2.61% of mass loss. The high participation of slag in the research material, which in combination with the relatively low participation of clay material, affects the mass loss of the product.
- **Compressive strength - dry state:** with this experiment, the basis has been structured to compare the compressive strength of the product before and after freeze-thaw cycles, to evaluate the performance of the material under different conditions. Sample number "23 $_{76\text{-}4\text{-}20}$" has the highest value of compressive strength F=7.6 MPa, while sample "22 $_{73\text{-}12\text{-}15}$" has the lowest value F=3.72 MPa. This shows that the low percentage of sawdust material, and the high percentage of clay affect the compressive strength value.

- **Compressive strength – condition after freeze thaw cycles:** with this experiment, the identification of possible losses of stability and durability of the product or any damage to the structure of the test sample was made. From the results obtained, sample "17 $_{86\text{-}4\text{-}10}$" has the highest value of compressive strength F=6.64 MPa, while sample "25 $_{68\text{-}12\text{-}20}$" has the lowest value F=3.24 MPa. Comparing the results of this experiment with the initial results of compressive strength of the dry state, it can be concluded that sample "17 $_{86\text{-}4\text{-}10}$" has a decrease in compressive strength of 3.86%, while sample "25 $_{68\text{-}12\text{-}20}$" has a decrease in compressive strength of 13.94%.
- **The thermal conductivity:** this laboratory method is considered a parameter to manage temperature changes, to determine the thermal efficiency of the product and the comfort in the interior spaces of buildings. While the product in question has the potential for use in the building envelope, the factor in question is also important in the physics of construction for the building facade. From experiments carried out in two laboratories: at the Faculty of Civil Engineering in Skopje and at the Faculty of Engineering in Pristina, samples "18 $_{82\text{-}8\text{-}10}$" and "24 $_{72\text{-}8\text{-}20}$" have achieved the lowest value of thermal conductivity λ=0.128W/m·K and λ=0.127W/m·K. While sample "25 $_{68\text{-}12\text{-}20}$" has the highest value of thermal conductivity λ=0.165W/m·K. At the end of the experiment, it is concluded that samples that have low density values have low thermal conductivity values.
- **The behavior of the masonry wall under the load - applications:** this experiment evaluates the flexibility of the material, the response of the product to loads, and the response to stress during long-term use in construction. These three mini walls are made from sample "18 $_{82\text{-}8\text{-}10}$" selected due to its optimal results. From the laboratory experiment, the following values are obtained for these mini walls: the bearing capacity in these mini walls is F=109.00 kN, while the modulus of elasticity is E =1821.29 MPa.
- **Bearing capacity-compressive strength:** can be considered as a key indicator for the structural stability of the material and to show the load bearing capacity under different conditions during the life of the product on the building facade. The average of the maximum acting force F reached in the mini walls is found, which is F =206.67 kN and compressive strength Rm =5.17 MPa. And it is observed that the mini wall "1" has resulted in having the greatest bearing capacity.

8. CONCLUSION

In conclusion of this doctoral thesis: “Comparative experimental research of innovative sustainable clay building material for facades”, the experimental methods used in this doctoral research, from the generated results it is shown that this product has the potential to replace some of the traditional materials existing on the market.
The practical and theoretical impact of this research targets the advantages of using this material in the engineering and architectural fields. Because in architecture, from this product we can design building facades, which can create an environmentally friendly silhouette, increasing the well-being of citizens and aesthetically acceptable by the community. Because such a product can offer a sustainable aesthetic structure that does not challenge internal comfort.

The physical and mechanical properties shown during the experiment make the research product in question effective for improving the energy efficiency of buildings. The stability to climatic conditions of freezing and thawing makes the product applicable to facades as a material that does not degrade from environmental influences. The compressive strength of the product provides resistance and durability of the brick and resistance to external loads. The clay material used in the combination of the product has refractory properties, while the product is also subjected to a furnace at a temperature of 900℃ during firing, making this product a fire-safe material. The light weight of the product offers the possibility of use in facades of high-rise buildings. The product with such a mixture of materials can be used in modern and traditional buildings, as a result of the natural textures and colors obtained during the drying and firing of the product.

The results achieved in the experiments conducted in the laboratory can be summarized as follows:

- In the dimensional experiment, all three sides of the brick have undergone shrinkage as a result of the shrinkage property of clay. In this case, the increase in sawdust affected the lower percentage of shrinkage, while the greater participation of clay affected the higher percentage of shrinkage. While the presence of slag in the product affected the constant value of shrinkage. The highest percentage of shrinkage was achieved in sample “17 $_{86\text{-}4\text{-}10}$ “ while the lowest shrinkage was presented in sample “19 $_{78\text{-}12\text{-}10}$“.
- In the bulk density experiment, it is observed that sample “19 $_{78\text{-}12\text{-}10}$“ has the lowest density ρ=1.37 g/cm3, while sample “23 $_{76\text{-}4\text{-}20}$” has the highest density ρ=1.73 g/cm3. In this case, with the increase in sawdust, the density decreased, with the increase in slag, the density increased.

- In the water absorption experiment, it is observed that sample "23 $_{76\text{-}4\text{-}20}$" has the lowest water absorption value of 15.60%, while the mixture "19 $_{78\text{-}12\text{-}10}$ " has the highest water absorption value of 22.71%. In these results, it was observed that with the increase of sawdust and slag, the water absorption rate increased, while the high clay content decreased the water absorption.
- Freezing and thawing cycles, this experiment showed that sample "18 $_{82\text{-}8\text{-}10}$" has the lowest mass loss value of 0.67%, while sample "23 $_{76\text{-}4\text{-}20}$" has the highest mass loss value of 2.61%. In these results, it was observed that samples with higher slag content had the highest mass loss, while the 8% sawdust content in the product offered the lowest mass loss after freezing and thawing cycles.
- Compressive strength in dry state condition, sample "23 $_{76\text{-}4\text{-}20}$" has the highest value of compressive strength 7.6 MPa, while sample "22 $_{73\text{-}12\text{-}15}$" with the lowest value of compressive strength 3.72 MPa. From this experiment it is observed that with increasing the proportion of sawdust and slag the value of compressive strength decreases, while with increasing the composition of clay it gradually affects the increase of compressive strength.
- Compressive strength experiment, carried out under freeze and thaw cycles, it is observed that sample "23 $_{76\text{-}4\text{-}20}$ " has the highest value of compressive strength reduction 13.29%, while sample "20 $_{81\text{-}4\text{-}15}$" has the lowest value of compressive strength reduction 0.51%. From the obtained values of the results, it is observed that with the increase in the slag content, the reduction in the compressive strength after freezing and thawing cycles also increases.
- In the thermal conductivity experiment, sample "24 $_{72\text{-}8\text{-}20}$" has the lowest value of thermal conductivity λ=0.127 (W/m·K), while the sample "25 $_{68\text{-}12\text{-}20}$ " has the highest value of thermal conductivity λ=0.165 (W/m·K). The results obtained show that with the increase in the participation of sawdust and clay, the value of thermal conductivity is also lower. While the high participation of slag affects high values of thermal conductivity.
- Experiment carried out for Mape-Antique Strutturale NHL bonding mortar, based on the values of the results obtained from the experiments carried out in the laboratory, the results rank the tested mortar in the category M9 (≥1 N/mm2), and CS IV (≥ 6MPa).
- The mini walls experiment " The behavior of the masonry wall under the load applications" n the walls made with the sample "18 $_{82\text{-}8\text{-}10}$", shows that average results of the modulus

of elasticity for bricks were obtained as: E= 1821.28 MPa, while for mortar E =1575.67 MPa. And with the increase of the force F (Kn) and the stress σ (MPa), according to the values read in the curve, the modulus of elasticity E (MPa) also increases.

- In the last experiment of mini walls "Bearing capacity-compressive strength" cracks caused at the edges of the three mini walls are as a result of the special types of these walls, which are different from the standard prototype of the walls and also as a result of the specific materials used in the research into bricks. While the average maximum acting force F reached in the mini walls is F =206.67 kN and the compressive strength is Rm =5.17 MPa.

The impact of the economic dimension on the product can be linked to the growth of a local economy or a wider reach if these products start to be used for the facade of buildings and begin to be placed in the construction market. From this approach, the use of other non-renewable products for facades can have a decrease in use by the consumer, resulting in social responsibility of citizens for the importance of bio and recycled products, therefore this focus of awareness promotes social responsibility for ecological constructions.

The impact of this product on technology and innovation can serve as an optional reference base for the development of new technologies and industrial construction innovations, always referring to energy efficiency and the connection with global sustainability objectives. The product in question lists several main points as advantages such as: Environmental sustainability, environmental suitability, innovation, assistance for the development of the industry, improvement of energy efficiency, improvement of the quality of comfort in the building, positive impact on health and well-being, visual diversification, natural aesthetics, encouragement of the use of local resources, creation of products with low ecological impact.

Disadvantages: The challenge of convincing industries in the market to switch from the use of traditional materials to bio and recycled products, due to earlier adopted practices and greater safety in the market. In some buildings, their nature and functional character may limit the application of this product on the facade. Also, the use of this product requires knowledge and skills from designers and builders for the application of these materials in bulk. The lack of standards and certifications for some bio-based materials can cause uncertainty for users and designers.

These advantages and disadvantages target the ecological and systematic dimensions of using bio-based and recycled materials in facades. While the advantages are oriented towards environmental sustainability and energy performance, the disadvantages are oriented towards economic, technical and logistical challenges.

8.1 Recommendations for further research

From this research, it is recommended to design projects to test the further implementation of this product in real construction conditions for the facade of a building. An interdisciplinary approach, the cooperation of engineers, architects and environmental scientists can initiate further steps for the development of this field. This approach can initiate attempts to realize agreements with the construction, technological industries and environmental certification institutions. Such an approach can accelerate the adaptation of this product in the construction market by contributing to the global goal of sustainability. Further standardization for this product is a recommendation and an important area for future research. Opportunities for environmental certifications such as LEED or BREEAM, the development of these international criteria and standards can increase reliability and easier adaptation in the construction industry.

If there is further development and refinement of these experiments and construction practices, bio and recycled materials can serve as a key step towards sustainable and ecologically self-sustaining construction. From the further elaboration of this research, it is recommended and directed for further research to analyze the cost of this product, business models, and also how it could affect the market economy if this product replaces some other products.

Suggestions for research on the possibility of approaching this product with intelligent systems, for example with visual kinetic facades that have the possibility of adapting to climate change, and monitoring performance over time, with the help of automated technologies. Exploring the potential of the product for self-repair, thanks to other analyses, processes and technologies.

Bibliography

[1] Rob Krier, Elements of Architecture, Second, Ed., London: Academy Group Ltd, 1992.

[2] Ayşe Tekel , Kemal Yıldırım , Leila Akbarishahabi , Bassirou Bande, "The role of symbolic architecture on aesthetic judgemnt: a cross-cultural investigation on the reception of african calabash figure," *Architecture & City and Urban Planning,* vol. 29, no. 3, pp. 525-536, 2016.

[3] Carmela Cucuzzella, Negarsadat Rahimi, Aristofanis Soulikias, "The Evolution of the Architectural Façade since 1950: A Contemporary Categorization," *MDPI,* pp. 1-32, 2023.

[4] Merriam-Webster,Online Dictionary, "Facade," 2024. [Online]. Available: https://www.merriam-webster.com/dictionary/facade.

[5] Robert Venturi, Complexity and Contradiction in Architecture, N. Museum of Modern Art (New York, Ed., The Museum of Modern Art, 1977, 1977, p. 132.

[6] Danijela Djuric Mijovic, Danijela Milanovic, Savic Jelena, "Curtain Walls: History and a Continuing Challenge," *XVIII International Scientific Conference "Construction and Architecture" VSU 2018,* 2018.

[7] Tillmann Klein, Integral Facade Construction, vol. 3, 2013.

[8] U Knaack, S Chung-Klatte, R Hasselbach, Prefabricated systems, Basel: Birkhäuser, 2012, p. 133.

[9] Mike Davis, "A Wall For All Seasons," *RIBA Journal ,* 1981.

[10] William Browning,Catherine Ryan,Joseph Clancy, 14 Patterns of Biophilic Design, Washington: Terrapin Bright Green llc, 2014.

[11] ICRROM UNESCO WHC, Conservation of Architectural Heritage, Historic Structures and Materials, vol. 1, Roma: Worls Heritage Fund, 1999.

[12] Mary Ben Bonham,Kyoung Hee Kim, "Biofacades: Integrating Biological Systems with Building Enclosures," *Facade Tectonics,* 2022.

[13] Eric Balwdin, "Cultural Heritage," 13 January 2024. [Online]. Available: https://www.archdaily.com/971945/architecture-and-unesco-rethinking-preservation-and-cultural-heritage.

[14] Philippe St-Jean , Osborne Grant Clark,Michael Jemtrud, "A review of the effects of architectural stimuli on human psychology and physiology," *Building and Environment,* vol. 219, 2022.

[15] Sheng Wang,Guilherme Sanches de Oliveira,Zakaria Djebbara,Klaus Gramann, "The Embodiment of Architectural Experience: A Methodological Perspective on Neuro-Architecture," *Front. Hum. Neurosci.,* vol. 16, 2022.

[16] Edward O. Wilson, Biophilia, United States of America: Harvard University Press, 2009.

[17] Stephen R. Kellert, Elizabeth F. Calabrese, The Practice of Biophilic Design, Yale: Yale University Press, 2018.

[18] E. M. Sternberg, Healing Spaces: The Science of Place and Well-Being, 1, Ed., Belknap Press: An Imprint of Harvard, 2010, p. 352.

[19] United Nations, "Conferences | Environment and Sustainable Development," 2023. [Online]. Available: https://www.un.org/en/conferences/environment.

[20] European Commission UN, "Commission welcomes completion of key 'Fit for 55' legislation, putting EU on track to exceed 2030 targets," European Commission, Brussels, 2023.

[21] European Commission EU, "2050 long-term strategy," 2023.

[22] National Institute of Building Sciences, "Green Building Standards And Certification Systems," WBDG Whole Building Design Guide, 2024. [Online]. Available: https://www.wbdg.org/resources/green-building-standards-and-certification-systems.

[23] United Nations, "THE 17 GOALS," 2024. [Online]. Available: https://sdgs.un.org/goals.

[24] WCED - The World Commission on Environment and Development, "The Sustainable Development Goals Report-2022," United Nations Publications, United States of America., 2022.

[25] Europe Sustainable Developmen, "Europe Sustainable Development Report 2023/2024," Dublin University Press Dublin,, Ireland, 2024.

[26] United Nations, "Understanding the Dimensions of Sustainable Development: Now available in 8 languages!," November 2024. [Online]. Available: https://www.unssc.org/news-and-insights/news/understanding-dimensions-sustainable-development-now-available-8-languages.

[27] UN environment programme, "Intergovernmental Negotiating Committee (INC) on Plastic Pollution," 2024. [Online]. Available: https://www.unep.org/.

[28] European Commission, "Life Cycle Assessment (LCA)," 2024. [Online]. Available: https://eplca.jrc.ec.europa.eu/lifecycleassessment.html.

[29] Ecochain Technologies, "Life Cycle Assessment (LCA)," 2024. [Online]. Available: https://ecochain.com/blog/life-cycle-assessment-lca-guide/.

[30] EPD International, "A short introduction to EPD," 2024. [Online]. Available: https://www.environdec.com/home.

[31] IEA, "The International Energy Agency (IEA)," 2023. [Online]. Available: https://www.iea.org/about.

[32] IEA, "Energy Efficiency," IEA Publications, France, 2024.

[33] World GBC, "What is a net zero carbon building?," 2024. [Online]. Available: https://worldgbc.org/advancing-net-zero/what-is-a-net-zero-carbon-building/.

[34] European Commission, "Energy Performance of Buildings Directive," 2024. [Online]. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en.

[35] IEA, "World Energy Investment 2024," 2024. [Online]. Available: https://www.iea.org/reports/world-energy-investment-2024/european-union.

[36] Region Forecast to 2033, "Green Construction Market Size," 2024. [Online]. Available: https://www.emergenresearch.com/industry-report/green-construction-market.

[37] Precedence Research, "Sustainable Construction Materials Market Size, Share, and Trends 2024 to 2033," 2024. [Online]. Available: https://www.precedenceresearch.com/sustainable-construction-materials-market.

[38] M.J.Singer, A.Gerorge, C.D.Childers, M.L.Merril-Davies, "What is pH and why do we care ?," *University of California, Agriculture and Natural Resources,* 2012.

[39] "pH," 2024. [Online]. Available: https://www.britannica.com/science/pH.

[40] UN Environment Programme, "Sustainable consumption and production," 2024. [Online]. Available: https://www.unep.org/topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-12-9.

[41] Nadine M. Piatak,Robert R. Seal II, Darryl A. Hoppe, Carlin J. Green ,Paul M. Buszka, "Geochemical Characterization of Iron and Steel Slag and Its Potential to Remove Phosphate and Neutralize Acid," *MDPI,* vol. 9, no. 8, 2019.

[42] Nippon Slag Association, "Chemical composition of iron and steel slag," 2024. [Online]. Available: https://www.slg.jp/e/slag/character.html.

[43] Anton Geffert,Jarmila Geffertova,Michal Dudiak, "Direct Method of Measuring the pH Value of Wood," *Nondestructive Evaluation of Forest Biomaterials: A Global Perspective,* p. 852, 2019.

[44] Xian-ju Wang, Xinfang Li,Shuo Yang, "Influence of pH and SDBS on the Stability and Thermal Conductivity of Nanofluids," *American Chemical Society,* vol. 23, no. 5, 2009.

[45] Zhiming Liu, Ali Basem, Loghman Mostafa, Dheyaa J. Jasim, Ameer H. Al-Rubaye, Soheil Salahshour, Maboud Hekmatifar, Hadi Esmaeili, "Investigating the effect of pH on the swelling process, mechanical and thermal attributes of polyacrylamide hydrogel structure: A molecular dynamics study," *Case Studies in Thermal Engineering,* vol. 55, 2024.

[46] Hayder H Abed,Issa Omle,Ali Habeeb Askar,Endre Kovács, "Experimental Study of the Stability and Thermophysical Properties for Different Particle Size of Al2o3-H2o Nanofluid," *Journal of Engineering Science and Technology,* vol. 18, no. 6, 2023.

[47] Chia-Wen Peng & Han Chien Lin, "Japanese cedar (Cryptomeria japonica) ash as a natural activating agent for preparing activated carbon," *Journal of Wood Science,* p. 316–325, 2015.

[48] Talat Mahmood, Abu Kamal, "Ash properties relevance to beneficial uses," vol. 141, pp. 282-289, 2022.

[49] N. L. Association, "Lime Terminology, Standards & Properties," National Lime Association, 2007.

[50] Nano Alemu Daba, Dongchu Li, Jing Huang,Tianfu Han, Lu Zhang, Sehrish Ali, Muhammad Numan Khan, Jiangxue Du, Shujun Liu, Tsegaye Gemechu Legesse, Lisheng Liu,Yongmei Xu, Huimin Zhang, Boren Wang, "Long-Term Fertilization and Lime-Induced Soil pH Changes Affect Nitrogen Use Efficiency and Grain Yields in Acidic Soil under Wheat-Maize Rotation," *MDPI,* vol. 11, no. 10.

[51] Georges Kogge Kome, Roger Kogge Enang, Fritz Oben Tabi, Bernard Palmer Kfuban Yerima, "Influence of Clay Minerals on Some Soil Fertility Attributes: A Review," *Journal of Soil Science,* vol. 9, pp. 155-188, 2019.

[52] Clarence S. Ross and Sterling B. Hendricks, "MINERALS OF THE MONTMORILLONITE GROUP," *GEOLOGICAL SURVEY PROFESSIONAL PAPER 205-B,* pp. 23-79, 1943.

[53] The University of Waikato, "What is Clay," 2024. [Online]. Available: https://www.sciencelearn.org.nz/resources/1771-what-is-clay.

[54] Abeer Abduljabbar Al-Saeedi, "Clay basics and their physical and chemical properties: Review Paper," *IAETSD Journal for Advanced Research in Applied Sciences,* vol. 10, no. 8, p. 13, 2022.

[55] ISO 14688-1:2017, "Geotechnical investigation and testing — Identification and classification of soil," ISO (International Organization for Standardization) , Geneva, Switzerland, 2017.

[56] ASTM International, "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)," ASTM International (American Society for Testing and Materials), Pennsylvania, 2020.

[57] ASTM International, "Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)," ASTM International (American Society for Testing and Materials), Pennsylvania, 2018.

[58] Arthur Casagrande, "Classification and Identification of Soils," *Transactions of the American Society of Civil Engineers,* vol. 113, no. 1, 1948.

[59] Ennio Polidori, "RELATIONSHIP BETWEEN THE ATTERBERG," *SOILS AND FOUNDATIONS,* vol. 47, no. 5, pp. 887-896, 2007.

[60] W. Arthur White, "Atterberg plastic limits of clay minerals," *American Mineralogist,* vol. 34, no. 7, pp. 508-512, 1949.

[61] Gupta P., "Contemporizing Vernacular," *Pittsburgh: Carnegie,* 2019.

[62] UN Environment Programme, "Bulding Materials and Climate: Construction a New Future," United Nations Environment Programme, Paris, 2023.

[63] M Y Muntari, A O Windapo, "Clay as Sustainable Building Material and its Benefits for Protection in Built Environment," *IOP Conference Series: Materials Science and Engineering,* 2021.

[64] Victor N. Kaliakin, "Example Problems Related to Soil Identification and Classification," *Soil Mechanics,* pp. 51-92, 2017.

[65] Brian T.Barnes, "Atterberg Limits of," *General News, Technical,* 2021.

[66] ASTM D4318-17, "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils," ASTM International (American Society for Testing and Materials), West Conshohocken, 2018.

[67] Liam R.Wesley, Geological Origin, Mechanical Properties and Industrial Applications, New York: Nova Science Publishers, 2014.

[68] Ralph E. Grim, Hideomi Kodama, "Clay mineral: Origin," *Britannica,* 2024.

[69] Jerry Stannard, "Pliny the Elder," *Britannica,* 2024.

[70] Bruce Velde, Alain Meunier, The Origin of Clay Minerals in Soils and Weathered Rocks, 1 ed., vol. 6, Berlin, Germany: Springer, 2008, p. 320.

[71] J. A. Cecilia, C. Garcı´a-Sancho, E. Vilarrasa-Garcı´a, J. Jime´nez-Jime´nez, E. Rodriguez-Castello´n, "Synthesis, Characterization, Uses and Applications of Porous Clays Heterostructures: A Review," *The Chemical Record ,* vol. 18, no. 7, pp. 1-21, 2018.

[72] Maria Franca Brigatti, Emilio Galán, Benny K.G. Theng, "Chapter 2 Structures and Mineralogy of Clay Minerals," *Developments in Clay Science,* vol. 1, pp. 19-86, 2006.

[73] Ralph E.Grim, PROPERTIES OF CLAY, URBANA, ILLINOIS: The American Association of Petroleum Geologists, Tulsa, Oklahoma, 1939.

[74] B.Velde, Origin and Mineralogy of Clay, Springer, 1995.

[75] Emmanuel Nyankson,Richard Q. Mensah,Lucky Kumafle,William N. Gblerkpor,Shadrack O. Aboagye,Bernard O. Asimeng &Elvis K. Tiburu |Ehab AlShamaileh, "Dual application of natural clay material for decolorization and adsorption of methylene blue dye," *Cogent Chemistry,* vol. 6, no. 1, 2020.

[76] Nora K. Foley, USGS science for changing world, "Environmental Characteristics of Clays and Clay Mineral Deposits," Reston, 1999.

[77] Greg McNally, Soil and Rock Construction Materials, 1 ed., London: CRC Press, 1998, p. 416.

[78] Praise Akisanmi, "Classification of Clay Minerals," in *Mineralogy*, IntechOpen, 2022, p. 266.

[79] Neeraj Kumari, Chandra Mohan, "Basics of Clay Minerals and Their Characteristic Properties," in *Clay and Clay Minerals*, London, W1W 5PF,, IntechOpen Limited, 2021, p. 222.

[80] S.K. Haldar, Basic Mineralogy, vol. 2, Oxford, USA: Elsevier Inc., 2020, p. 341.

[81] Dr. Thair Al-Ani and Dr. Olli Sarapää, Clay and mineralogy physical-chemical properties and industrial uses, GTK Espoo, 2008.

[82] Ochieng Ombaka, "Characterization and classification of clay minerals for potential applications in Rugi Ward, Kenya," *African Journal of Environmental Science and Technology,* 2016.

[83] Yasin Erdogan, "Physicochemical Properties of Handere Clays and Their Use as a Building Material," *Journal of Chamestry,* vol. 2015, no. 1, 2015.

[84] Arnold O. Tanner, "Mineral resource of the month: vermiculite," *Earth,* vol. 59, no. 10, p. 63, 2014.

[85] P. S. Kumar, "Removal of toxic algal blooms from marine water," *Modern Treatment Strategies for Marine Pollution,* pp. 145-164, 2021.

[86] Swayze, G.A., Lowers, H.A., Benzel, W.M., Clark, R.N., Driscoll, R.L., Perlman, Z.S., Hoefen, T.M., and Dyar, M.D., "Locations of the four major historical vermiculite ore sources," *American Mineralogist, USGS science for a changing world,* vol. 103, pp. 517-549, 2018.

[87] D.G. Schulze, "Chlorites," *Encyclopedia of Soils in the Environment,* vol. 4, pp. 246-254, 2005.

[88] Geologyscience, "Chlorite," 2023. [Online]. Available: https://geologyscience.com/minerals/chlorite/.

[89] Sheldon L.Glover, Clays and shales of Washington, Olympia, Washington: STATE. PRINTING PLANT, 1941.

[90] Chin-Fu Tsang, Peter Blümling and Frederic Bernier, Lawrence Berkeley National Laboratory (LBNL, USA), Nationale Genossenschaft fur die Lagerung Radioaktiver Abfalle, European Underground Research Infrastructure for Disposal of Nuclear Waste in Clay, "Coupled hydro-mechanical processes in crystalline rock and in indurated and plastic clays: a comparative discussion," *Lawrence Berkeley National Laboratory,* 2008.

[91] Fernanda Daud Sarruf, Vecxi Judith Pereda Contreras, Renata Miliani Martinez,Valeria Robles Velasco, Prof. André Baby, "The Scenario of Clays' and Clay Minerals' Use in Cosmetics/Dermocosmetics," *Preprints,* 2023.

[92] The Indepedent Commission for Mines and Minerals, "Geology," 2010. [Online]. Available: https://www.kosovo-mining.org/resurset-minerale/gjeologjia/. [Accessed 2024].

[93] The Indepedent Commission for Mines and Minerals, "GEOLOGICAL MAP OF KOSOVO," The Indepedent Commission for Mines and Minerals, Prishtinë, Kosovo, 2008.

[94] GAP Institute, "Analiza për Sektorin e Prodhuesve të Materialit Ndërtimor me Bazë nga Argjila," GAP Institute, Prishtine, 2016.

[95] Ndërmarrja Shërbyese për Projektim dhe Matje "Inxhiniering", "Elaborati Gjeologjik i Depozitimeve Argjilore Pliocenike për M.S "Apollonia"-sh.p.k- LLazarevë- K.K.Obiliq," Ndërmarrja Shërbyese për Projektim dhe Matje "Inxhiniering", Lipjan, 2009.

[96] Refaey, Yasser, Jansen, Boris, l-Shater, Abdel-Hamid, El-Haddad, Abdel-Aziz, Kalbitz, Karsten/ Elsevier B.V, "Clay minerals of Pliocene deposits and their potential use for the purification of polluted wastewater in the Sohag area, Egypt," *Geoderma Regional,* vol. 05, pp. 215-225, 2015.

[97] Beata Jabłonska, "Optimization of Ni(II), Pb(II), and Zn(II) Ion AdsorptionConditions on Pliocene Clays from Post-Mining Wast," *Minerals,* vol. 11, p. 568, 2021.

[98] "Mineral Projekt "Prishtine, "Elaborati i Klasisfikimit, Kategorizimit te Rezervave dhe Percaktimi i Cilesise se Argjilave ne F.M.N "Perparimi" Skenderaj," "Mineral Projekt "Prishtine, Viti, 2003.

[99] Sameer Maithel, Sonal Kumar, Satyendra Rana, "Manual for Trainers, Brick Kiln Workers Skill Development," Centre for Education and Communication, New Delhi, 2018.

[100] CHwB, Traditional Architecture and Documentation Methodologies, Prishtina: Cultural Heritage Without Borders CHwB, 2010, p. 238.

[101] Riza Fazliu, "Housing Facilities Construction with Accessories and," *Proceedings of the 2nd International Conference on Literature,* pp. 116-122, 2015.

[102] Abedin Sutaj, Msheftësit e gojës, Prishine: Lena Graphic Design, 2022, p. 629.

[103] Jingying Wang, Yan Yung Edward Ng, "Post-earthquake housing recovery with traditional construction: A preliminary review," *Progress in Disaster Science,* vol. 18, 2023.

[104] Bharath B, Maheshwar Reddy L, Juberahmed Pathan, Rahul R Patel, "Studies on Stabilised Adobe Blocks," *International Journal of Research in Engineering and Technology,* vol. 03, no. 06, pp. 259-264, 2014.

[105] Gernot Mike, Building With Earth: Design and Technology of a Sustainable Architecture., vol. 4, Berlin: Birkhauser , 2022, p. 208.

[106] Paul Graham McHenry Jr., Adobe and Rammed Earth Buildings: Design and Construction, University of Arizona Pressz, 1989, p. 235.

[107] Victor N. Kaliakin, Example Problems Related to Soil Identification and Classification, Elsevier, 2017, p. 447.

[108] Technology and Action for Rural Advancement-TARA, "Green Brick Making Manual," Technology and Action for Rural Advancement, New Delhi, 2014.

[109] Anne Beamish, Will Donovan, "Village-Level Brickmaking," Deutsches Zentrum für Entwicklungstechnologien - GATE, Eschborn, 1993.

[110] National Minerals Information Center, "Iron and Steel Slag Statistics and Information," 2024. [Online]. Available: https://www.usgs.gov/centers/national-minerals-information-center/nickel-statistics-and-information.

[111] Ministry of Economic Development, "Mining strategy of the Republic of Kosovo for the period 2012-2025," Ministry of Economic Development, Prishtine, 2012.

[112] USGS science for a changing world, "Iron and Steel Slag Statistics and Information," National Minerals Information Center, 2024.

[113] Encyclopaedia Britannica, "Nickel," 2024. [Online]. Available: https://www.britannica.com/science/nickel-chemical-element.

[114] Annie Tom Chang, G.Donald Sherman, THE NICKEL CONTENT of Some Hawaiian Soils and Plants and the Relation of Nickel to Plant Growth, vol. 19, Honolulu, Hawaii: TECHNICAL BULLETIN, UNIVERSITY OF HAWAU, 1953.

[115] Tony Christie and Bob Brathwaite, "Mineral Commodity," Institute of Geological and Nuclear Sciences Ltd, 2024.

[116] Quentin Dehaine, Laurens T. Tijsseling, Hylke J. Glass, Tuomo Törmänen, Alan R. Butcher, "Geometallurgy of cobalt ores: A review," *Minerals Engineering,* vol. 160, 2021.

[117] Shuronjit Kumar Sarker, Nawshad Haque, Muhammed Bhuiyan,Warren Bruckard, Biplob Kumar Pramanik , "Recovery of strategically important critical minerals from mine tailings," *Journal of Environmental Chemical Engineering,* vol. 10, no. 3, 2022.

[118] Cobalt Institute, "Essential Cobalt," 2024. [Online]. Available: https://www.cobaltinstitute.org/essential-cobalt-2/.

[119] Wenhao Gao, Wentao Zhou, Xianjun Lyu, Xiao Liu, "Comprehensive utilization of steel slag: A review," *Powder Technology,* 2023.

[120] Maohui Li, Youjun Lu, Yajuan Liu, Jingjun Chu, Tongsheng Zhang, Wei Wang, "Influence of the Steel Slag Particle Size on the Mechanical Properties and Microstructure of Concrete," *Sustainability,* vol. 16, no. 5, p. 2083, 2024.

[121] Mugahed Amran, G. Murali, Nur Hafizah A. Khalid, Roman Fediuk, Togay Ozbakkaloglu, Yeong Huei Lee, Sani Haruna, Yee Yong Lee, "Slag uses in making an ecofriendly and sustainable concrete: A review," *Construction and Building Materials,* vol. 272, 2021.

[122] D. Shanmuga Priya, N. Sakthieswaran, O. Ganesh Babu, "Experimental study on mortar as partial replacement using sawdust powder and GGBS," *Materialstoday Proceedings,* vol. 37, pp. 1051-1055, 2021.

[123] S. O. Ehikhuenmen, E. E. Ikponmwosa, F. A. Falade, "Structural performance of sawdust ash blended steel slag aggregate concrete," *Engineering and Applied Science Letters (EASL),* vol. 4, no. 1, pp. 50-61, 2021.

[124] Faisal I. Shalabi, Ibrahim Asi, Hisham Qasrawi, "Effect of by-product Steel Slag on the Engineering Properties of Clay Soils," *Journal of King Saud University - Engineering Sciences,* vol. 29, no. 4, p. 394–399, 2017.

[125] Liang Jia, Li Zhang, Jian Guo, Kai Yao, Sin Mei Lim, Bin Li, Hui Xu, "Evaluation on Strength Properties of Lime–Slag Stabilized Loess as Pavement Base Material," *Sustainability,* vol. 11, no. 15, p. 4099, 2019.

[126] Co-Chair, FICCI Mining Committee and Chief Regulatory Affairs,Tata Steel Limited, "Slag is a co-product in circular economy, not a waste," 2018. [Online]. Available: https://blog.ficci.com/archives/8432.

[127] Gus Gunn, Critical Metals Handbook, John Wiley & Sons, 2014, p. 464.

[128] Popescu Mazela, "Solid Wood," *Performance of Bio-Based Building Materials,* pp. 22-39, 2017.

[129] Jieying Wang, Senior Scientist, Advanced Building Systems , "Guide for On-site Moisture Management of Wood Construction," FPInnovations, Vancuver, 2016.

[130] Forest Products Laboratory, Wood Handbook, Wood as an Engineering Material, Madison, Wisconsin: United States Department of Agriculture Forest Service, 2010, p. 508.

[131] EUR-Lex EU, "Commission Implementing Regulation (EU)," Publications Office of the European Union, 2013.

[132] Ministry of Agriculture, Ferestry and Rural Development, "National Forest Inventory Kosovo 2012," Prishtine, 2013.

[133] Timber Bloger, Brij, "Beech Wood Properties | Its Advantages and Disadvantages," 2024. [Online]. Available: https://www.timberblogger.com/beech-wood-properties-and-advantages-and-disadvantages/.

[134] Abraham Mwango, Chewe Kambole, "Engineering Characteristics and Potential Increased Utilisation of Sawdust Composites in Construction—A Review," *Journal of Building Construction and Planning Research,* vol. 7, pp. 59-88, 2019.

[135] Dilip Kumar,Smita Singh,Neetesh Kumar,Ashish Gupta, "Low Cost Construction Material for Concrete as Sawdust," *Global Journal of Researches in Engineering,* vol. 14, no. 4, pp. 32-35, 2014.

[136] Nural Yilgor, O. Unsal,S. Nami Kartal, "Physical, mechanical, and chemical properties of steamed beech wood," *Forest Products Journal,* vol. 51, pp. 89-93, 2001.

[137] Anna Sandak, Jakub Sandak, Marcin Brzezicki, Andreja Kutnar, Bio-based Building Skin, Singapore: Springer Nature, 2019, p. 183.

[138] Naomi Keena, Marco Raugei, Mae-ling Lokko, Mohamed Aly Etman,Vicki Achnani,Barbara K. Reck,Anna Dyson, "A life-cycle approach to Investigate the Potential of Novel Biobased Construction Materials toward a Circular Built Environment," *Energies,* vol. 15, no. 19, 2022.

[139] Lunguleasa, A., Spirchez, C., and Griu, T, "Effects and modeling of sawdust torrefaction for beech pellets," *BioResurce,* pp. 4726-4739, 2015.

[140] Monika Aniszewska, Arkadiusz Gendek, Barbora Tamelová, Jan Malaťák, Jan Velebil, Jozef Krilek, Iveta Čabalová, Reneusz Mikłaszewicz, Witold Zychowicz, Michał Drożdżek, Andrzej Mazurek, "Physico-

Mechanical and Energy Properties of Pine (Pinus sylvestris) and Beech (Fagus sylvatica) Wood from Railroad Ties," *Advances in Technology and Solutions for Wood Processing,* p. 485, 2024.

[141] Ed Perry, "Wood Ashes as a Garden Fertilizer," vol. 21305, California, Cooperative Extension, University of California, 1982.

[142] Christina Trautmann, "Wood Ash Composition and Its Density: Alternative to Sustainable Raw Material," 2023. [Online]. Available: https://materialhow.com/wood-ash-composition-density-alternative-sustainable-raw-material/.

[143] A Demeyer, J.C Voundi Nkana, M.G Verloo, "Characteristics of wood ash and influence on soil properties and nutrient uptake: an overview," vol. 77, no. 3, pp. 287-295, 2001.

[144] Ece Ezgi Teker Ercan, Lale Andreas, Andrzej Cwirzen, Karin Habermehl-Cwirzen, "Wood Ash as Sustainable Alternative Raw Material for the Production of Concrete—A Review," *Advances in Sustainable Construction and Building Materials,* vol. 16, no. 7, p. 2557, 2023.

[145] Piotr-Robert Lazik, J. Bošnjak, Ebru Çetin, A. Küçük, "Application of Wood Ash as a Substitute For Fly Ash And Investigation of Concrete Properties," *Google Scholar,* pp. 103-118, 2020.

[146] Najib Gerges, Camille A. Issa, Marc Antoun, Elias Sleiman, Fouad Hallal, Perla Shamoun, Joelle Hayek, "Eco-friendly mortar: Optimum combination of wood ash, crumb rubber, and fine crushed glass," *Case Studies in Construction Materials,* vol. 15, 2021.

[147] Ahmed Omran, Nancy Soliman,Ailing Xie,Tatyana Davidenko,Arezki Tagnit-Hamou , "Field trials with concrete incorporating biomass-fly ash," *Construction and Building Materials,* vol. 186, pp. 660-669, 2018.

[148] Hamed Gharibi, Davood Mostofinejad, Mohammad Teymouri, "Impacts of Conifer Leaves and Pine Ashes on Concrete Thermal Properties," *Construction and Building Materials,* vol. 377, 2023.

[149] Mark Risse, Julia Gaskin, "Best Management Practices for Wood Ash as Agricultural Soil Amendment," College of Agricultural and Environmental Sciences College of Family and Consumer Science, Georgia, 2013.

[150] Haimei Zhang , Air Hardening Binding Materials, 1, Ed., Woodhead Publishing, 2011, pp. 29-45.

[151] Harley J. McKee, "Introduction to Early American Masonry: Stone, Brick, Mortar, and Plaster," Columbia University, 1973.

[152] Frank Granger, "Vitruvius: On Architecture," London, W. Heinemann, ltd.; New York, G. P. Putnam's sons, London, 1931.

[153] Critical Conrete, "LIME: Everything you need to know to get started," 2023. [Online]. Available: https://criticalconcrete.com/lime-everything-you-need-to-know-to-get-started/.

[154] Abirami Manoharan, C. Umarani, "Properties of Air Lime Mortar with Bio-Additives," *Sustainability,* vol. 14, no. 14, p. 8355, 2022.

[155] Lei Zhang, Weixiao Han, "Simultaneous Investigation of Mechanical and Hygrothermal Properties of Lime Stabilized Earth Bricks," *OP Conf. Series: Earth and Environmental Science,* 2021.

[156] EuLA, "European Lime Association," 2023. [Online]. Available: https://eula.eu/.

[157] Brick Development Association, "The UK Clay Brickmaking Process," Brick Development Association, Londer, 2023.

[158] Heinrich Mueller, Dr. Soumen Maithy, Suyesh Prajapat, Anil Datta Bhatta, Bijay Lal Shrestha, "Green Brick Making Manual," Hillside Press, Kathmandu, Nepal, 2008.

[159] Association la Voûte Nubienne - AVN, "The Nubian Masonn's Manual," Association la Voûte Nubienne - AVN, 2018.

[160] BS 3921:1985, "Specification for Clay brick," British Standards Institution (BSI), London, 1998.

[161] EN 771-1:2011+A1, "Specification for masonry units - Part 1: Clay masonry units," European Committee for Standardization (CEN), Brussels, 2015.

[162] EN 772-16:2011, "Methods of test for masonry units, Part 16: Determination of dimensions," European Committee for Standardization (CEN), Brussels, 2011.

[163] Brick Development Association, "Designing to Brickwork Dimensions," Brick Development Association, London, 2023.

[164] Brick Development Association, "Designing to Brickwork Dimensions," Brick Development Association 2023, London, 2023.

[165] A. Moropoulou, Asterios Bakolas, Eleni Aggelakopoulou, "The Effects of Limestone Characteristics and Calcination Temperature on the Reactivity of Quicklime," *Cement and Concrete Research,* vol. 31, no. 4, pp. 633-639, 2001.

[166] Kaixuan Zhang, Shuhuan Wang, Chenxiao Li, Huakang Sun and Yun Zhang, "Decomposition Mechanism and Calcination Properties of Small-Sized Limestone at Steelmaking Temperature," *MDPI,* vol. 11, no. 4, 2023.

[167] The Bespoke Brick Company, "Lime bowling," 2023. [Online]. Available: https://bespokebrick.com/brick-education/lime-blowing/.

[168] Wienerberger , "Lime Bowling," 2021. [Online]. Available: https://www.wienerberger.co.uk/content/dam/wienerberger/united-kingdom/marketing/documents-magazines/technical/brick-technical-guidance-sheets/UK_MKT_DOC_Lime%20Blowing%20(REV2).pdf.

[169] Emeh Chukwuebuka, Ogbonnaya Igwe, "The combined effect of wood ash and lime on the engineering properties of expansive soils," *International Journal of Geotechnical Engineering,* vol. 10, no. 3, pp. 246-256, 2016.

[170] Bukunmi Akinwunmi, Linlin Sun, Janne T. Hirvi, Seppo Kasa, Tapani A. Pakkanen, "Influence of temperature on the swelling pressure of bentonite clay," *Chemical Physics,* vol. 516, pp. 177-181, 2019.

[171] E. L. Hansen, H. Hemmen, D. M. Fonseca, C. Coutant, K. D. Knudsen, T. S. Plivelic, D. Bonn & J. O. Fossum, "Swelling transition of a clay induced by heating," *Chemical Physics,* vol. 618, no. 2, pp. 177-181, 2012.

[172] Anuwat Srisuwan, Supachai Sompech, Chiawchan Saengthong, Sukhontip Thaomola, Prinya Chindraprasirt, Nonthaphong Phonphuak, "Preparation and properties of fired clay bricks with added wood ash," *Journal of Metals, Materials and Minerals,* vol. 30, no. 4, pp. 84-89, 2020.

[173] F.G. Bell, "Lime stabilization of clay minerals and soils," *Engineering Geology,* vol. 42, no. 4, pp. 223-237, 2019.

[174] Lun-jian CHEN, Jun HE, Jun-qi CHAO, Ben-dong QIN, "Swelling and breaking characteristics of limestone under high temperatures," *Mining Science and Technology (China),* vol. 19, no. 4, pp. 503-507, 2009.

[175] Rama Indera Kusuma, Rizki Januardi, Enden Mina, Woelandari Fathonah, Ina Asha Nurjanah, "The Influence of Clay Soil Stabilization Using Nickel Slag on Unsoaked CBR Values," *Journal of Transactions in Systems Engineering (JTSE),* vol. 2, no. 3, p. 316, 2024.

[176] Jhamir A. Llatas-Contreras & Ángel A. Ruiz-Pico, "Use of steel slag to improve the mechanical properties of subgrades in clayey soils," *Revista DYNA,* vol. 91, no. 231, pp. 128-134, 2023.

[177] EN 772-1:2011+A1, "Methods of test for masonry units - Part 1: Determination of compressive strength," European Committee for Standardization (CEN), Brussels, 2015.

[178] EN 772-13:2000, "Methods of test for masonry units - Part 13: Determination of net and gross dry density of masonry units (except for natural stone)," European Committee for Standardization (CEN), Brussels, 2000.

[179] EN 772-21:2011, "Determination of water absorption of clay and calcium silicate masonry units by cold water absorption," Komiteti Evropian për Standardizim (CEN), Brussel, 2011.

[180] EN 772-22:2018, "Determination of freeze/thaw resisitance of clay masonry units," Komiteti Evropian për Standardizim (CEN), Brussels, 2018.

[181] Eurocode 6 EN1996-1-1, "Design of masonry structures - Part 1-1: General," European Committee for Standardization (CEN), Brussels, 2005.

[182] Eurocod 6 EN1996-2, "Design of masonry structures - Part 2: Design considerations, selection of materials and execution of masonry," European Committee for Standardization (CEN), Brussels, 2006.

[183] BS EN 1052-1:1998, "Part 1: Determination of compressive strength," European Standard EN, London, 2002.

[184] EN 1015-11:2019, "Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strenth pf hardened mortar," European Organization for Standardization (CEN), Brussels, 2019.

[185] EN 998-2:2016, "Specification for mortar for masonry - Part 2: Masonry mortar," European Committee for Standardization (CEN), Brussels, 2016.

[186] BS 5628-1:1992, "Part 1: Structural use of unreinforced masnry," British Standards Institution (BSI), London, 2002.

[187] BS 5628-2:2000, "Part2:Structural use of reinforced and prestressed masonry," British Standards Institution (BSI), London, 2000.

[188] BS 5628-3:2001, "Code of practice for use masonry. Part 3: Materials and components, design and wormanship," British Standards Institution (BSI), London, 2001.

[189] The Engineering Toolbox, "Brick Densities," 2011. [Online]. Available: https://www.engineeringtoolbox.com/bricks-density-d_1777.html.

[190] ASTM C67/C67M-19, "Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile," American Association State Highway and Transportation, West Conshohocken, 2019.

[191] Controls Group, "PILOT PRO | EN Automatic Compression Testers for Cubes, Cylinders and Blocks," 2023. [Online]. Available: https://controls-group.com/product/en-automatic-compression-testers-for-cubes-cylinders-and-blocks-pilot-pro/.

[192] Na Li, Yalan Zhu, Fang Zhang, Sin Mei Lim, Wangyi Wu, Wei Wang, "Unconfined Compressive Properties of Fiber-Stabilized Coastal Cement Clay Subjected to Freeze–Thaw Cycles," *MDPI ,* vol. 9, no. 2, 2021.

[193] Anshun Zhang, Junhui Zhang, Junhui Peng, Chao Huang, Chao Zhou, "Effect of Freeze-Thaw Cycles on Mechanical Properties of an Embankment Clay: Laboratory Tests and Model Evaluations," *Landslide Hazards in Alpine Region: Mechanics and Mitigation,* vol. 10, 2022.

[194] Mengtong Liu, Hui Liu, Minqi Hua, Chunhong Chen, Xinjie Wang, Xiang Guo, Tianyu Ma, "Potential for Recycling Metakaolin/Slag-Based Geopolymer Concrete of Various Strength Levels in Freeze–Thaw Conditions," *MDPI,* vol. 17, no. 9, 2024.

[195] Valber Domingos Pinheiro, Jonas Alexandre, Gustavo de Castro Xavier, Markssuel Teixeira Marvila, Sergio Neves Monteiro, Afonso Rangel Garcez de Azevedo, "Methods for Evaluating Pozzolanic Reactivity in Calcined Clays- A Review," *MDPI, Materials,* vol. 16, no. 13, 2023.

[196] L Turanli ,F Bektas,P.J.M Monteiro, "Use of ground clay brick as a pozzolanic material to reduce the alkali–silica reaction," *Elsevier,* vol. 33, no. 10, pp. 1539-1542, 2003.

[197] NETZSCH , "Heat Flow Meter – HFM 436 Lambda," Linseis Messgeraete GmbH, 2023. [Online]. Available: https://www.strath.ac.uk/media/departments/mechanicalengineering/compositematerials/officedocuments/HFM_436_Lambda_brochure.pdf.

[198] ASTM C518-21 , "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus," ASTM International, United States, 2021.

[199] ISO 8301:1991, "Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus," ISO-International Organization of Standardization, Zwitzerland, 1991.

[200] BS EN 12667:2001, "Thermal performance of building materials and products —Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Products of high and medium thermal resistance," British Standard BSI, Dublin, 2001.

[201] Howard Harris, Structatherm Projects, "Thermal Conductivity Common Clay Masonry Material," in *Technical Note 1: Thermal Conductivity of Common Clay Masonry*, The voice of the clay brick industry, 2016, p. 4.

[202] GUNT, "WL 376 Thermal conductivity of building materials," 2024. [Online]. Available: https://gunt.de/en/products/thermal-conductivity-of-building-materials/060.37600/wl376/glct-1:pa-148:pr-1516.

[203] DIN 52612-2:1984-06, "Testing of thermal insulating materials - Determination of thermal conductivity by the plate apparatus - Test procedure and evaluation of results," German Institute for Standardisation, Berlin, 2013.

[204] H.Harris & S.Project, "Thermal Conductivity, Common Clay Masonry Material," Clay Brick Association, 2013.

[205] MAPEI, "Mape-Antique Strutturale NHL," Institut Bauen und Umwelt e.V. (IBU), Berlin, 2022.

[206] MAPEI, "Mape-Antique Strutturale NHL," Institut Bauen und Umwelt e.V. (IBU), 2016.

[207] Groundtest Equipment , "UNIFRAME Universal Testers," 2022. [Online]. Available: https://www.groundtest.co.nz/uniframe-universal-testers.html.

[208] EN 998-1:2010, "Specification for mortar for masonry - Part 1: Rendering," European Committee for Standardization (CEN), Brussels, 2016.

[209] Control Group, "High Stiffness Flexural Frame, 200 kN Cap., DUPLEX," 2015. [Online]. Available: https://controls-group.com/product/high-stiffness-flexural-frame-200-kn-cap-duplex/#contact-form.

[210] Control Group, "Automax PRO-M SMART line, Fully Automatic Control Console for Advanced Testing," 2015. [Online]. Available: https://controls-group.com/product/automax-pro-m-smart-line-fully-automatic-control-console-for-advanced-testing/.

[211] Control Group, "MCC8 Multitest," 2015. [Online]. Available: https://controls-group.com/product/additional-communication-module-for-the-connectionof-the-units-mcc8-classic-mcc8-multitest-and-advantest9-to-the-pc-it-shall-be-ordered-in-combination-with-the-pc-mod-82-p8000-pc-and-factory-instal/.

[212] Donald Askeland, Pradeep Fulay, Wendelin J. Wright, The Science & Engineering of Materials, 6. edition, Ed., CL Engineering, 2010, p. 944.

[213] The Brick Industri, "Technical Notes 3A - Brick Masonry Material Properties," 1992.

[214] Form&Test, "FORM+TEST Seidner&Co. GmbH," 2024. [Online]. Available: https://www.domagroup.eu/en/s/formtest.

[215] The Constructor building ideas, "Universal Testing Machine-Components and Function," 2021. [Online]. Available: https://theconstructor.org/practical-guide/universal-testing-machine-components-functions/2449/.

[216] Aamer Nazir, Jeng-Ywan Jeng, "Buckling behavior of additively manufactured cellular columns: Experimental and simulation validation," *Materials and Design,* vol. 186, 2020.

A. ATTACHMENT - ANNEX

A.1 Bearing capacity - Compressive strength

Attached to this part of this annex are the photos taken during the experiment, with the help of the "Bearing capacity - Compressive strength" apparatus, for testing three mini walls.

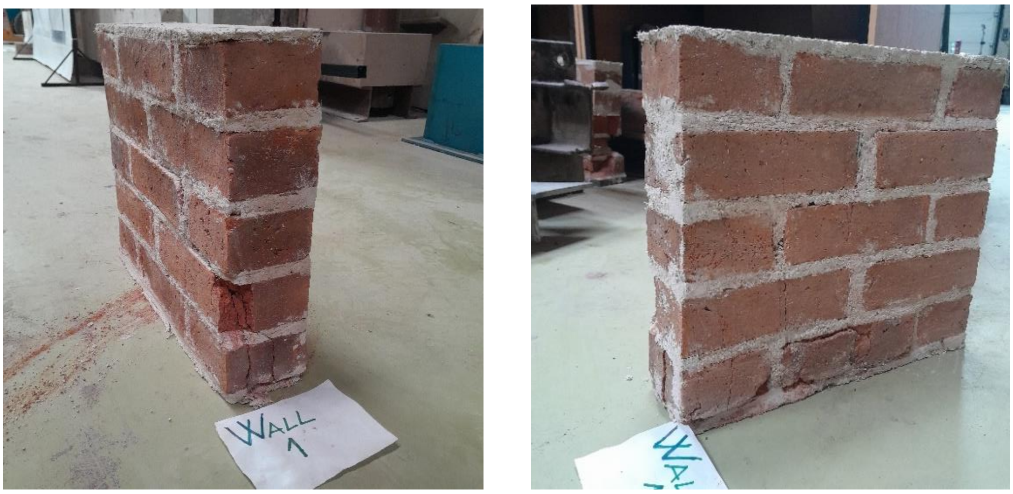


Figure 186. The mini wall "1” after testing

Figure 187. The mini wall "2” after testing

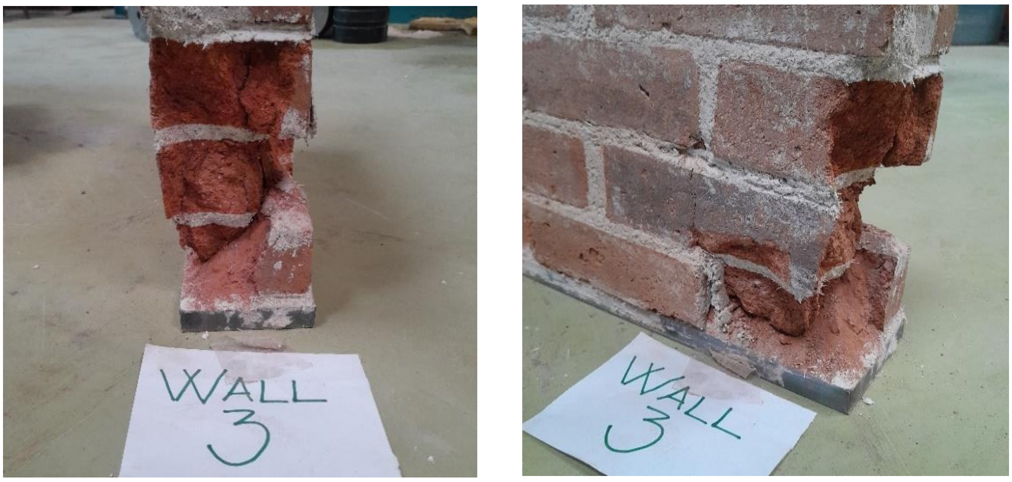


Figure 188. The mini wall "3” after testing

Kaltrina Agim Spahiu

Biography

Kaltrina Spahiu was born on February 18, 1989 in Prishtina. She completed her primary school education at the primary school: “Liria” - Obiliq, then continued her secondary education at the general secondary school, “Sami Frashëri” - Prishtina. In 2008, she began her studies at the University of Prishtina, at the Faculty of Civil Engineering and Architecture - Department of Architecture. On July 17, 2013, she defended her diploma thesis entitled “High School of Applied Arts - Research and Design”, and received the title of Bachelor of Architecture. In the academic year 2013/2014, she enrolled in post-graduate studies at the University of Prishtina, Faculty of Civil Engineering and Architecture, at the Department of Architecture. On June 9, 2016, he defended his diploma thesis entitled "Architecture and Contemporary Envelope Techniques: Art Gallery, Prishtina", and earned the academic degree Master of Technical Sciences - Architecture.
On date: 25.01.2021, he registered for PhD (doctorate) at the "Ss. Cyril and Methodius University" - Faculty of Civil Engineering - in Skopje .
Se has participated in these conferences:

- "T2P International Scientific Conference” ERASMUS+ Capacity Building Program , Mitrovica 2020.
- "9-th UBT Internacional Conference" , Conference on Business Technology and Inovation 2020 - Prishtine .
- " MASE- 19 International Symposium – Oher " Macedonian Association of Structural Engineers, 2022.
- "MASE- 20 International Symposium -Skopje" Macedonian Association of Structural Engineers, 2023.
- "Annual Conference - Skopje" Civil Engneering Faculty , Ss. CYRIL AND METHODIUS UNIVERSITY IN SKOPJE, 2022
- "Annual Conference - Skopje" Civil Engneering Faculty , Ss. CYRIL AND METHODIUS UNIVERSITY IN SKOPJE, 2023
- Annual Conference - Skopje" Civil Engneering Faculty , Ss. CYRIL AND METHODIUS UNIVERSITY IN SKOPJE, 2024
- 1-st International Conference on Architecture and Urbanism - Architectural Identity of the City - Prishtina 2022
- “International Conference on New Achievements in Science, Technology and Arts” – ICNA-STA - Prishtine 2023 .
- “12-th UBT Internacional Conference" International Conference on Architecture and Spatial Planning – Prishtina 2023.
- “5-rth International Conference on Architecture and Urban Design - SELF-SUFFICIENT CITY" – Tirana 2024.
- 3rd International Conference on IPAU 2024 – Future Frames - AI in Architecture and Urban Evolution, Prishtina .
- SUBLime Conference 2024, Towards the next generation of sustainable masonry systems: Mortars, renders, plasters and other challenges - Madeira, Portugal .
- MATEC Web Conference; eISSN: 2261-236X, 2024.
- “Training for Energy Efficient Auditors in buildings” Center for Energy and Sustainability (CEC) of the University of Prishtina, Prishtina 2024 .