BAŞKENT UNIVERSITY
INSTITUTE OF SCIENCE AND ENGINEERING
DEPARTMENT OF ARCHITECTURE
MASTER OF SCIENCE IN ARCHITECTURE

USING BIOMATERIALS IN ARCHITECTURAL DESIGN: EXPLORING THE UPCYCLING POTENTIAL OF NUTSHELLS TO BE USED AS AN ELASTOMER MATERIAL IN FLOATING FLOOR SYSTEM

BY

ELİF DENİZ HABERAL

MASTER OF SCIENCE

ANKARA – 2023

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ELİF DENİZ HABERAL

MASTER OF SCIENCE

ADVISOR

DOC. DR. AYSU SAGUN KENTEL

ANKARA – 2023

BAŞKENT UNIVERSITY

INSTITUTE OF SCIENCE AND ENGINEERING

This study, which was prepared by ELİF DENİZ HABERAL, for the program of ARCHITECTURE, has been approved in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in the Architecture Department by the following committee.

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Examining Committee Members	**Signature**
Prof. Dr. Cüneyt KURTAY, Baskent University (Moderator)	....
Prof. Dr. İdil AYÇAM, Gazi University (Member)	....
Doc. Dr. Aysu SAGUN KENTEL, Baskent University (Advisor)	....

APPROVAL

Prof. Dr. Faruk ELALDI

Institute of Science

Date: ... / ... / ....

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Student Name/Surname: Elif Deniz HABERAL

Student Number: 22010173

Department: Architecture

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Advisor's Title/Name/Surname: Doc. Dr. Aysu SAGUN KENTEL

Thesis Headline: Using Biomaterials In Architectural Design: Exploring The Upcycling Potential Of Nutshells To Be Used As An Elastomer Material In Floating Floor System

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Doc. Dr. Aysu SAGUN KENTEL

……………………………………..

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ABSTRACT

Elif Deniz HABERAL

USING BIOMATERIALS IN ARCHITECTURAL DESIGN: EXPLORING THE UPCYCLING POTENTIAL OF NUTSHELLS TO BE USED AS AN ELASTOMER MATERIAL IN FLOATING FLOOR SYSTEM

Baskent University Institute of Science
Architecture Department 2023

In recent years, the field of architecture has witnessed a growing interest in sustainable design practices using biomaterials and living materials. This thesis investigates the untapped potential of walnut shells as a viable biomaterial and proposes their upcycling as waste material in architectural design. Walnut shells, often discarded as agricultural waste, have unique properties that make them an intriguing alternative for sustainable construction. Walnut shells can offer significant advantages in architectural applications by using their natural structural strength, thermal insulation properties and natural aesthetics.

This thesis discusses the potential of combining walnut shells with other biomaterials to create composite materials with improved performance properties. Within the scope of the experiments, it is aimed to produce an elastomer biomaterial using a powder material obtained from walnut shells and use it in floating flooring system. While the aim is to produce a material that will absorb the vibration caused by sound and impact between the boards in floating floor construction, it is also aimed to emphasize the importance of increasing the use of more environmentally friendly and sustainable solutions in the construction sector with materials converted from waste. The results of the laboratory tests revealed that further experimental research is needed to improve the structure, elasticity and sound absorption properties of the material produced within the scope of this thesis study.

This thesis also presents a discussion on the environmental and social benefits of using nut shells as biomaterials in architectural design. By repurposing this abundant waste source found in our country, architects and designers can contribute to reducing the environmental impact associated with traditional building materials, promote circular economy principles, and support local economies.

KEYWORDS: Biomaterial, upcycling, nutshell, food waste, waste management.

ÖZET

Elif Deniz HABERAL

MİMARİ TASARIMDA BİYOMATERYALLERİN KULLANIMI: CEVİZ KABUKLARININ YÜZER DÖŞEME SİSTEMİNDE ELASTOMER MALZEME OLARAK KULLANILARAK İLERİ DÖNÜŞÜM POTANSİYELİNİN ARAŞTIRILMASI

Başkent Üniversitesi Fen Bilimleri Enstitüsü

Mimarlık Anabilim Dalı 2023

Son yıllarda mimarlık alanı, biyomalzemeler ve canlı malzemeler kullanan sürdürülebilir tasarım uygulamalarına yönelik artan bir ilgiye tanık olmuştur. Bu tez, ceviz kabuklarının biyomalzeme olarak kullanılma potansiyelini araştırmakta ve mimari tasarımda atık malzeme olarak ileri dönüşümünü önermektedir. Genellikle tarımsal atık olarak kabul edilen ceviz kabukları, sürdürülebilir inşaat için ilgi çekici bir alternatif oluşturabilecek özelliklere sahiptir. Ceviz kabuklarının, doğal yapısal mukavemeti, ısı yalıtım özellikleri ve doğal estetiği kullanılarak mimari uygulamalarda önemli avantajlar elde edilebilir.

Bu tezde, ceviz kabuklarının diğer biyomalzemelerle birleştirilerek performans özellikleri iyileştirilmiş kompozit malzemeler geliştirme potansiyeli tartışılmaktadır. Deneyler kapsamında ceviz kabuklarından elde edilen toz ile yüzer döşeme sisteminde kullanılmak üzere elastomer bir biyomalzeme üretilmesi hedeflenmektedir. Çalışmada yüzer döşeme sistemlerindeki levhalar arasında ses ve darbe kaynaklı titreşimi emebilecek malzeme üretilmesi hedeflenirken, aynı zamanda atıklardan dönüştürülen malzeme geliştirilerek inşaat sektöründe daha çevreci ve sürdürülebilir çözümlerin üretilmesi için araştırmaların artırılmasının önemi de vurgulanmıştır. Laboratuvar testlerinin sonuçları, bu tez çalışması kapsamında üretilen malzemenin yapısının, elastik ve ses emme açısından iyileştirilmesi için daha fazla deneysel araştırmaya ihtiyaç olduğunu ortaya koymuştur.

Aynı zamanda tezde, kuruyemiş kabuklarının mimari tasarımda biyomalzeme olarak kullanılmasının çevresel ve sosyal faydaları üzerine bir tartışma sunulmaktadır. Mimarlar ve tasarımcılar, ülkemizde bolca bulunan bu atık kaynağını yeniden değerlendirerek geleneksel yapı malzemeleriyle ilişkili çevresel etkilerin azaltılmasına katkıda bulunabilir, döngüsel ekonomi ilkelerini teşvik edebilir ve yerel ekonomileri destekleyebilirler.

ANAHTAR KELIMELER: Biyomateryal, ileri dönüşüm, ceviz kabuğu, gıda atıkları, atık yönetimi.

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	Celcius
ml	Mililitre
cm	Centimetre
min.	Minutes
tsp	Teaspoon (1 Teaspoon = 2.36 gram)
μm	Micrometer or Micron

1. INTRODUCTION

In recent years, sustainable design practices have gained significant traction in the field of architecture, with a particular emphasis on the utilization of biomaterials and living materials. This emerging trend aims to create environmentally friendly structures that minimize the negative impact of construction on our planet. One promising area within this realm of sustainable architecture is the exploration of nutshells as a viable biomaterial for upcycling, offering new possibilities for architectural design.

Nutshells, often overlooked and discarded as agricultural waste, possess unique properties that make them an intriguing alternative for sustainable construction. These seemingly insignificant remnants from the food industry have caught the attention of architects and designers due to their inherent structural strength, thermal insulation properties, and natural aesthetics. The inherent qualities of nutshells open up a world of architectural possibilities, paving the way for innovative applications that capitalize on their advantageous attributes.

This thesis delves into the potential of upcycling nutshells as a viable biomaterial to be used with some other biomaterials like gelatin or seaweed aka agar agar and creation an elastomer rubber-like material to absorbing sound in architectural design, shedding light on their diverse applications and benefits. Through a comprehensive exploration of existing case studies, it showcases successful integration of nutshells into various building elements, such as façade cladding, interior wall panels, and furniture design. These examples not only demonstrate the versatility of nutshells but also serve as inspiration for architects seeking sustainable alternatives in their projects.

Moreover, the thesis explores the potential of combining nutshells with other biomaterials to create composite materials with enhanced performance characteristics. By blending nutshells with compatible materials, architects and designers can create innovative composites that offer improved properties such as strength, durability, and insulation. This approach paves the way for the development of biomaterials tailored to meet the specific requirements of architectural applications.

In addition to the technical aspects, the thesis also addresses the environmental and social benefits associated with the utilization of nutshells as biomaterials in architectural design. By repurposing this abundant waste resource, architects and designers can contribute to the reduction of environmental impact caused by traditional building materials. Furthermore, the use of nutshells aligns with circular economy principles by transforming discarded agricultural waste into valuable resources. This sustainable approach not only minimizes waste but also supports local economies by utilizing locally available materials and promoting regional industries.

In summary, this thesis aims to delve into the potential of upcycling nutshells as a viable biomaterial for sound insulation in sustainable architectural design. By harnessing their inherent properties and exploring their diverse applications, architects and designers can contribute to the development of environmentally friendly buildings. Additionally, by incorporating nutshells into their projects, they can promote circular economy principles, reduce waste, and support local economies. Through this exploration, nutshells emerge as an exciting avenue for sustainable construction, offering promising solutions in the quest for greener and more sustainable architectural practices.

In this thesis, aims and objectives of the research, research questions and methodology are explained below in the first chapter. In the second chapter environmental problems caused by building design, importance of integrating sustainable materials, waste management and circularity in architectural design are demonstrated with examples. Then biomaterials and their benefit in architectural design, the relation that they have with the Sustainability Goals and problems that can be occur while using biomaterials are explained in the following chapter. In the fourth chapter, Walnut Shell Upcycling will be explained by discussing the basic features of walnut shells. In the last chapter, the thesis will discuss material production experiments in accordance with the targeted purposes, the results of these experiments and tests, and the issues that can be improved with the tests.

1.1. Aim and Objectives of the Research

As a result of the initial research on sustainable architectural design, it has been determined that the increasing resource consumption and waste generation have vital negative effects on sustainability of nature, social life, and economies. Solution alternatives to this problem were investigated and it was determined that biomaterials have been used as alternative materials in recent building design and construction as well as they are used in other disciplines. In the light of this new approach in sustainable design, biomaterials associated with the field of architecture were explored in more detail. While the use of biomaterials is common in the field of design, applications in the field of architecture have increased in recent years. It is an emerging field of study and there are many gaps in the literature on use of biomaterials in architecture. The main reason for this can be the lack of time and financial support needed to conduct tests on performance and durability of proposed biomaterials, and the need to comply with standardized test methods and results. In addition, the lack of sufficient information on how biomaterials will behave over time and the scarcity of evaluations about their life cycles also create a question mark about their use in the field of architecture. Biomaterials that are in development for architectural design, but difficult to integrate into construction methods, have not yet been documented in terms of compliance with building codes and are therefore not commonly used. Finally, there are deficiencies in the use of biomaterials aesthetically in architecture. In this regard, studies on color, texture and similar subjects are ongoing. Studies on biomaterials with the collaboration of many disciplines reveal important innovative and sustainable solutions in terms of increasing their applicability and improving biomaterials. Within this context, this research study aimed to understand and explore;

- the recent approaches in use of biomaterials in architectural design to support waste management,
- types of bio-wastes produced in Turkiye
- the potential of upcycling nutshells as bio-wastes to produce a biomaterial that will be used as an elastomer rubber-like material for floating floor construction in architectural design.

In order to achieve the aims stated above, the study is conducted with the following objectives:

- To make an extensive literature review to explore the impacts of resource consumption and waste generation in architectural design on sustainability,
- To make an extensive literature review on the nature and types of biomaterials that are used in architectural design,
- To make research on bio-wastes in Turkiye that can be upcycled to produce a biodegradable alternative material,
- To produce an alternative biomaterial with nutshells which are the most produced bio-waste(s) in Turkiye and test them for their potential in use for physical environmental control such as heat, sound, and fire insulation in architectural design as a case study.

1.2. Research Questions

During this research study the following research questions were identified based on the aims and objectives stated above:

- Do biomaterials have potential in decreasing resource consumption and waste generation in architecture?
- What are the potentials of use of biomaterials in architectural design to support sustainable architecture?
- Can upcycling biomaterials create alternative building materials that can improve physical environmental control?

1.3. Methodology

In this thesis study, an extensive literature review and experimental study research methods were used. The use of biomaterials in the field of architecture and recent research and case studies about biomaterials have been searched in the literature. The study has also aimed to produce and propose an alternative biomaterial material as an alternative to the traditional architectural materials by conducting an experimental study focused on upcycling shells of nuts, which are considered as bio-wastes.

For literature review, Google Scholar, JSTOR, Scopus and Web of Science databases are mainly used. Articles, theses, and books that are focused on research on biomaterials and the use of these materials in the design sector, especially architecture and the built environment, are explored. By the light of these resources, information about how biomaterials have been used and their potential for future were investigated. During this research, the search operation was conducted focusing on architectural design by using the keywords: *biomaterial, upcycling, nut shells, food waste* and *waste management*. However, relevant research on chemistry, biology, and other design-based areas were also examined, as the subject concerns several different fields.

The experiment stage of the research study was influenced by the Summer School of 2022 at Aalto University which was focused on “Nordic Biomaterials” and integrating biomaterials in design fields. The experiments were designed based on the methodology of the experiments found in the Cookbook of Aalto University ChemArts community. Also, the selection of materials, methods used in experimental setups, and the findings obtained in experiments carried out in these summer schools shed light to the development of the experiments conducted in this research. It was determined based on the findings obtained in the literature research that this material is difficult to use as a structural material in terms of its usage area. However, it was aimed to be durable in terms of heat, moisture, and elasticity and to be used as an elastomer rubber-like material for sound insulation. At this point, research on the durability of walnuts was used.

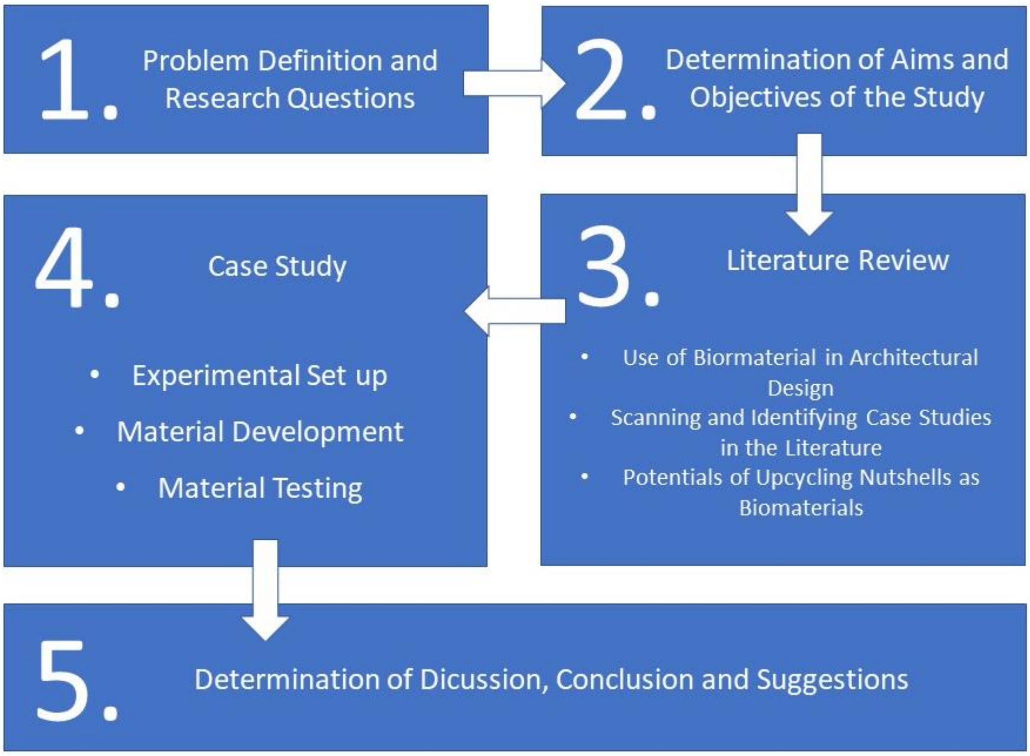


Figure 1.1. Methodology of thesis.

2. SUSTAINABLE ARCHITECTURAL DESIGN

Our present, past, and future are interconnected. As our generation is experiencing the effects of the past today, future generations will also experience the effects of today in the future. In a world where technology is developing rapidly, and renewable and non-renewable resources are decreasing day by day, economic investments have become consumer-based, and human has now focused on sustainability to ensure that human needs are met today as well as in the future, in order to protect and to provide a balanced order for both current and future generations. Sustainability basically aims to present a system that meets the needs of the present by providing an economic, environmental, and social balance, without compromising the needs of future generations [1]. According to the definition of the Cambridge Dictionary of Sustainability is;

> “ The quality of being able to continue over a period of time,
> the quality of causing little or no damage to
> the environment and therefore able to continue for a long time.”

Within this context, important objectives of sustainable approaches can be summarized as preventing the exploitation of resources, determining the direction of investments and technological developments, and supporting productive change for future.

Although the concept of sustainability came to the fore at the end of the 20th century, the idea underlying this concept dates to earlier times. Environmental concerns such as pollution, deforestation and, most importantly, depletion of resources are important in the emergence of this concept. In “The Limits to Growth" published in 1972, it was mentioned that a balanced approach is needed in the limited nature of resources. In 1972, the importance of this issue was emphasized at The United Nations Conference on the Human Environment and similar global meetings [2]. Environmental movements began to rise during this period. The efforts of governments, international organizations and academic institutions have demonstrated the need for a holistic approach and led to the emergence of sustainability as a guiding principle for addressing global problems and ensuring long-term prosperity [3]. The concept of sustainability, which came to the fore with the publication of the Brundtland Report in 1987, was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2]. This report aims to draw attention to the importance of ensuring a balance among economy, environment, and social life for long-term welfare. This concept, which has spread over time after this report, has become a central concept not only in the environment but also in many different fields. Various studies on sustainability have been conducted in various sectors over time. The sustainability concept which basically explores ways to achieve the balance among energy, source and material production and consumption; functionality and flexibility; and life cycle and durability also gained importance in the field of design and architecture in time.

Social, economic, political, and scientific events, developments and changes in the world can cause new environmental problems that require strategic planning. As technology and science advance in the world, many new business lines emerge and existing sectors develop and grow, however, in some cases, some of these new developments cause unintended or unexpected environmental problems. The construction sector, which is one of the most apparent sectors that is developing and producing innovative solutions every day, has been shown as the root of many environmental problems. Concepts such as "green", "ecological" and "environmentalist" have emerged in the construction sector to emphasize that designs should be made considering the sustainability of natural environment [1]. In addition to these concepts that emerged in the 1970s, "low energy", "solar", "passive systems" and similar concepts emerged due to living in an energy-based world and natural resources being an important source of energy [2]. Advanced research is vital on these concepts to emphasize and protect the importance of the natural environment and resources necessary for living.

2.1. Environmental Problems Caused by the Building Design and Construction Sector

Critical environmental problems such as climate change and the depletion of natural resources are forcing humanity to take some serious cautions and make radical changes, especially in the building sector [3]. The construction sector plays an important role in being responsible for the majority of resource and energy use, CO2 emissions and waste generation among industrial sectors [2]. As innovative solutions are developed in how the built environment is designed and shaped, new perspectives should also be developed on how the built environment is constructed. The approaches that prefer to use reusable, nature-friendly, bio-based and/or sustainable materials when designing buildings, can increase the use of renewable energy sources saving extinction of non-renewable resources such as fossils [1].

Basic environmental problems that are caused by the construction sector are summarized in Table1.

Table 2.1. Examples of basic environmental problems caused by the construction sector.

Environmental problem	**Definition**	**Negative Impacts on Human and/or Nature**	**Example(s) that can cause the problem**
Global warning	With the accumulation of greenhouse gases in the atmosphere, the radiation is trapped in earth increasing the temperature on earth and causing changes on climate.	• temperatures rise • climate change • disruption on agricultural systems • food shortages • melting glaciers • sea level rise • risk of coastal flooding • natural disasters (e.g. hurricanes, fires and droughts) • extinction of many plant and animal species • changes in migration routes	Increased transportation in built environment planning Increased transportation for transferring construction materials Removal/demolition of construction wastes Lack of green spaces Industrial emissions Urban sprawl Energy-inefficient buildings Deficient waste management
Pollution	It is the situation of air, water, and soil pollution in a way that harms biodiversity and the environment. The natural environment is in danger due to the pollutants released as a result of fossil fuels, industrial wastes and other human activities.	• problems in human health (e.g., respiratory problems and cardiovascular diseases) • water pollution, • loss of plant and animal species by damaging biodiversity and ecosystems, • disrupting the balance of nature, • soil pollution.	Improper waste disposal, Urban runoff, Industrial emissions, Agricultural runoff, Construction activities, Demolition waste, Vehicle emissions, Chemical spills and leaks, Mining activities,…
Thinning of the Ozone Layer	As a result of the thinning of this layer, which protects the Earth from UV rays, many substances diffuse into the atmosphere. This causes the risk of cancer in humans mainly. Also, problems with people's immune systems and inefficiency of crops are caused by	• thinning of the ozone layer • increasing the risk of skin cancer and cataracts, • weakening of the immune system increase, • harming the ecosystems and biodiversity, • causing climate change.	Building insulation materials, Solvent and cleaning agents, Air conditioning and heat pump systems, Insulation blowing agents, Foam insulation materials, Fire suppression systems,…

	degradation of the ozone layer.		
Water Pollution	Pollution of water, which is a basic need, is very important not only for humans but also for the life of animals and plants. It is getting harder and harder to access clean water resources around the world. 1/3 of the population cannot reach clean water resources and many different diseases occur due to the use of dirty water. As population growth continues and waste and pollution increase, the cleanliness of water resources will be compromised, and their quality will deteriorate.	• water pollution, • causing cholera, dysentery, and gastrointestinal diseases, • damaging aquatic ecosystems, • causing loss of biodiversity, • indirectly causing soil pollution.	Industrial discharges, Stormwater runoff, Sewage and wastewater, Agriculture runoff, Improper waste disposal, Construction activities, Oil and fuel spills, Landfills and waste disposal sites, Sewer system overflows,…
Resource Consumption	Resources are divided into two renewable and non-renewable resources. Non-renewable resources are doomed to run out over time. The excessive use of renewable resources puts them at risk. The imbalance between production time and consumption time threatens the existence of resources by causing excessive use.	• overuse of natural resources, • environmental degradation and habitat destruction, • deforestation, • resulting climate change, • causing increased costs and affects the economy, • generating large amounts of waste and pollution.	Energy intensive buildings, Urban sprawl, Excessive water use, Concrete and steel production, Single-use and disposable items, Land development and deforestation, Waste generation, Water infrastructure, Land use changes,…
Deforestation	The unconscious cutting of forest lands endangers many plant and animal species. While their natural life is being destroyed, global warming and pollution are increasing.	• deforestation, • causing loss of livelihoods for communities that depend on forests, • disrupting water cycles, • causing droughts and floods, • causing climate change by increased carbon, • loss of many ecosystems and threatens plant and animal life,	Clearing land for agriculture, Logging and timber extraction, Infrastructure development, Urbanization and human settlements, Industrial activities, Forest fires, Population growth and urban expansion, Road construction,…

		• disrupting the ecological balance in increasing soil erosion and decreasing soil fertility.	
Soil Degradation	Urbanization is one of the main causes of soil degradation. With the collapse of forest and agricultural areas, the soil loses its quality and becomes polluted. This increases the risk of flooding and reduces natural habitats.	• soil degradation • causing hunger, • worsening of the economy, especially in agriculture-dependent societies, • causing pollution of water channels • destroying habitats by causing a decrease in biodiversity, • increasing carbon emissions, • causing climate change.	Unsustainable agriculture practices, Overgrazing, Land pollution, Deforestation, Construction and urbanization, Improper land management and land-use change, Soil erosion due to water and wind, Soil compaction, Soil salinization, Acid rain deposition,…
Waste Production	Increasing waste is an important environmental problem. The fact that the wastes are made of insoluble materials or burned when they cannot be stored leave toxic residues and cause air, water, and soil pollution.	• causing air, water and soil pollution, • leading to the emergence of many diseases, • releasing of harmful chemicals and greenhouse gases to the atmosphere, • consuming natural resources, • causing permanent pollution and endanger animal life.	Industrial activities, Population growth, Construction and demolition, Landfills and waste disposal practices, Consumerism and disposal culture, Packaging waste, Electronic waste, Food waste, Infrastructure and building waste, Transportation-related waste, Plastic pollution, Single-use and disposable items,…
The Extinction of Flora and Fauna	Issues such as extinction of species and decrease in diversity are caused by the shrinking and harmful habitats of animals and plants due to pollution and construction.	• disrupting ecosystems and loss of flora and fauna, • causing a decrease in resources such as food, medicine, and raw materials, • causing extinction of pollinators such	Habitat loss and fragmentation, Pollution, Climate change, Invasive species, Overexploitation and illegal wildlife trade,

		as bees and butterflies, • threating agricultural, • causing disruption of the food chain, • causing the loss of the habitats of the species, leaving the natural life in danger in the long term.	Fragmented landscape and barrier effects, Loss of genetic diversity, Light and noise pollution, Unsustainable fishing practices, Pesticide use,…
Population Increase	The increasing human population also causes an increase in waste, structurization, pollution and resource consumption. Therefore, it harms the environment.	• making it difficult to use limited resources, • causing increased competition for food, water, and energy, • causing urbanization and is responsible for habitat loss and destruction of natural areas,	Urbanization, Infrastructure development, Economic development, Natural resource availability, Government policies and incentives, Availability of housing, Job opportunities, Migration and refugee movements, Lack of education and research centers, Lack of social services and amenities, Improved infrastructure,…

Moreover, the construction sector causes the most waste generation in the world after the food sector. Especially when the solid waste issue is taken into consideration, 10-15% of the solid waste in the world occurs during the construction and demolition of the buildings. As the awareness on ecological issues is increasing, the process of recycling, which is one of the basic approaches in waste management, is being integrated into architectural design solutions as well as daily routines in human life [3]. Considering the United Nations Sustainable Development Goals regarding materials, it replaces existing materials, systems, and applications with alternatives in terms of consumption, enabling habits to evolve into more sustainable forms [4].

2.2. Importance of Using Sustainable Materials in Architectural Design and Sustainable Development Goals

The increasing population in the world has brought the problem of uncontrolled resource consumption together with the increasing energy and resource needs. This has shown its effects in many areas, especially in environmental problems, economy, and social life. In order to increase the production speed, increasing prices and artificial solutions resulting from human interventions on nature have neither been enough to fulfill the needs and requirements of increased populations, nor have they ensured that the world continues to live unharmed [5]. The increase in needs and requirements of increased populations has revealed mass production. As a result, the use of artificially mixed or artificially produced materials has increased in order to lower the increasing prices to a reasonable scale. In addition to this huge consumption of natural resources, development and increase in use of many artificial products that harm the nature and the world have also been observed such as increase in the use of plastic and the use of fossil fuel [5].

Plastic has become a widely used material in many areas because it is easy to shape, durable, light, and affordable compared to many other materials. However, researchers have proven in many ways that the trait that is accepted and taken as resilience actually harms the world over the years. Plastic, which cannot disappear from nature, remaining intact, pollutes the environment. Not only water, air, and soil, but also human health is under threat due to microplastics [1]. In recent years, as a result of the increase in social awareness on problems raising from the increase in the production and use of plastic and similar materials for a long time, it has been understood that the production of plastic waste needs to be reduced.

Other examples for harmful substances that harm the environment and human health are the use of fossil fuels in terms of energy use, asbestos-based construction materials, heavy metals, solvents, and pesticides, which are widely used in the construction industry. It is known that these materials cause harm to the environment not only during their production and consumption, but also in their entire life cycle. Storing and incineration of end-of-life materials as waste is just as important as the damage that occurs during their production. When these materials are stored as waste, they are interfused with water, soil and even air, threatening both the ecosystem and human health [6]. Burning does not offer a good solution either since the resulting gases and chemicals are also harmful to the natural environment and health of human. As a result of the efforts to search for conscious and effective solutions to overcome these environmental problems, all branches of engineering, environmental and social science disciplines have been developing, implementing, and investing for various environmentally friendly, ecological solutions under the concept of sustainability [5].

In recent years, climate change and resource shortages lead to an increase in the development of variety of new products used as building materials. The continuation of overuse of raw materials can cause a major consumption crisis in the world. Therefore, there is an urgent need to evolve the lifestyles of human populations according to the changing circumstances in nature, social life, and economy. There is a need to decrease consumption and use of raw materials as precautions for the future since the need for materials for the continuation of human life will never end [7]. For instance, developing more sustainable alternative materials, systems, and consumption habits, and replacing them with the existing ones with new innovative ideas, collaborations and research can support the change needed.

2.3. Waste Management and Circularity in Architectural Design

Circularity, which is emerged in the 1970s, describes economic, technical, and environmental systems that aim to eliminate waste and maximize the reuse of resources. In other words, it can be explained as the maximum level of reuse or recycling in economic, technical, and environmental systems without producing waste. It is an industrial system that is restorative or regenerative by intent and design. The degradation of nature and the destruction/change of most of the ecosystems leave irreversible effects on the world. In the circular economy, something does not expire, it is restored. For instance, it is important that the energy used is renewable and reuse is the focus in the energy systems. For this reason, any factor that will prevent reuse is tried to be eliminated in order to prevent waste generation [31]. Moreover, the design phase of materials, products and systems have the most superior / good / favorable characteristics that will enable reuse. Only 9% of the world is included in the circular economy, which shows us that there is an urgent need for progress that employs circular economy for the future of our world [8].

A circular economy can be considered as a restorative, regenerative and transformative industrial system. The prioritization of the environmental economy and the transition to the circular economy can be achieved as a result of a systemic change, which raises many questions about how it will be implemented in practice. In practice, circular economy concept makes use of many principles. These principles have emerged from the initial approach of 3R concepts (Reduce, Reuse Recycle), which aim to minimize waste and to conserve natural resources [8]. The most desirable approach, the concept of reduce is effective especially in the design phase, minimizing the amount of the materials, time and money used. Reuse aims to find ways to use the products again and again without any additional process. In this approach, the product being used does not change, but its purpose of use or the area of use can change. For implementation of this concept, the products that are being used need to be durable, or at least repairable. Last R, recycle, refers to conversion of waste products to another product. In this case, the end product will be a new product produced via specific processes such as burning, melting, and shredding. All three approaches can reduce the negative impact of production and consumption on sustainability because they help to conserve natural resources and also reduce the amount of waste that can be generated. In this way, they help to eliminate the harm and pollution that can be caused by toxic waste. Moreover, these approaches are also cost saving in terms of time, money, and effort [31].

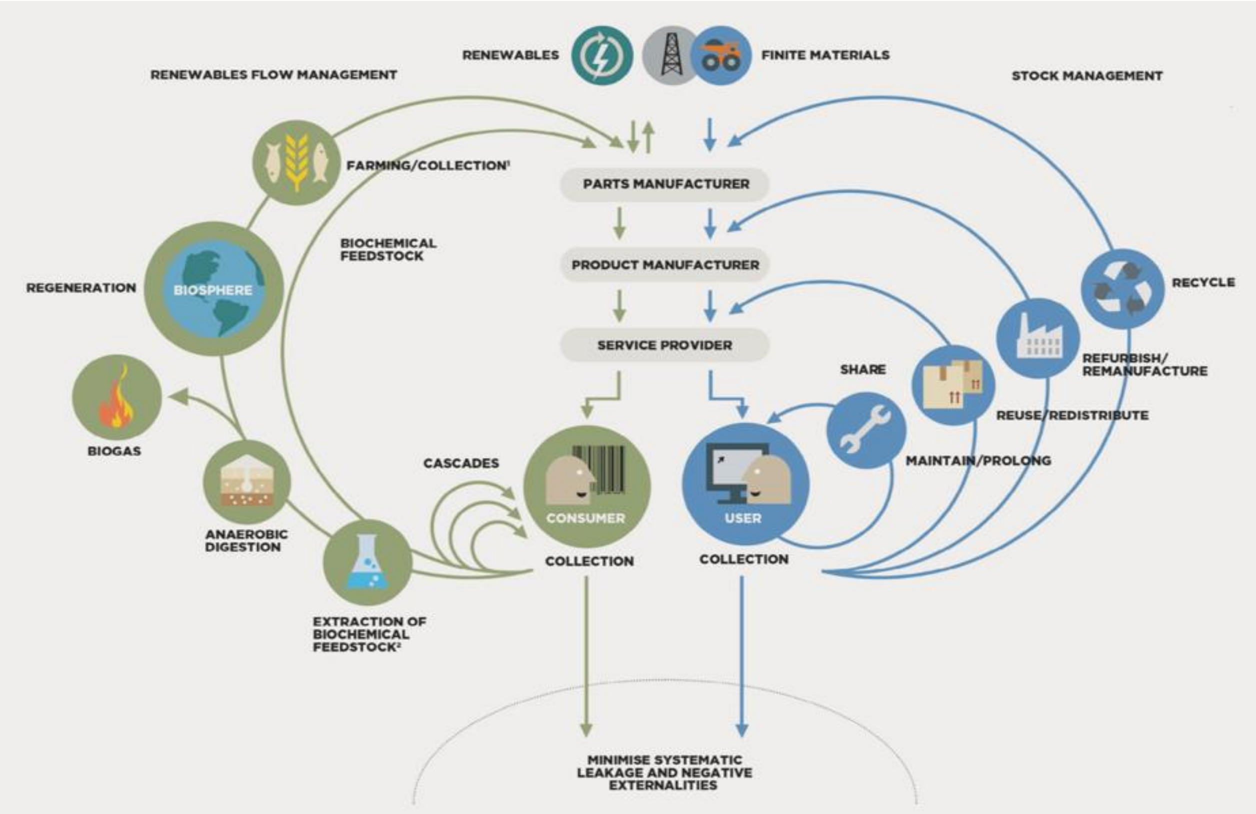


Figure 2.1. Renewable and Finite Sources' Cycle [8].

With the increase in awareness on sustainable design, 3R approaches are improved further with more comprehensive solutions that can enhance circularity, defining 10R (Refuse, Reduce, Renew, Reuse, Repair, Refurbish, Remanufacture, Re-purpose, Recycle and Recover) concepts [8]. Table 2 explains the scope of the 10R model with examples from the built environment in more detail.

Table 2.2. Explanation of 10R [8].

Concept	Definition	Example
Refuse	To prevent the use of raw materials,	Preventing the use of harmful materials in the design of a product or space
Reduce	Reducing the use of raw materials,	Implementing energy efficient lighting systems and motion sensors to control lights automatically.
Renew	Redesign within the scope of circularity,	Installing systems into building design to use renewable energy sources like solar panels.
Re-use	To use repeatedly,	Incorporating reclaimed materials like wood flooring into the construction of a new building.
Repair	To repair and extend the period of use,	Design buildings with modular components to replace or repair them when it is necessary.
Refurbish	To re-enactment,	Renovating an old building with modern infrastructure without changing its character and cultural value.
Remanufacture	To produce a new product from a second-hand product,	Using recycled steel in the construction of a new building.
Re-purpose	To use a product in a new function,	Converting an old shipping container and creating flexible and adaptable space.
Recycle	To transform and evaluate the material,	Recycling building materials like glass, concrete, metal, vs. Collect those materials and use them to make new products.
Recover	To get back the use of something	Installing rainwater harvesting systems.

The implementations of 3R and then 10R concepts, which are initiated and mostly used in product design, have started to spread to other disciplines in time. Although they have not been fully implemented in the design and construction of the built environment yet, they have become significantly popular. The adaptation of 3R and 10R approaches to building design is still being studied, pioneering the development of many design strategies. Examples of these are design for reuse, design for biomaterials and biodegradable materials, design with waste recycling, and adaptive design. Some examples for use of the 3R concept in architecture are explained below:

Biobased Facade, LINQ. This design is an example for Reduce approach in building design approach. This project conducted in 2018, includes covering the exterior of an apartment complex with smart technology [8]. A passive energy system can be integrated in building design where the temperatures are high in regions with hot and arid climates. In this design example, the building system includes double-glazed windows with a matte cladding, highly insulated walls made of bio-foam, the choice of pale reflective colors on the exterior, and most importantly the use of a 15 degree inclined cladding material for the south façade wall cladding. Use of passive and natural methods that use natural cooling and insulation features with green facades to reduce the temperature's effect on the building, has ensured minimal energy use.

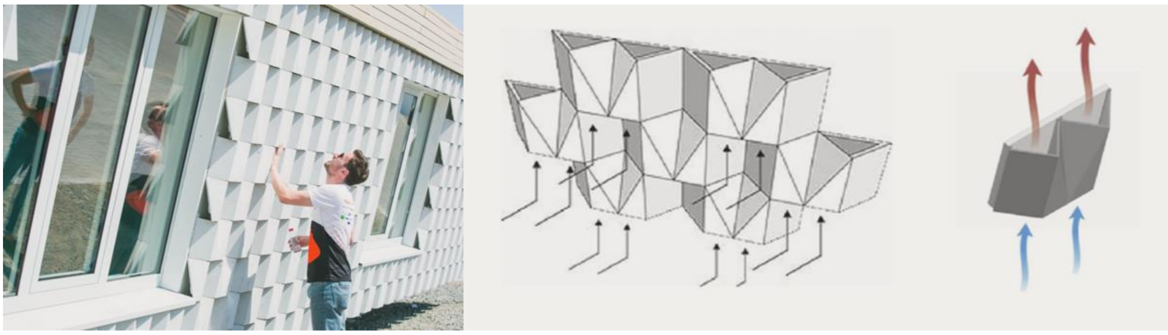


Figure 2.2. Biobased Façade, LINQ [8].

Biopartner 5. As an example, for Re-use approach in building design, built in 2021, is in the Leiden Bio Science Park. It is a layered laboratory building in which existing materials were used in the construction of the building [8]. A removable concrete hollow slab was placed on top of the existing steel structure of a nearby university building to create a flexible structure. In the construction of the green facade, the rubble from the building was used as a material source. The rainwater collected in the courtyard garden of the building was used to irrigate these plants. In order to increase the interaction with the natural environment the plants around the building are continued on the façade of the building. Second-hand items such as stone flooring, sanitary ware, carpets, and furniture made of reclaimed wood were used in the interior, to extend the concept of reuse concept applied in the structure to the interior design.

Figure 2.3. Biopartner 5 [8].

BlueCity Offices Project. This project as an example for Recycle approach in building design, is designed using 90% recycled materials. This circular building has a Lego-like structure. It has adjustable flexibility which enables reuse of materials and elements in the building. In this office building, the use of local recycled materials and the use of local labor save energy as well as protecting the environment [8].

Figure 2.4. BlueCitty Offices Project [8].

Although strategies developed for 10R concepts guide and have many advantages for sustainable building design, some of them may also contradict each other in some cases. Therefore, their selection is important based on the design problem, users' needs and characteristics, and social and economic factors.

3. BIOMATERIALS IN ARCHITECTURAL DESIGN

Efficient use of space and resources in nature is effective in the development and growth processes of ecosystems. The same is true in architecture. Effective use of space and resources is important for efficiency [1]. Waltraut Hoheneder and Petra Gruber give examples of effective use of space and modularity in design as the architectural equivalent of cells in biological ecosystems. Effective use of space and adaptation to space is possible with combinations of modular units [9]. Modularity provides flexibility and makes structures adaptable to the unique needs of each design problem. This advantage of modularity and flexibility is similar when we compare architectural structures with biological structures [9]. While living organisms extend their life cycles with their adaptability to changing environmental conditions, they also increase their endurance in many respects [10]. In architectural structures, this is made possible by the technology developed under the concept of imitating nature [11]. It is possible to create environmentally compatible designs inspired by ecosystems with special system designs such as energy-producing facades and systems that increase resistance to environmental effects, and flexible and modular structures that will allow deformation or movement. This is explained by the concept of biomimicry [11]. Biomimicry can be defined as imitation of an organism, or a system found in nature. Although this concept originated in the 1960s, its popularity has increased in the 1990s with the research studies conducted by Janine Benyus. Benyus claims that the solution for many problems can actually be found in nature [12]. Environmentally friendly solutions can be developed by combining what we learn from nature with today's technologies.

Another environmentally friendly approach is the biomaterial approach. Biomaterials can be considered under two main headings as natural materials and living materials [10]. It is the integration of natural materials and living organisms into systems by creating an alternative to traditional materials. Biomaterials, which are more ecological than contemporary building materials, provide advantages in many respects. First of all, they are more sustainable and environmentally friendly, and they also have positive effects in terms of user health [32]. For this reason, if they are preferred in architecture, they can be effective in minimizing the problems caused by construction today. In the construction sector, they will have a significant impact on both increasing sustainability and reducing water, soil, and air pollution [13].

The main resources needed for building construction are energy, water, and materials. The building materials need to be chosen considering the entire life cycle of the building. An approach that adopts the organization of the whole product/building life-cycle process from the initial design stage to storage, transportation, assembly, and construction, and further to the management and demolition of expired structures, can increase sustainability within the circular structure. The selection of materials considering various purposes within the whole design is an important decision for creating integrity. Choosing materials that are worn easily, are not durable, and are not suitable for environmental conditions shortens the life of the building and increases the need for renovation and maintenance in time, which can become a heavy economic burden.

Conventional materials that perform according to certain quality and standards, are known, determined, approved by legislation and certifications. With the emergence of new and alternative materials and new systems in the building sector, new quality control methods have emerged. Some alternative materials are produced from waste materials, industrial by-products and/or natural resources instead of traditional resources. Testing to determine the strengths and weaknesses of new materials and technologies is a vital process for their applicability. More and more designers, scientists and engineers are working on research focused on the development of innovative alternative materials that are appropriate to be approved by building legislations and certifications.

The use of bio-based materials in architectural design is one of the most popular examples of recent innovative design approaches. Biomaterials are renewable materials that are derived from biological resources and organisms such as plants, animals, and microorganisms [13]. Natural materials, in other words nature-based materials, can be defined as materials that are found and grown in nature without human intervention [1].

Wood is the longest used and still the most popular biomaterial [9]. It has been used mainly as a material for furniture and construction. Other than that, for many years wood has been used for making paper and pulp. It is commonly used for manufacturing boxes, pallets and paper or cardboard based packaging materials. Wood is also used as energy and biomass source. Main qualities, which make wood a valuable biomaterial, are its strength, durability, and aesthetic appeal. There are many biomaterials other than wood, and they have become more and more popular in many sectors, especially in design-based fields, in recent years [9]. Some of the popular examples of biomaterials can be listed but not limited to the followings [14]:

- Wood: Used for flooring, wall cladding, roofing, and furniture.
- Stone: Natural stones such as granite, marble, and limestone are used for exterior cladding, paving, and landscaping.
- Bamboo: A fast-growing and renewable resource used for flooring, wall cladding, and furniture.
- Cork: An eco-friendly and sustainable material used for flooring, wall cladding, and acoustic insulation.
- Hempcrete: A mixture of hemp, lime, and water used as an alternative to traditional concrete for walls, floors, and roofs.
- Straw bale: A natural and sustainable insulation material made from straw.
- Adobe: A natural building material made from earth, water, and organic materials like straw and grass.
- Rammed earth: A technique where soil is compacted into forms to create walls and structures.
- Clay: Used for making bricks, tiles, and other building materials.
- Slate: A natural stone used for roofing, flooring, and wall cladding.
- Seagrass: A natural fiber used for insulation and wall cladding.
- Reclaimed wood: Old wood salvaged from buildings or other structures and repurposed for new construction or design elements.
- Vegetation: Mostly used on living/green walls, these are vertical gardens made up of living plants.
- Corkcrete: A blend of cork and concrete used for insulation and wall cladding.
- Wool: Used as insulation material in walls, roofs, and floors.
- Coconut husk: A natural fiber used for wall cladding and insulation.
- Mycelium: A natural material made from mushroom roots used for insulation and building blocks.
- Hemp fiberboard: A sustainable alternative to traditional MDF made from hemp fibers.
- Wattle and daub: A traditional technique of building walls with woven branches covered in a clay or earth mixture.
- Ferrock: An eco-friendly alternative to concrete made from recycled materials including steel dust and carbon dioxide.

  Bioplastics: Bioplastics are plastic-like materials produced by some bacteria under certain conditions. They can also be obtained from renewable biomass sources such as vegetable oils, corn starch, hay bales, wood chips, food, and scraps. The most important feature of these polymers is that they dissolve in nature in a shorter time than traditional plastics originating from petroleum.

Figure 3.1. Biomaterial Examples.

Biomaterials have been increasingly incorporated into architecture as a means of designing sustainable, eco-friendly buildings. These materials can be derived from renewable sources [13]. In addition to their functional benefits, biomaterials can also contribute to the aesthetic appeal of a building.

In order to make a circular and bio-based design, material research is necessary to understand where a specific material can be used, how it is applied, how it can be recycled, and in what cycle it can be used after the demolition stage. In addition, it is a necessity to carry out tests on comfort, safety, and lifespan with a comprehensive study before the application of the material in building construction, in order to ensure the durability of the design. Moreover, in most cases, new production, assembly and application methods and techniques are required to be developed to use these alternative new building components for a more efficient, purposeful, and economical design solution [13].

3.1. Benefits of Using Biomaterials

Biomaterials are used in many fields. Basically, they are materials that are widely used in fields such as tissue engineering and medicine, due to their easy adaptation to living systems [10]. In design-based sectors, its use not only provides many advantages, but also increases the potential for innovative design. The use of biomaterials in design provides an aesthetically different and environmentally friendly perspective with natural colors, textures, and patterns [15]. However, the reason why they are preferred in the main design is that they constitute an alternative to traditional materials. They are lightweight, strong, and robust so they can be used in many different ways [13]. Their main features include being renewable and biodegradable. This enables them to contribute to the environment and circular economy [8].

Many biomaterials have self-healing properties. In this way, they can repair themselves and show endurance against many different environments and events. Moreover, those with bioluminescent properties can convert chemical energy into light energy during chemical reactions, and thus emit light production to the environment. In addition, some biomaterials are conductive, and some are insulators. These properties provide advantages for sustainable design. Most important advantages of bio-based materials can be summarized as [13]:

- renewability,
- reduce carbon footprint,
- biodegradability,
- low environmental impact,
- good insulation properties.

3.2. The Relation of Sustainability Goals and Biomaterials

The sustainability goals aimed to be achieved by 2030 have been determined by United Nations under 17 main headings. These goals focus on finding solutions to social, cultural, economic, and ecological problems such as hunger, poverty, climate change, social equality, qualified education, responsible production, and consumption, which are accepted as contemporary common problems of the whole world [4].

Figure 3.2. Sustainable Development Goals identified by United Nations until 2030 [4].

Sustainable solutions are aimed at reducing carbon emissions in the atmosphere, minimizing waste generation, and finding solutions to the consumption of natural resources. Biomaterials has the potential to be an alternative and effective solution to some of these purposes. They can make significant contributions to the following Sustainable Development Goals.

3.2.1. Clean Water and Sanitation (Goal 6)

The clean water and sanitation clause covers all accessible water and wastewater services. In this context, it is important to protect clean water resources in order to ensure water management and prevent water scarcity. Climate change and the resulting global warming are the primary factors affecting water resources. In addition, the decrease in clean water resources in time is a result of the increase in the use of petroleum and similar fuels and the discharge of garbage into the water. Water quality can be increased by preventing harmful chemicals and substances from contacting with water, ensuring safe use of water [4]. Reliable and accessible clean water resources need to be secured and the importance of prevention of water pollution need to be emphasized.

Biomaterials do not pollute the water as they are derived from nature, are renewable and can dissolve naturally. Moreover, some of the biomaterials such as algae, some types of bacteria and fungi can even provide water purification and filtration systems and clean the water, contributing to sustainability. The biomaterials used in the purification of wastewater act as filters and provide effective removal of pollutants from water resources. They offer environmentally friendly alternatives to traditional water treatment chemicals [34]. Biomaterials, which not only clean the water but also reduce the possibility of contamination, also reduce environmental pollution resulting from the accumulation of waste created by disposable hygiene products. It is obvious that these materials, which can also be used to produce innovative and environmentally friendly sanitary systems, will also have a potential to protect clean water resources for future generations.

3.2.2. Affordable and Clean Energy (Goal 7)

The main reason for the deficits in energy needs is depletion of the energy resources due to their insufficient amount. Therefore, the importance of controlling the use of renewable energy sources has emerged in recent years. Electricity and fuel have become a necessary resource in all aspects of daily life, from food to shelter. Recently, with the effect of the war in Ukraine, an energy problem that affected the whole world has emerged and the prices of energy resources have increased. Therefore, many countries have been developing strategies and systems to use renewable energy sources. However, there are also around 660 million people who live without electricity and 2 billion people who live without clean fuel. Within the scope of the development goals, it is aimed to ensure that everyone has access to affordable, reliable, and sustainable energy until 2030. At the same time the use of renewable energy sources is aimed to be encouraged in order to protect the environment and not destroy nature [4].

Biomaterials contribute to the seventh goal because they play a very important role in bioenergy production. They provide a sustainable energy source for many areas by releasing biogas during the decomposition of organic waste. Moreover, biofuels produced from organic wastes can also be used as green alternatives to fossil fuels, reducing greenhouse gas emissions [38]. Contribution of biomaterials and biofuels to development of efficient energy systems support prevention of increase in climate change.

3.2.3. Decent Work and Economic Growth (Goal 8)

The development and use of biomaterials and the increase in research on this subject have accelerated new markets and industries. This, in turn, can stimulate the emergence of new business lines and support economic growth. Biomaterials are environmentally friendly and socially responsible products. Increasing demand for these products can support investment in entrepreneurship and sustainable businesses. Biomaterials support a sustainable economy as well as the concept of circular economy. Renewable resources are produced and used in a cyclical system. In addition, recyclable resources reduce waste generation and resource consumption. Encouraging technological developments and innovation supports the development of applications and increases productivity. It contributes to the eighth goal by causing productive employment and growth of the working force [4].

3.2.4. Industry, Innovation, and Infrastructure (Goal 9)

Industrialization can be encouraged and developed by including the concept of sustainability in various disciplines that support industrialization. The use of biomaterials can contribute to the development of an innovative infrastructure, advancing the ninth goal. It can accelerate sustainable industrialization by providing alternative fuels that can replace non-renewable sources such as fossil fuels. Use of sustainable alternatives to traditional materials such as bio composites and bioplastics instead of plastics, is another valuable approach to support sustainable industrialization [34]. These approaches offer significant benefits to reduce carbon footprint and to increase resource efficiency.

3.2.5. Sustainable Cities and Communities (Goal 11)

The impact of increase in urbanization is mostly seen on the natural environment. Therefore, it is so important to design cities according to the needs and demands of people, inclusive, safe, resilient, and sustainable. Biomaterials also contribute to sustainable urbanization and environmental protection and improvement of cities (the eleventh Sustainable Development Goals) because they offer options for bio-based building materials that enhance the design of sustainable buildings, which are energy efficient and environmentally friendly infrastructures [34]. They also play a role in the waste management of cities, reducing waste accumulation and pollution caused by building and construction sectors. Efficient and sustainable waste processing and recycling technologies related to biomaterials also play a role in the formation of a circular approach in waste management. Moreover, integration of biomaterials in city planning and infrastructure development leads to the formation of flexible cities and construction of more sustainable, livable, and nature-friendly cities [34].

3.2.6. Responsible Consumption and Production (Goal 12)

If consumption exceeds production, it adversely affects life. Ensuring sustainability in consumption and production by encouraging conscious consumption, in which bio-based products and biomaterials are preferred to minimize wastes that can harm the natural environment. This approach supports advancing the twelfth goal [4]. For instance, in order to prevent the use of plastics, which create significant environmental pollution, bio-based plastics can replace disposable materials as a more healthy and sustainable alternative solution. Other examples for the use of sustainable materials such as cotton and bamboo instead of traditional textile materials can be another example. Preferring to use sustainable and bio-based materials, entirely dependent on consumers consciousness on advantages of sustainable choices. The biodegradable property of biomaterials allows them to be destroyed naturally and reduces the environmental burden. Biomaterials that can be recycled also reduce the consumption of raw resources and production of waste. Biomaterials also encourage the use of renewable resources through natural processes, reducing the dependence on non-renewable resources and energy. In this way, circular low-carbon economy is supported.

3.2.7. Climate Action (Goal 13)

Climate change is a reality that threatens the earth and all living things. Climate change, which affects not only the natural environment but also all living species, is one of the most serious problems of the last century that requires urgent action is [4]. Factors such as greenhouse gas emissions and carbon emissions that cause climate change to accelerate need to be reduced. Biomaterials offer sustainable alternatives to fossil fuels, reduce greenhouse gas emissions and carbon footprints, and are used to produce energy-efficient and advanced technologies [38]. For example, the recycling of wood products in the construction industry can help to reduce carbon footprint with carbon storage by ensuring carbon sequestration. Biomaterials also promote afforestation and sustainable agriculture, encouraging conscious practices in land management. This, in turn, preserves biodiversity and ecosystems. Within the scope of the thirteenth goal, biomaterials, which are important with their positive impact on climate diversity, play an important role for a sustainable future.

3.2.8. Life Below Water (Goal 14)

Although the subject of biomaterials is not directly related to the fourteenth goal, they can contribute to this goal within the scope of subjects such as biodiversity, protection of ecosystems and prevention of pollution of water resources [4]. The use of biomaterials and biofuels, instead of non-disposable plastics and fossil fuels that leak into and pollute water resources, threatening the lives of sea creatures, can be a sustainable solution to prevent water pollution. Moreover, in order to ensure the sustainability of the fishing industry and aquaculture, paying attention to prefer bio alternatives in material use can minimize the ecological footprint of the industry (e.g., in fishing line and nets). Another positive impact of the use of biomaterials can be on the conservation and restoration of marine habitats. This, in turn, supports the health of marine habitats and protects ecosystems.

3.2.9. Life on Land (Goal 15)

The use of biomaterials has an impact not only on aquatic ecosystems but also on terrestrial ecosystems. While it supports the protection of biodiversity, it also contributes to the fight against deforestation, desertification, and land degradation. Therefore, it contributes to the fifteenth goal by supporting the restoration of terrestrial ecosystems [4]. An important factor in land degradation is the use of some traditional materials. For example, wood, in addition to being a biomaterial, is also one of the most used traditional construction materials. Excessive use of this material causes deforestation, which causes ecosystems to deteriorate, the quality and diversity of forests to decrease, and soil quality to deteriorate. In addition, the frequent changes in demands due to the changing lifestyle and the resulting shortening of the average life of buildings cause demolition and reconstruction in the construction industry [34]. This means that the materials used create tons of waste every year. In addition, the development of the construction industry means increased energy use. This leads to the emergence of a fossil fuel-dependent system. The use of some alternative biomaterials and the controlled use of some traditional biomaterials during land management can reduce erosion and support the healthy functioning of terrestrial ecosystems.

Biomaterials also support the protection of the forest ecosystem by using them in the construction of shelters for the protection of endangered species, in the protection of biodiversity, in the construction of biodegradable, sustainable seedling pots, and in the process of plowing and covering the soil. Finally, biomaterials can offer alternatives to traditional wood materials. In this way, they can support forestry practices and reduce deforestation by reducing timber harvesting for commonly used trees. This reduces the pressure on forests.

3.2.10. Partnerships to achieve the (Goal 17)

It is important to strengthen global partnerships for sustainable development. Although not directly related, collaborative research studies on the use and development of biomaterials for the seventeenth goal contribute to supporting partnerships and collaborations [4]. Research on biomaterials is carried out in collaboration with experts from many different fields. Governments, industries, and many institutions are involved in the development and production of these materials. Collaborative efforts on this subject, which requires knowledge and expertise, play an important role in finding and developing sustainable solutions. Ensuring unity in the international arena increases the sharing of information and enables the rapid development of studies in the field of biomaterials. Collaborations can support equitable access and contribute to developing countries' use of sustainable technologies. Moreover, the formation of cooperation on biomaterials contributes to the energy and water sectors, encourages international meetings on climate, develops industries and creates new business lines. It also accelerates the development of innovative technologies by creating competition.

3.3. Challenges and Problems When Using Biomaterials

There are some inherent difficulties in the use of biomaterials. Due to the nature and unique processes of remanufacturing, recycling, and upcycling of biomaterials, it is difficult to find areas where they can be reused. The use and reuse of biomaterials requires attention in identifying function and purpose of use for their efficient adaptation to design. One of the challenges in deciding for the biomaterial in design is to meet the quality standard and health and safety requirements in the construction industry. Another challenge is related to the aesthetical characteristics of biomaterials, as aesthetics and harmony are very important in architecture in all other design-based sectors. Due to their nature, some of the biomaterials may not provide consistent structure, texture, pattern, and color every time. They may result in different aesthetical characteristics with the effect of the independent variables such as time, changing air quality, temperature change, and light effect. It will be more accurate to follow an approach with this awareness in the designs where biomaterials will be used. When it comes to biocompatibility, this concept, which represents tissue compatibility under medicine and similar titles, can be considered as the harmony with the environment and people in the design sectors. For example, the use of local materials not only saves energy, but also ensures harmony with the environment and nature. In addition, biomaterials become a means of communication between nature and human beings and affect human life in the formation of a healthier environment.

Biomaterials are expected not only to be aesthetically or environmentally compatible, but also functionally compatible. They must also meet requirements in terms of structural support, ergonomics, and usability [34]. Functionality is an important element for successful designs and for the integration of materials with the structure.

Production techniques and processes of biomaterials are also different. This is also important for designers. Imbalance between consumption and production causes lack of resources and unconscious use. Therefore, mass production of biomaterials poses a threat to sustainability. In addition, the methods used in the production of biomaterials may cause limitations in terms of design. In this respect, cooperation with different fields such as materials engineering is valuable in terms of optimizing the production process.

Considering the life cycle of materials is one of the environmental and sustainable responsibilities of designers. Production processes, supply methods and duration of use are as important as the life span of materials in terms of sustainability. For this reason, not only being environmentally friendly and edible, but also addressing the cyclical design principles in design contributes to more sustainable designs [34].

Prototyping and testing are the most important aspects of biomaterials. They should be tested not only in terms of functionality and durability of designs, but also in many aspects from user reaction to possible effects. Since it is a mystery whether they meet the existing building standards, it is very important that consumers, designers, and individuals involved in the building construction process be made aware of materials. In addition, prioritizing improvement in design rather than production is important in planning for structures to be built with these materials.

Biomaterials, which are not the study of a single field, require the cooperation of experts in many fields. At the stage of recognizing the materials, the designs will be developed, and their applicability will increase as the designers get help from experts in biology, materials science and similar fields and interact one-on-one.

It is still a matter of debate whether these environmentally preferred materials should be economically preferred. The production of some materials may require more steps and resources than others. Some biomaterials can be easily produced and made usable even at home with a few basic materials. This issue raises questions about how economically preferable they are. An important solution to this would be to increase knowledge about materials. This can be achieved through the advancement and development of current research.

Upcycling is based on the concept of using old, used or waste materials in another way for a new superior purpose. In this way, the material acquires a new and better environmental value. Unlike recycled or reused materials

Nutshell upcycling in architecture involves using waste nut shells as a raw material to create new products with higher value and functionality for architectural design. This process involves transforming nut shells into a range of architectural products, such as insulation material, cladding, flooring, and even furniture. Upcycling nut shells reduces the amount of waste that would otherwise end up in landfills or be burned, releasing greenhouse gases into the atmosphere. It also reduces the need for raw resources and lowers the carbon footprint of construction materials. Upcycling nut shells in architecture can also enhance the sustainability and aesthetic appeal of buildings by providing unique natural textures, colors, and patterns that cannot be found in traditional materials. Overall, nutshell upcycling offers an innovative and sustainable approach to building design, providing a range of benefits that promote environmental responsibility and resource efficiency.

4. PROPERTIES OF NUTSHELLS AND UPCYCLING THEM AS A BIOMATERIAL FOR ARCHITECTURAL DESIGN

Upcycling nutshell to be used as a biomaterial for architectural design offers several advantages. Firstly, it aligns with principles of sustainability by utilizing waste material that would otherwise be discarded, reducing the demand for raw resources, and minimizing landfill waste. Additionally, nut shells are abundant byproducts of the food industry, making them readily available for upcycling purposes. Being renewable and biodegradable, nut shells are derived from natural sources and have minimal environmental impact over time. Moreover, they possess desirable properties for architectural applications, such as being lightweight and insulative, which aids in construction and improves energy efficiency [19]. Furthermore, nutshell materials provide aesthetic appeal with their unique textures and patterns, adding a touch of natural beauty to architectural designs. Their versatility allows for various applications, including panels, tiles, and composite materials, enhancing design flexibility. However, it is important to conduct proper testing and evaluation to ensure the performance, durability, and safety of nutshell biomaterials in architectural design, considering factors such as regional availability and processing techniques. [16].

Nutshells can be considered to be used as a biomaterial in architectural design in Turkiye for several compelling reasons. Firstly, Turkiye's agricultural sector produces a significant amount of nut crops, resulting in abundant nutshell waste that can be upcycled. By utilizing this local resource, Turkiye can address waste management problems and promote a more sustainable approach to construction [17]. Additionally, the insulation properties of nutshell biomaterials are well-suited to Turkiye's diverse climate, offering improved energy efficiency and reducing heating and cooling demands in buildings. Moreover, incorporating nutshell materials aligns with Turkiye's cultural aesthetics, adding a touch of natural beauty and reflecting the country's rich heritage. This choice can also stimulate local industries involved in nutshell processing, creating economic opportunities, and contributing to the country's economy [17]. Furthermore, adopting nutshell biomaterials showcases Turkiye's commitment to sustainability and positions it as a leader in eco-friendly construction practices. Overall, choosing nut shells as a biomaterial for architectural design in Turkiye offers environmental, economic, cultural, and image-related benefits.

Nut waste are agricultural by-products that would otherwise be discarded as waste. Although the shells of walnuts and their derivatives are generally used as fuel, they are also used as natural material in upcycling in many areas [18]. Shells, which are mainly used as biomass fuel, release a great deal of energy and heat when burned. Other than that, some nuts for animals are used for dietary fiber supplements such as peanuts. They are also used as a place to sleep for animals or instead of sawdust laid under them.

They also have a low carbon footprint compared to wood, as they do not require logging or transportation. Nut waste is also biodegradable, compostable, and durable. The versatility of nut wastes makes them a highly promising biomaterial for use in a wide range of architectural applications, providing sustainable and eco-friendly alternatives to traditional building materials. Various ways in which nut wastes can be used in architecture and construction can be summarized as [19];

- insulation material,
- in walls, floors, and roofs to enhance energy efficiency and thermal performance,
- decorative elements, such as in wall panels or flooring,
- cladding or siding, providing an aesthetically pleasing and sustainable alternative to traditional materials such as vinyl or aluminum, and
- load-bearing elements in structural systems, such as in the form of laminated beams or trusses.

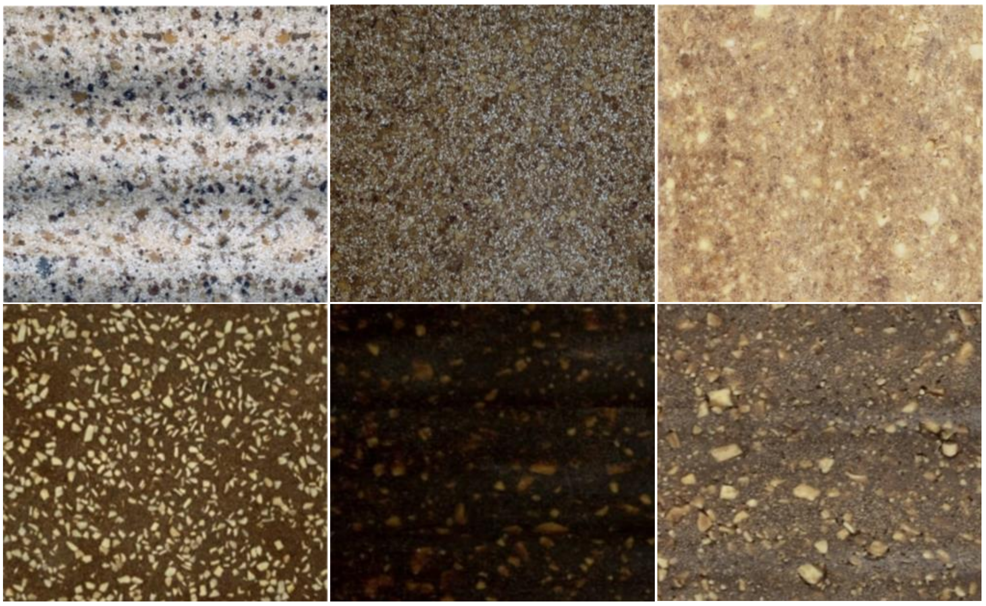


Figure 4.1. Nutshell based biomaterials by Ottan Studio [36].

Nutshells possess several properties that make them attractive as sustainable biomaterials. Firstly, they are abundant and readily available as agricultural waste, reducing the need for new resources and diverting waste from landfills. Secondly, nut shells have a high lignin content, a natural polymer that enhances their strength and durability, making them resistant to deformation and wear. They also have good insulation properties, with low thermal conductivity, making them an effective material for use in building envelopes. Furthermore, nut shells are lightweight and have a high strength-to-weight ratio, making them suitable for use in load-bearing applications. They are also non-toxic, biodegradable, and compostable, making them environmentally friendly and safe to handle. Overall, nut shells offer a promising sustainable alternative to traditional building materials, providing unique properties that can enhance the performance and sustainability of buildings.

5. EXPERIMENTAL RESEARCH STUDY

The experimental research study started with an extensive literature review on biomaterial and nutshells. Figure 5.1 presents the process of experimental research study.

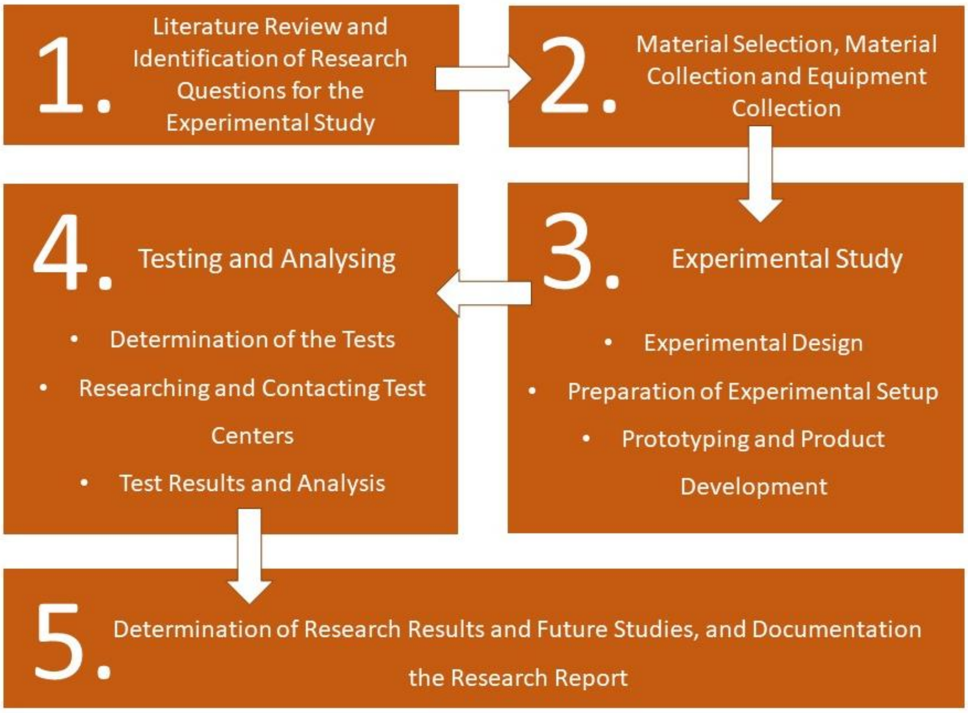


Figure 5.1. Research Process of Experimental Studies.

In this section, the findings obtained as a result of the research and the results of the experiments conducted in the light of previous experiments found in literature will be shared [20]. The materials, tools, experimental setups, and the data obtained as a result of each experimental setup will be explained in detail.

5.1. Aims and Objectives of the Experimental Study

The aim of this experimental study is to design, produce and test a biomaterial that can be used in construction or finishing systems in architectural design such as floating floor, wall panel and ceiling tile in order to help reduce the environmental impact of the construction industry by creating more sustainable and healthier building material alternatives. Traditional sound and vibration absorbing materials, such as mineral wool and fiberglass, are often made from non-renewable resources and can release harmful chemicals into the environment. Pumpkin seed shell and walnut shell powder are promising biomaterials with a wide range of potential applications in architectural design. They are sustainable and biodegradable alternatives that can be obtained as by-product of the nuts industry. Therefore, they are used as the base materials in order to offer a more environmentally friendly alternative to the sound and vibration absorbing elastomer material used in floating floor systems. It was aimed to produce a durable elastomer rubber-like material which has an elastic structure and is composed of 100% biomaterials that can be molded into a desired shape. Therefore, Pumpkin shell and walnut shell powders are combined with various bio-binders and other additives, namely gelatin and agar agar. Throughout the experimental research process, various experiments were conducted to produce alternative elastomer material(s) in different thicknesses using different grain sizes. The properties aimed for the alternative materials are summarized below:

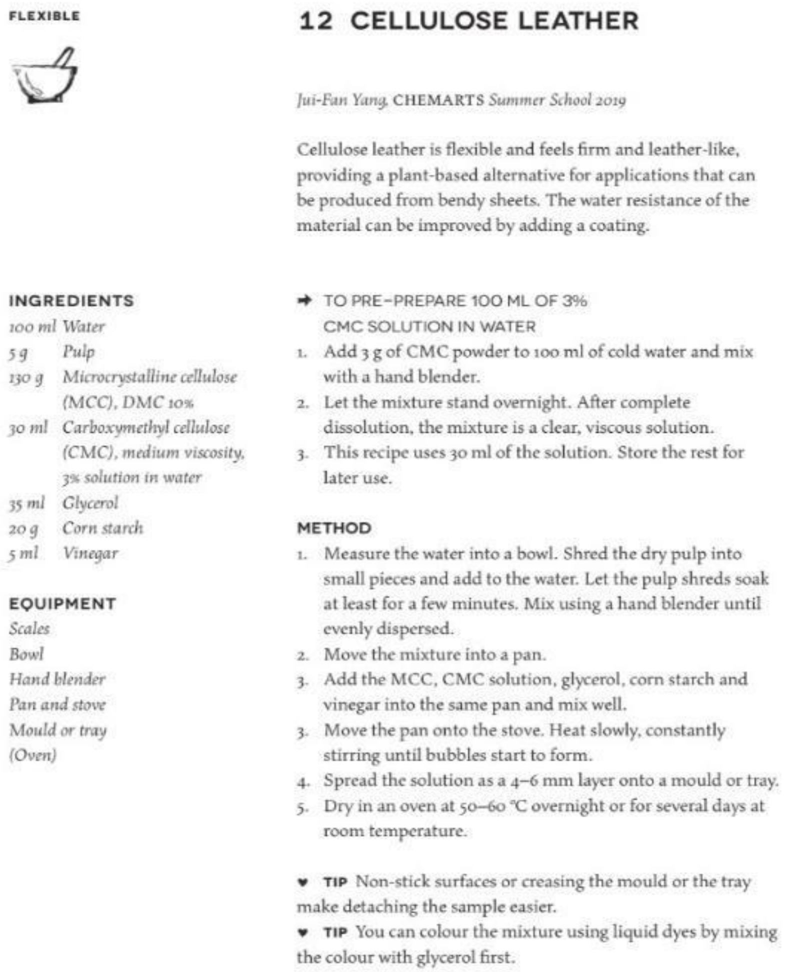
- to be biodegradable when its product life is over.
- to take shape easily and to maintain their shape,
- to be elastic enough to work as an elastomer material,
- to have the ability to absorb impact and sound.

Although it cannot be tested within the scope of thesis study, the materials were also expected to have a long life and to be resistant to mechanical defects such as bacteria and mold, that may occur over time. The results of this experimental study could help pave the way for the development of more sustainable and environmentally friendly building materials.

5.2 Background

The experiment process was influenced by the research studies conducted by Aalto University ChemArts community, which conducts research and studies on biomaterials and sustainable solutions for design, in research laboratories and production workshops. The ChemArts community was founded as a collaboration of the Departments of Chemical Engineering and The School of Arts, Design and Architecture under Aalto University [20]. This community basically carries out sustainable solution projects focusing on forests, which are of great importance in Finland as an industry. Their aim is to create a new bioeconomy by combining design, innovative thinking, and natural materials. While using completely natural materials in the projects that basically use cellulose obtained from trees as a material, they also aim to support local economy by saving time, effort, and energy due to the easy accessibility of natural materials in the local area. For this reason, they present experiments that can be carried out with simple kitchen utensils that can be found easily. The community even published a book called "Chemarts Cookbook", in which they propose recipes for some alternative material production methods [20]

This book, designed to guide future research, includes production methods and material content for biomaterials that can be used in various fields. In this thesis, experiments were designed and carried out in a similar process used for the experimental setups in this book. The “Cellulose Leather” experiment in the book has been revised and developed with nut shells and seeds instead of cellulose as the basic material [20]. In addition, nut shells and seeds, i.e., waste parts, were adapted to the experiments in two different ways. One of them is in the form of pieces and the other is in the form of powder.



FLEXIBLE

12 CELLULOSE LEATHER

Jui-Fan Yang, CHEMARTS *Summer School 2019*

Cellulose leather is flexible and feels firm and leather-like, providing a plant-based alternative for applications that can be produced from bendy sheets. The water resistance of the material can be improved by adding a coating.

INGREDIENTS

100 ml Water
5 g Pulp
130 g Microcrystalline cellulose (MCC), DMC 10%
30 ml Carboxymethyl cellulose (CMC), medium viscosity, 3% solution in water
35 ml Glycerol
20 g Corn starch
5 ml Vinegar

EQUIPMENT

Scales
Bowl
Hand blender
Pan and stove
Mould or tray
(Oven)

➜ TO PRE-PREPARE 100 ML OF 3% CMC SOLUTION IN WATER

1. Add 3 g of CMC powder to 100 ml of cold water and mix with a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.
3. This recipe uses 30 ml of the solution. Store the rest for later use.

METHOD

1. Measure the water into a bowl. Shred the dry pulp into small pieces and add to the water. Let the pulp shreds soak at least for a few minutes. Mix using a hand blender until evenly dispersed.
2. Move the mixture into a pan.
3. Add the MCC, CMC solution, glycerol, corn starch and vinegar into the same pan and mix well.
3. Move the pan onto the stove. Heat slowly, constantly stirring until bubbles start to form.
4. Spread the solution as a 4–6 mm layer onto a mould or tray.
5. Dry in an oven at 50–60 °C overnight or for several days at room temperature.

♥ TIP Non-stick surfaces or creasing the mould or the tray make detaching the sample easier.
♥ TIP You can colour the mixture using liquid dyes by mixing the colour with glycerol first.

Figure 5.2. Example of the Biomaterial Research Study in Chemarts Cookbook [20].

In this research, the shells of walnuts and pumpkin seeds which have fibrous structure were used as the basic bio-waste material instead of cellulosic fiber, because they are the most consumed type of nuts and thus most produced bio-waste among others in Turkiye. Alternative biomaterials were developed by mixing walnuts and pumpkin seeds with Water, Glycerol, Vinegar, and Starch, which were also used as the basic materials in Chemarts Cookbook to combine, thicken and bind the bio-waste pieces to form a biomaterial. In addition to these, seaweed aka agar agar and gelatin were added in order to increase the binding properties in the next experimental setups.

Most of the examples where agar agar and gelatin are used in the field of design are in the production of bioplastics. Bioplastics are biodegradable, reduces carbon emission and more sustainable materials that are still being studied in order to be an alternative to plastics that do not disappear in nature. The reasons for the use of agar agar and gelatin in the production of bioplastics are that these materials have a gel-like structure and are mixed with cellulose, starch, and similar materials to form composite biomaterials. Below are a few examples of projects in which agar agar and gelatin are used to make plastic-like biomaterials from the design world.

Tiare Ribeaux is a filmmaker who studied bioplastics and wrote a book entitled "Bioplastic Cookbook". In the book she explained the process of producing bioplastics from gelatin, agar agar, starch, chitosan, etc. In the results of her agar agar experiment, agar agar shrinks in size and thickness, during the drying phase. After 24 hours of drying, the texture of the mixture is felt like a skin and more flexible than gelatin experiment. In experiment conducted with gelatin, she used a typical waste product for food industry. The texture of the results is dry, and the material is brittle. The material was still stiff although more glycerol was added.

Figure 5.3. Bioplastic Examples.

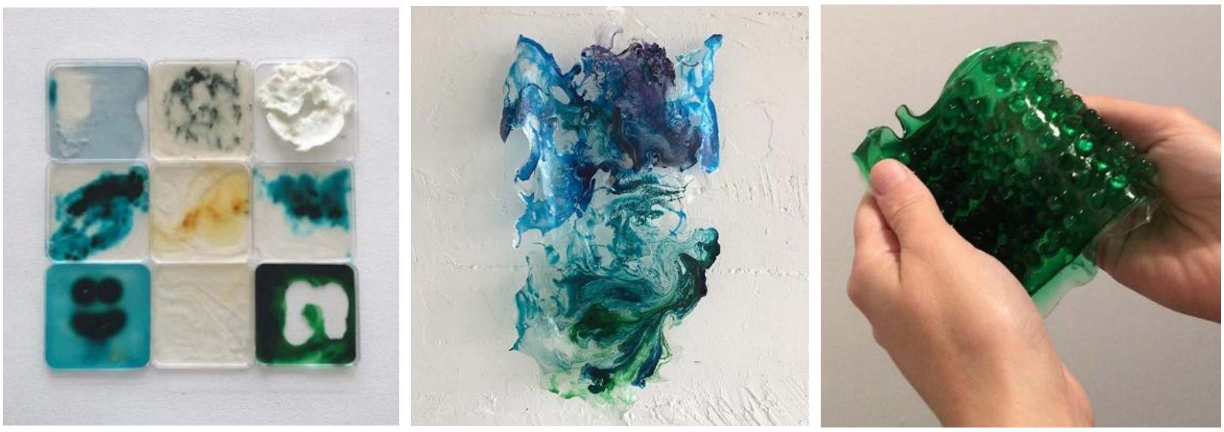


Figure 5.4. Bioplastic Examples.

Another example is the biomaterials produced by Valentin Martinez Missir, a sustainable product designer, who studied homemade bioplastics and used agar agar and gelatin in her experiments. She also used the “Bioplastic Cookbook” mainly for designing plastic like textile, packaging and furniture materials.

Figure 5.5. Gelatin Based Bioplastics.

Juliana Schneider is a futuristic designer. She works on biomaterials like bacterial cellulose, organic food waste-based materials and seaweed aka agar agar. She defined seaweed as a sustainable source of bioplastics and naturally dyed them by using red cabbage water. She studied the drying process of the agar agar mixture that she shaped. She observed how the shapes were going to change when they shrink.

Figure 5.6. Seaweed Based Bioplastics.

The biomaterial that was developed within the scope of this research was intended to be an alternative to the elastomer materials found in floating floor systems. Floating floor system is a type of flooring that is not fixed to the ground below with nails or adhesive. The floors are attached to each other with systems such as locks, and their main purpose is to provide sound and heat insulation between the upper and lower floors [35]. They are easier to install than traditional flooring. Floating floor systems can include laminate flooring, vinyl flooring, and similar materials. Regardless of the specific material chosen, one common requirement for all floating floors is their capacity to provide sound and heat insulation. This feature ensures that they fulfill their primary purpose of reducing noise transmission between floors and helping to maintain a comfortable indoor temperature [35].

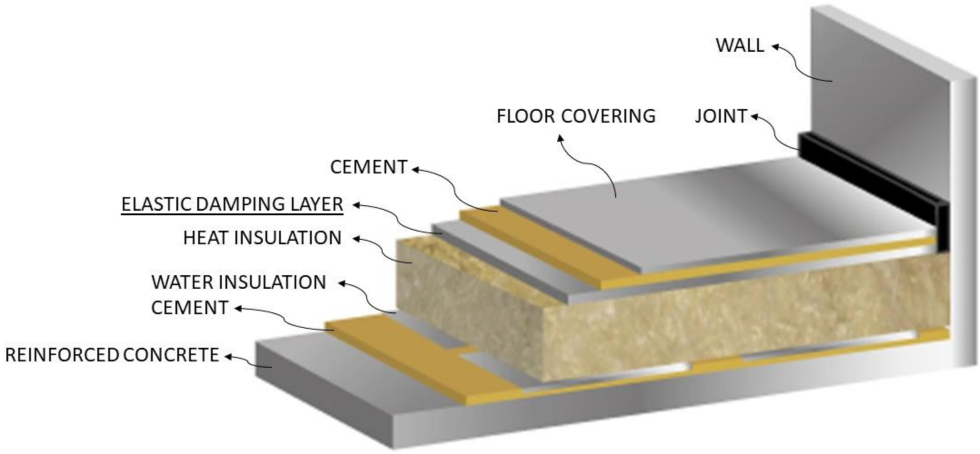


Figure 5.7. Floating Floor Detail.

Traditional insulation materials are rubber, sponge, polyurethane foam, and similar materials, which are widely used for sound insulation on walls, ceilings, floors, doors, and windows. These materials are elastic materials and have the features of absorbing vibration and absorbing sound which can help to reduce unwanted noise in an enclosed environment. Reducing noise pollution increases the quality of life, increases work efficiency, and improves the working environment.

Elastic rubber, polymer, vinyl, latex, polyurethane, and similar materials are used in architectural design and construction. The most commonly used is rubber, which is used for the purposes of increasing resistance to earthquakes, sound insulation, heat insulation, and finishing for surfaces because it can be shaped and textured with molds with an aesthetically pleasing appearance.

There are two versions of rubber: synthetic and natural. Natural rubber is obtained from the sap of the tree, while the basic material of synthetic rubber is petroleum. Although natural rubber is more advantageous, synthetic rubber is used more because it is more expensive. This type of rubber has certain disadvantages. For example, synthetic rubber can cause allergic reactions, they are sensitive to tearing and abrasion, which can cause them to contaminate the air, water, and soil.

Natural rubber is a very flexible and durable material. Its ability to easily stretch and return to its original state makes it effective for use in many places. This waterproof material also provides an advantage in terms of being used in insulation.

The basic raw material of many elastic materials used in the construction industry is petroleum or plastic. The main reason why environmentally friendly and natural alternatives are sought instead of these materials is that these materials, which generally harm nature, do not break down in nature and have carcinogenic and mutagenic properties.

Plastic is the material that remains intact in nature for the longest time. This causes environmental pollution. Oil is a fossil fuel and when burned, carbon dioxide and greenhouse gases are released. These materials, which contribute to climate change, pollute the environment, threaten the lives of many living creatures, and cause a decrease in living diversity. Considering today's conditions, it has become important to reduce the use of plastic and petroleum-containing components in order to turn to environmentally friendly solutions. This has encouraged plastic recycling and the use of natural resources for energy.

5.3. Research Question for the Experimental Study

The biomaterial intended to be produced from nutshells was expected to be strong and to absorb vibration of sound so that it can be used as an alternative sound insulation material to be used in traditional floating floor systems. Therefore, the following questions were specifically investigated for each biomaterial produced during the experimental studies.

- Can nutshells be used to produce a biomaterial which may be an alternative to traditional elastomer materials used in the floating floor system?
- Can a nutshell-based biomaterial provide sufficient elasticity to be used as an alternative to traditional elastomer material?
- Do(es) the biomaterial sample(s) produced with different thickness in the experiments have similar strength properties with the traditional materials used in floating floors systems?
- Do(es) the thickness of the produced biomaterial sample(s) affect the elastic structure of the material?
- Do(es) the biomaterial sample(s) produced in the experiments have the vibration of sound absorption properties?

5.4. Research Set-up

In this thesis study, a simple set-up was prepared with basic tools to mix and mold the materials and to conduct the experiments. In the first stage, different types of nutshell waste were collected from a group of consumers. The shells of pistachios, walnuts, hazelnuts, and pumpkin seeds, which are the waste parts of the collected nuts, were crushed with different tools. For this process, a malt making machine, meat hammer and pestle were tested to be used to grind the nutshells, and the closest results to the desired grain size were obtained with a blender. The shells are then grinded into two different grain sizes, (a) piece by sieve and (b) the smallest possible size as powder.

In the experiments, walnut shell and pumpkin seed shell were preferred to be used mainly for two reasons:

- Their consumption is high in Turkiye, producing a high amount of biowaste.
- It was easier to obtain the desired piece size with walnut shell and pumpkin seed shells due to their softer structure compared to pistachio and hazelnut shell.

Since pumpkin seed shell is different from walnut shell in terms of structure, it was used to create experimental control setups [21]. Walnut shells were chosen as a biomaterial for architectural design in Turkiye due to several compelling reasons. Firstly, Turkiye is a leading producer of walnuts, resulting in an abundance of walnut shell waste. By utilizing this local resource, Turkiye can promote sustainable practices and reduce waste generation. Secondly, walnut shells offer durability and strength when processed into biomaterials, making them suitable for load-bearing applications in architectural design. This is particularly important in seismic-prone regions of Turkiye, where structural integrity is crucial. Additionally, walnut shells provide excellent thermal insulation properties, which are advantageous in Turkiye's diverse climate, contributing to energy efficiency and reduced heating and cooling needs. Moreover, the unique texture and pattern of walnut shells add aesthetic appeal, creating a distinct and natural ambiance in architectural designs. Lastly, incorporating walnut shell biomaterials in Turkiye's architecture showcases the country's cultural heritage and symbolizes prosperity, creating a sense of identity and connection with the local environment. Overall, the use of walnut shells as a biomaterial offers environmental, structural, thermal, aesthetic, and cultural benefits for architectural design in Turkiye.

Figure 5.8. Walnut Shell Dust.

Figure 5.9. Pumpkin Seed Dust.

Although walnut shells chips were also used in the first part of the experiment, this was left as a prospective research and the experiment was continued with powdered shells. The main reason for this was that the walnut shells in pieces absorbed too much water and the resulting material is fragile and the pieces cannot hold together enough.

Figure 5.10. Walnut Shell Chips.

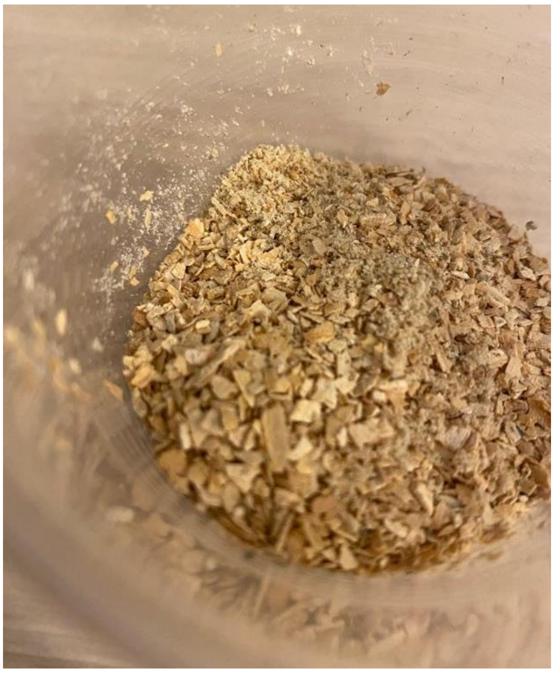


Figure 5.11. Pumpkin Seed Chips.

In the next stage of the experiment, bio binding materials were investigated to identify the most efficient material that can bond and strengthen the grains. It has been found that gelatin or agar agar is commonly used in biomaterials and upcycling process of nutshells. Gelatin is a material produced from animal connective tissue, and Agar agar, a is a vegan alternative to gelatin derived from algae.

In the next stage, each nutshell waste was mixed with the following materials, which will be explained in more detail in Section 5.5.2;

- Water
- Vinegar
- Glycerol
- Agar agar/Gelatin
- Wheat starch

The experiments were carried out in Ankara in May 2023. The temperature can be considered between 20-22 degrees and the humidity is between 50-60%. The mixtures were prepared with the help of a mixer in plastic containers. The amount of water was determined according to density needed for the mixtures to be heated in the oven to produce sheets of materials. Vinegar was added to the mixture to prevent possible deterioration. Glycerol was added in order to increase the moisture retention feature and to provide binding between the substances. However, the binding feature was not dependent on amount of glycerol in the following stages in which alternative materials were produced. As a result of the water holding feature of glycerol, it was observed that when the alternative material produced gets thicker, the fractures in the material could not be prevented due to the water loss. Therefore, other bio binding alternatives have been sought.

After it was decided to use gelatin as a bio binder, the same experimental setup was established with agar agar as a vegan alternative. In the following stages of the biomaterial experimental setups, gelatin and agar agar were also added. All experimental setups were heated in the oven in plastic molds at 180°C. These experimental setups, which were still in a dense liquid consistency when they came out of the oven, were allowed to cool for a while at normal room temperature and to come to harder structure. As a result, an elastic, thick and durable biomaterial was obtained.

5.4.1. Tools

The tools used in the experiments were restricted to simple tools for measuring, grinding, sieving, mixing, molding, and firing process. Platform gram scales and measures of teaspoons and tablespoons were used to identify the amounts of materials. The teaspoon used in the experiment was measured as 2.61 grams. A 5 mL syringe was used in milliliter calculations. In addition, when calculating milliliters of water usage, it was preferred to use a 100 mL beaker.

While plastic cups and a hand mixer were used to mix the materials in the experimental setups, a sieve was used during the separation of the shells into powder and pieces. The mixed materials were transferred to the molds and heated in the oven at 180^{o} temperature in the oven. The molds used are 3cm and 10cm diameter circular metal molds and 5x8cm2 rectangular plastic molds. While plastic molds were used in the early stages of the experiment, metal molds were used in the testing phase. The main reason for choosing circular molds during the testing phase is that samples suitable for the devices to be tested must be produced in the form of diarrhea. Since plastic molds with diameters of 3cm and 10cm could not be found, production was made with metal molds. Afterwards, the material produced was kept in the mold to cool down at room conditions and was taken out of the molds within 1-2 days. The experiments were carried out in Ankara in May 2023. The temperature can be considered between 20-22 degrees and the humidity is between 50-60%.

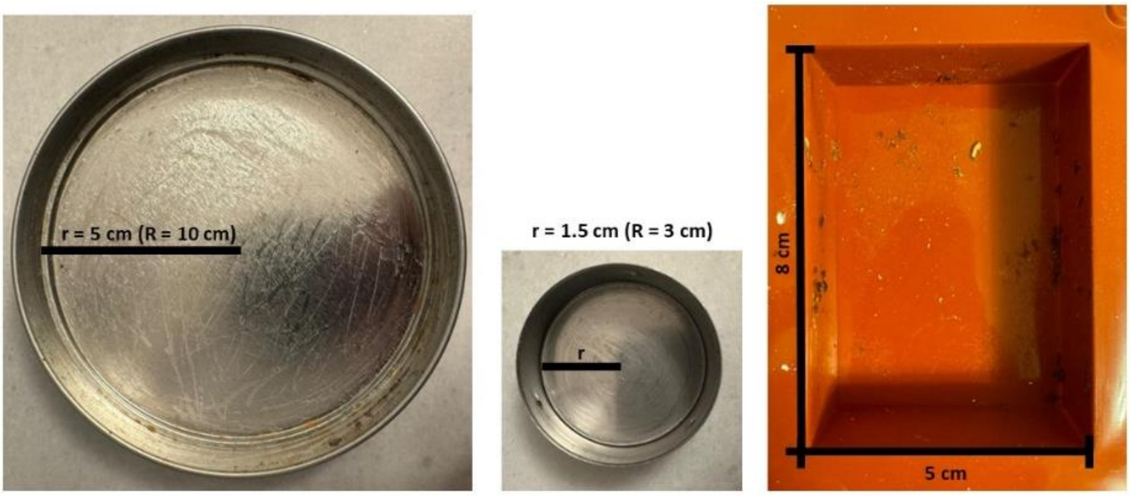


Figure 5.12. Mold Sizes.

5.4.2. Materials

Walnut Shell

Walnut shell is a material that can be included in the production of biomaterials in both powder and particulate form. It is a sustainable and functional material, which is used as a natural filling material, has high strength and hardness in particulate form. It is also a natural carbon source. It can contribute to the improvement of the mechanical properties of biomaterials to produce structures that are more durable and resistant to deformation. Walnut extract and oil also contain bioactive compounds such as antioxidants and polyphenols [18].

Figure 5.13. Walnut Shell Powder.

Pumpkin Seed

Pumpkin seeds contain many antioxidants, vitamins, and fatty acids. It has antimicrobial properties. Pumpkin seeds, which also provide good mechanical strength, have a fibrous structure, making it easier for the components to come together in terms of biomaterials [21].

Glycerol

Glycerol is mainly used as a plasticizer in making biomaterials. It gives flexibility and elasticity properties to the material. Glycerol is included in the biomaterial formulation, reducing brittleness, and increasing the ability of the material to take on different shapes and adapt. At the same time, glycerol, which attracts moisture, retains moisture, and prevents drying and dehydration of biomaterials. Because of this feature, it is used in the production of hydrogel-like materials. Finally, it inhibits the growth of certain microorganisms. It has antimicrobial properties. This extends the life of the materials.

Vinegar

Vinegar strengthens biomaterials by forming chemical bonds between polymer chains. This essentially prevents mechanical deterioration. Vinegar, which also helps to sterilize biomaterials, has antimicrobial properties, and prevents bacterial growth and similar situations by preventing microbial contamination. It also provides the appropriate environment for the biological process by adjusting the pH.

Starch

Starch, a cost-effective, easily accessible material, is obtained from plants such as corn or wheat. Starch, which has the ability to form gels, films and coatings in biomaterial formulation, provides structural support. They serve to provide mechanical strength, stability, and control.

Figure 5.14. Wheat Starch.

Water

Water helps other materials come together to create homogeneous solutions or suspensions. It is an essential element for chemical reactions and synthesis of materials. It facilitates the dissolution of many materials and allows mixtures to come together easily.

Gelatin

Gelatin is a translucent material which is derived from collagen found in animal bones. Most important reason for using gelatin in this experiment is to avoid fading color of nuts and seeds. Gelatin is biodegradable. It holds plenty of water and helps hydrogel formation by forming three-dimensional networks.

Figure 5.15. Gelatin.

Agar Agar

Agar agar was used as the second ingredient as a vegan alternative for gelatin. It is a jelly-like material which is made by boiling some species of red algae. Agar agar is mainly used in culinary for making puddings and custards. It is semi-translucent and sold in powdered form.

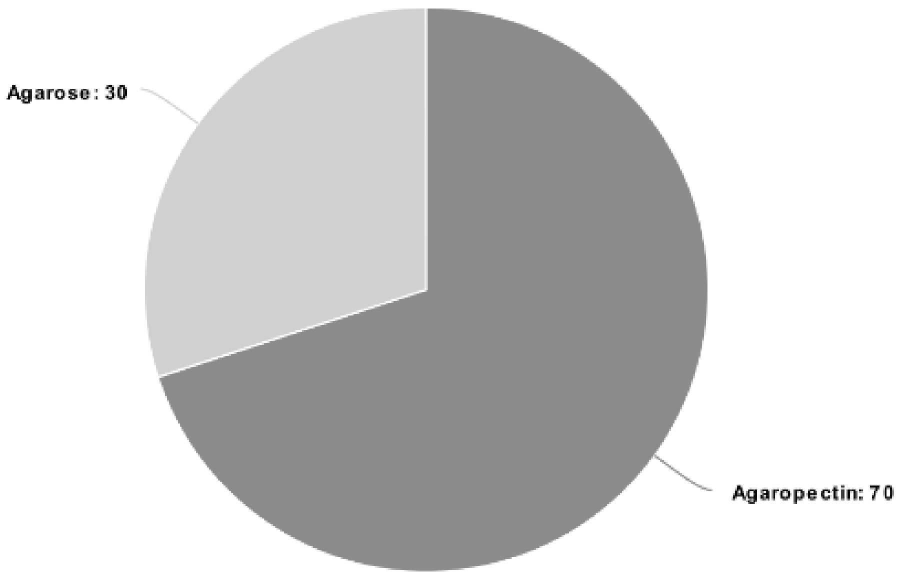


Figure 5.16. Agar agar Chemical Composition.

Figure 5.17. Agar agar.

Other than culinary, it is used in microbiology to make agar plate. Agar plate is a petri dish where microorganisms like bacteria and fungi can be cultured and observed under the microscope. Other than those, agar agar is also used in dentistry, electrochemistry, biofertilizer in organic farming and natural clay making for kids [22].

5.4.3 Laboratory Testing

The following tests were conducted in the laboratory, which focus on the research questions defined for the experimental study;

- Elasticity: to determine whether the floating floor detail under the floor covering has an elastic structure with absorbing properties of sound vibration, similar to the traditional materials such as rubber, vinyl, or latex.
- Particle size: In order to determine whether the dimensions of the powdered walnut shells are sufficient to create a homogeneous mixture and to eliminate the disadvantages that may arise if they are not of sufficient size,
- Strength test: to understand the impact of the forces that will act on the biomaterial if it is applied on the ground.

Material strength and elasticity tests are crucial for various reasons when dealing with rubber-like materials. Firstly, they play a pivotal role in maintaining product quality and safety. Rubber is used in a diverse range of applications, and understanding its mechanical properties is essential to ensure that these products perform as intended and are safe for use. Secondly, these tests assist in material selection, allowing engineers and designers to choose the most appropriate rubber material for a specific application, depending on its strength and elasticity. They are also instrumental in research and development, helping scientists to gain deeper insights into material behavior and to develop new, improved materials. Moreover, these tests aid in compliance with industry standards and regulations, ensuring that rubber products adhere to required specifications. Additionally, they support failure analysis, enabling investigators to identify the root causes of material failures. Finally, material tests lead to process improvement in manufacturing, as they provide insights into factors affecting material quality and performance.

5.5. Experimental Studies

The experimental setups are presented in Table 3, Table 4, and Table 5 below. The details of the tables include the types and amounts of materials used in the experiments well as the temperature that the produced material is exposed to.

Table 5.1. Experimental Setups for the Experiments I - II - III.

	NUT SHELL	GLYSEROL	VINEGAR	WATER	STARCH	OTHER INGREDIENTS	TIME
Experiment I	5 tsp Walnut Shell Dust	6 ml	2 ml	10 ml	3 tsp Wheat Starch	-	30 min.
Experiment II	5 tsp Pumpkin Seed Dust	6 ml	2 ml	10 ml	3 tsp Wheat Starch	-	30 min.
Experiment III	5 tsp Walnut Shell Chips	20 ml	5 ml	50 ml	5 tsp Wheat Starch	-	50 min.

*(All experimental setups were heated at 180°C.)

The first 3 experimental setups were prepared and fired at the same time. The number of components (glycerol, vinegar, water, and starch) added to the wall nutshell dust and pumpkin seed dust were the same. The amount of walnut shell chips and the components were increased in the 3rd Experiment because as the size of the pieces increased, the number of components became insufficient to be bound together.

Experiment I Observations:

In the first experimental setup, walnut shell dust was used. Small sized epoxy molds were preferred for this setup. Although the color tone, thickness and texture of the resulting material are as expected, it was observed that the produced biomaterial can easily break because it does not have enough elasticity. Moreover, fragile material is not durable and does not have sufficient inter-material bonds. At the same time, while one side was in the expected brown tone, the other side got a more gray-brown color.

Experiment II Observations:

çIn the second experimental setup, pumpkin seed dust was used. Same, small sized epoxy molds are also preferred for this setup. Although the color tone, thickness and texture of the resulting material are as expected, it was observed that the biomaterial produced can easily break because it does not have enough elasticity. This fragile material is not durable and does not have sufficient inter-material bonds.

Figure 5.18. Experiment I&II.

Experiment III Observations:

In the third experimental setup, chips of walnut shell were used instead of walnut shell powder. Although the particle appearance and texture of the produced biomaterial are aesthetically appealing presenting a natural texture, it is observed that it can easily be broken and scattered. The emerging material's elasticity is low and therefore it is extremely fragile. Moreover, as it was kept in room conditions, its appearance was also changed, and its color acquired a pale gray-brown color over time.

Figure 5.19. Experiment III.

After the first three experimental studies, it was understood that the material would be brittle without a binding material. The possible reasons for the brittleness of the produced material in the first three experiments were lack of sufficient amount of fibrous structure and lack of binders. Therefore, the experimental setups were improved with organic binding materials. Extensive research was conducted to investigate bio-binding materials to decide for an effective bio-binding material.

One of the candidates as a bio-binding material was found to be glycerol. Although glycerol has a binding feature, it is not intended to be used in the following experiments. The reason for this is due to its water-retaining feature because there was the possibility of causing breaks when the mixture is heated in the oven.

Gelatin and Agar agar were found to be more suitable for the following experiments due to their properties on binding. Agar agar has also been used as a vegan alternative to gelatin. It was found that apart from these two materials, egg yolk, lignin, chitosan, bio-based resin, and similar materials can also be used as bio-binders.

Table 5.2. Experimental Setups for the Experiments IV – V – VI – VII.

	NUT SHELL	GLYSEROL	VINEGAR	WATER	STARCH	OTHER INGREDIENTS	TIME
Experiment IV	5 tsp Walnut Shell Dust	6 ml	2 ml	10 ml	3 tsp Wheat Starch	2 tsp Gelatin	50 min.
Experiment V	5 tsp Pumpkin Seed Dust	6 ml	2 ml	10 ml	3 tsp Wheat Starch	2 tsp Gelatin	50 min.
Experiment VI	5 tsp Walnut Shell Dust	6 ml	2 ml	10 ml	3 tsp Wheat Starch	1 tsp Agar Agar	30 min.
Experiment VII	5 tsp Pumpkin Seed Dust	6 ml	2 ml	10 ml	3 tsp Wheat Starch	1 tsp Agar Agar	30 min.

*(All experimental setups were heated at 180°C.)

Figure 5.20. Walnut Shell Chips and Dust.

Figure 5.21. Pumpkin Seed Chips and Dust.

Experiment IV Observations:

In Experiment IV, walnut shell dust was used, and the basic change was to add gelatin as a bio-binder. The amount of time of exposure to heat was also increased. The color and texture of the biomaterial obtained was as expected. Despite the increase in time of exposure to heat, it remained at almost liquid state when removed, and it took 2-3 days for the material to cool down and solidify in room conditions. The problem identified with this setup was that the composite material, which was poured into the mold to create a thin layer, was fired without resting after it was processed in the mixer. Because of this, bubbles were formed, which prevented obtaining a solid material and resulting in a prolonged solidification process. The biomaterial produced in this experimental setup had a crusted outer surface and the inside layer could not completely solidify, it only condensed.

Experiment V Observations:

Experiment V involved pumpkin seed dust as the main material. Again, gelatin was used as a bio-binder and the temperature was increased. Similar results with Experiment IV were obtained. The color and texture of the produced biomaterial were as it was expected; it remained liquid when it was removed from the oven; and bubbles were formed which resulted in the need for a long time, 2-3 days, for the material to cool down and solidify at room conditions.

Figure 5.22. Experiments IV&V.

Experiment VI Observations:

The main change in Experiment VI is the use of agar agar, a vegan alternative to gelatin, as a bio-binder. This experimental setup resulted in the closest outcome to the expected results. The color and texture of these assemblies appeared as desired. However, it has been observed that there are still fractures on the material surface in large sized molds. It was predicted that the reason for this could be the change in the size of the material because of dehydration with the loss of water, due to exposure to temperature. These findings and discussions revealed as a question for the next stage to understand, whether this problem could be solved if the material was molded as a thicker piece. Bubbles were not formed because the components were mixed with a hand mixer. This is important because when a mixer is used, there is no need to wait for the mixture to rest, shortening the production process.

Experiment VII Observations:

Agar agar is used again as a bio-binder in Experiment VII. The biomaterial produced has properties closest to expected and similar to the previous stage. Considering the fibrous structure of pumpkin seeds used in Experiment VII, it can be said that a better bond is established among the materials used. Therefore, the biomaterial produced at this stage was decided to be tested for its durability and stretching/elasticity.

Figure 5.23. Experiments VI&VII.

Table 5.3. Experimental Setups for the Experiments VIII – IX – X - XI.

	NUT SHELL	GLYSEROL	VINEGAR	WATER	STARCH	OTHER INGREDIENTS	TIME
Experiment VIII	5 tsp Walnut Shell Dust	8 ml	4 ml	25 ml	3 tsp Wheat Starch	2 tsp Gelatin	30 min.
Experiment IX	5 tsp Pumpkin Seed Dust	8 ml	4 ml	25 ml	3 tsp Wheat Starch	2 tsp Gelatin	30 min.
Experiment X	5 tsp Walnut Shell Dust	8 ml	4 ml	25 ml	3 tsp Wheat Starch	2 tsp Agar Agar	30 min.
Experiment XI	5 tsp Pumpkin Seed Dust	8 ml	4 ml	25 ml	3 tsp Wheat Starch	2 tsp Agar Agar	30 min.

*(All experimental setups were heated at 180°C.)

Experiment VIII Observations:

In this experimental setup, walnut shell dust was used. The main change in Experiment VIII is that the produced biomaterial is poured into thicker molds. Moreover, the amount of water was increased in order to avoid cracks that may occur on the surface of the thick material due to dehydration. In addition, the components were mixed with a mixer and rested for minimum 30 minutes and poured into the mold in order to prevent bubble formation. The reason for this action is because the surface of the molded mixture cannot be fully flattened to obtain a smooth surface due to its sticky and dense structure.

Experiment IX Observations:

Experiment IX was conducted with pumpkin seed dust. The properties of the biomaterial produced in this experimental setup were similar to the results obtained in Experiment VIII as well as the components, tools and the process followed. Both materials produced in these two experimental setups shrank in size after they are exposed to temperature. We can define this reduction in size as a result of water loss.

Figure 5.24. Experiment VIII&IX&X&XI Setups.

Experiment X Observations:

In Experiment X, agar agar was used instead of gelatin. Other parameters are all the same as the Experiments VII and IX setups. The most important difference found about this mixture when compared to the previous biomaterial experimental setups made with gelatin is that it is very easy to shape since it does not have a very dense structure. The biomaterial, which also shrinks in size after being exposed to temperature, just like the biomaterials produced in the previous experimental setups, meets the expected criteria in terms of durability and flexibility so it was saved to be tested.

Experiment XI Observations:

The setup of Experiment XI was the same as Experiment XI. Only pumpkin seed dust was used instead of walnut shell dust. The biomaterial produced in this experimental setup has the potential to be easily shaped. The resulting biomaterial also has flexibility and durability conditions.

Figure 5.25. Experiment VIII&IX&X&XI Setups in Mold.

The best results in terms of color, texture and physical properties were obtained in Experiments X and XI. However, in order to obtain definitive results, scientific tests must be performed in the laboratory environment. Therefore, these biomaterials are sent for testing for their elastic capacity measurement in the next stage of the research study. The next section presents the results of the tests conducted for the biomaterials produced in Experiments VII, X and XI.

5.6 Limitations in the Experimental Study

The biomaterial produced using walnut shell powder in Experiment X was sent to testing for elastic capacity measurement in the next stage of the research study because in this experimental setup a single-piece biomaterials was produced without cracks and tears and the sample biomaterial had elasticity and was more resistant to the pulling force applied by hand when compared to samples produced in other experimental setups. Therefore, only this sample was continued to the testing phase, although many biomaterial samples were produced during the prototype production process. The reason for testing one of the produced materials is due to the limited duration of the master's thesis study. Additionally, the material development process was slow and had disruptions due to the experimental research environment. The experiments carried out to produce sample biomaterials needed to be conducted in a more suitable laboratory environment with advanced tools and technology in further research studies in future.

There were also restrictions in the tools used to develop the biomaterial samples. Round and rectangular molds were used as molds. Since these molds are epoxy-based molds, the drying of the surfaces remaining in the mold after the heat treatment stage was slower than the surface in direct contact with air. This caused the surface in contact with air to shrink more than other surfaces in some samples. At the same time, since the dimensions of the molds were not required for many tests, the tests were limited to those explained in the next section.

The thesis study period for the development of the biomaterial samples was limited, which has led to lack of time for retest after the first test results were released. It is planned to continue with further experimental studies to improve the biomaterial to have the defined and desired characteristics to be used as a biomaterial in architectural design in future. The next section presents the results of the tests performed for the biomaterial produced in Experiment X.

5.7. Testing Process and the Expected Test Results

In order to test the resulting materials produced in the experiment, first the test methods for the intended use and then the test methods for the structure were investigated. As the targeted test result, the produced material was expected to be an alternative to traditional elastic material found in the floating floor systems. Therefore, the characteristics of traditional elastic materials used in floating floor systems were explored. The layers of the floating floor, in order from top to bottom, are parquet or similar floor covering, screed, waterproofing, polystyrene and similar elastomer material, rock wool, polyethylene foil or PVC foil and reinforced concrete flooring [35]. Rubber-like elastomer materials intended to absorb impact and sound are standardized according to TS EN 12354-2 and have the capacity to absorb sounds at certain decibels. TS EN ISO 12354-2 standard is a standard accepted on 28.01.2019 under the name "Building acoustics - Determination of the acoustic performance of buildings from the performance of the elements - Part 2: Insulation of impact sound between rooms"[37]. The scope of this standard includes estimating and calculating sound propagation by measuring the direct or indirect transmission of impact-induced sound between rooms in buildings. In accordance with ISO 717-1, the calculation model includes details for band analysis calculations in the frequency range of 1/3 octave 100 Hz to 3150 Hz. It enables the "Sound reduction index (R)" values of this experimental model, which was created based on theoretical calculations regarding sound insulation, to be found. In order to find the R value in the relevant calculations in the ISO 12354 standard, it is necessary to know the material's thickness, density, surface mass, elasticity modulus, internal loss factor and the speed of sound in air [37].

When the tests carried out for elastomer materials used in the construction sector were investigated, the information received from many companies in the sector, TSE laboratory and METU Central Laboratory clarified that performing the following tests will provide important data for the development of the biomaterial in this research:

- Particle Size Analysis Test,
- Tension/Compression/Bending Test,
- Shore A Test,
- Impedance Tube Test.

5.8. Findings and Discussion: The Effectiveness and Sustainability of Nutshell Biomaterials in The Context of Experiments

Experimental study conducted within the scope of this thesis study revealed some problems associated with the use of nutshells as a biomaterial for architectural design. Processing nutshells can be challenging due to their complex structure and varying physical properties, which can affect the quality and consistency of the composite material.

Additionally, while nutshells are biodegradable, their long-term durability as a building material is still unknown.

Therefore, it is important to note that the experimental research presented in the article is just an initial step in the process of exploring nutshells as a sustainable biomaterial for architectural design. More research, testing and development are needed to optimize the use of nutshells as a biomaterial and to address the problems associated with their processing and durability. Further experimentation and testing can help improve our understanding of nutshell-based composites and their potential applications in the built environment.

Since all of the components used in each experiment were biomaterials, the negative impacts that can be caused by the produced biomaterials on nature and environment are minimal. However, the biomaterials produced in experiments presented in the thesis had the following problems:

- Cracks were found in the nutshell-based composites after they were heated in oven. This is likely due to a decrease in their humidity when they are exposed to high temperatures during the manufacturing process.
- Brittleness caused as a result of reduced elasticity is another significant problem faced in the biomaterials produced, as they have natural fibers with various physical properties.

Therefore, it is concluded that it is crucial to optimize the processing techniques used with nutshells and other biomaterials to ensure that they maintain their mechanical properties and resist cracking and other forms of damage.

To address these issues, further research is needed to identify processing techniques that can minimize the risk of cracking and other forms of damage to nutshell-based composites.

Figure 5.26. Walnut Shell Chips and Dust.

Figure 5.27. Pumpkin Seed Chips and Dust.

5.9. Test Results

Particle Size Analysis Test:

The characteristic features of grain sizes in materials affect many areas such as durability, chemical reactivity, opacity, fluidity, and material strength. Particle size analysis is performed by measuring the refraction and permeability of light around the particles with the Mie scattering theory. Grain sizes may vary between 0.02 and 2000 microns depending on the material [41]. In Mie scattering, front, edge, and back scatter analysis is performed with red light, while wide-angle front and back scatter analysis is performed with blue light.

Macro- and nano-sized particles can be distinguished in terms of their size. Macro particles are 100 micrometers (μm) or larger, while nano particles are 100 nanometers (nm) or smaller [41]. This size difference significantly affects the properties and behavior of the particles. Macro particles are usually visible to the naked eye. These particles can generally be solid, liquid, or gaseous. Macro particles are used in many different fields. For example, they are used in construction materials, foods, and medicines. Nano particles cannot be seen with the naked eye [41]. These particles are usually in solid form. Nanoparticles are used in the development of new and advanced materials, devices, and technologies. For example, nanoparticles are used in the fields of electronics, medicine, and energy.

Some common measurement methods used for macro and nano sized particles are:

- Imaging: The size and shape of particles are measured visually using a microscope or electron microscope.
- Diffraction: The scattering of light or electrons by particles is used to determine the size of the particles.
- Filtering: Particles are separated and sized by size using a filter.
- Sedimentation: Particles are separated according to their size by settling in a liquid and their dimensions are determined.
- Dynamic light scattering: Particles are scattered by light to determine their size.
- Measuring the size of particles is an important part of understanding the properties and behavior of particles. This information is important in applications where particles are used.

There are 2 methods of particle size analysis: dry and wet methods [41].

- Dry particle size analysis is performed on solid, dry particles. In this method, particles are not suspended in a liquid but analyzed in a dry state. This analysis offers advantages in terms of its simplicity and speed, and it is particularly suitable for solid materials like powders and granules. It eliminates concerns about changes in particle size due to wetting or dissolution. However, it may not be suitable for particles naturally in a wet state or prone to agglomeration.
- Wet particle size analysis involves the suspension of particles in a liquid. It is versatile and suitable for a wide range of particle types. Wet analysis often yields more accurate particle size distribution data. However, it requires careful sample preparation and dispersion techniques to prevent particle agglomeration or settling. The addition of a dispersing medium can introduce potential errors or inaccuracies.

In summary, the choice between dry and wet particle size analysis depends on the specific requirements of your application and the nature of the particles you are analyzing.

If you are working with dry, non-aggregating particles, dry analysis may be sufficient and more appropriate. However, if your particles are naturally wet and sticky, or if you need to understand their behavior in a liquid environment, wet analysis is the preferred method. Proper sample preparation and instrument calibration are crucial to obtaining accurate and meaningful results with both methods.

This test was carried out at METU Central Laboratory. The device used to measure particle size in the Central Laboratory is the Malvern Masterzsizer 2000 model. Wet measurement method was used for walnut powder. For this, 200 mg of walnut powder was used. As a result of the test, walnut powder gave average results in macro size. Macro-sized particles have visible and distinguishable sizes. In the walnut powder sample, 1% of the particles were 35 µm (micrometer or micron: It is a unit of length equal to one thousandth of a millimeter or one millionth of a meter). 5% of the particles were 325 µm and 9% were 865 µm. This resulted in the possibility of dissolution in water without cross-linking due to its large particles. Cross-linking is a form of bonding that occurs when chains are covalently bonded to each other in different directions. Hydrogel-like materials feature a network structure consisting of hydrophilic polymer chains with physical, chemical, or biological cross-linking and can retain water with surface tension and capillary forces. In this way, they can remain undissolved in an aqueous environment or when they enter a solvent [23].

Figure 5.28. Mastersizer 2000.

MASTERSIZER 2000

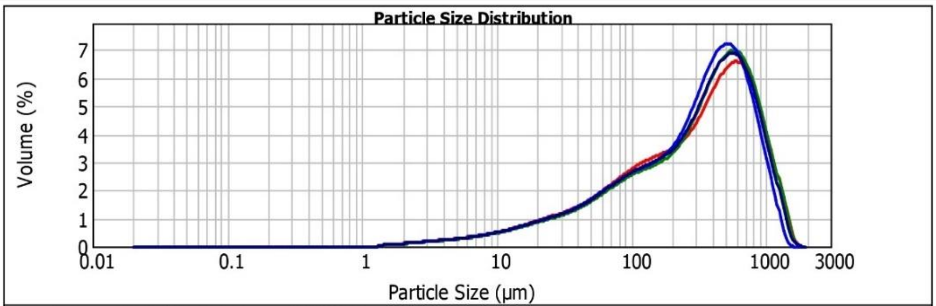
Result Analysis Report

Sample Name: ceviz tozu - Average	**SOP Name:**	**Measured:** 01 Eylül 2023 Cuma 10:53:29
Sample Source & type:	**Measured by:** PBA	**Analysed:** 01 Eylül 2023 Cuma 10:53:31
Sample bulk lot ref:	**Result Source:** Averaged	

Particle Name: Default	**Accessory Name:** Hydro 2000S (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.520	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 11.44 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.685 %	**Result Emulation:** Off

Concentration: 0.1081 %Vol	**Span :** 2.553	**Uniformity:** 0.811	**Result units:** Volume
Specific Surface Area: 0.09 m^2/g	**Surface Weighted Mean D[3,2]:** 66.645 um	**Vol. Weighted Mean D[4,3]:** 392.825 um	

d(0.1): 35.040 um **d(0.5): 324.871 um** **d(0.9): 864.386 um**



—ceviz tozu, 01 Eylül 2023 Cuma 10:53:29
—ceviz tozu, 01 Eylül 2023 Cuma 10:53:45
—ceviz tozu, 01 Eylül 2023 Cuma 10:54:01
—ceviz tozu - Average, 01 Eylül 2023 Cuma 10:53:29

Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %
0.010	0.00	0.105	0.00	1.096	0.00	11.482	0.54	120.226	2.62	1258.925	1.18
0.011	0.00	0.120	0.00	1.259	0.01	13.183	0.61	138.038	2.73	1445.440	0.23
0.013	0.00	0.138	0.00	1.445	0.07	15.136	0.69	158.489	2.87	1659.587	0.02
0.015	0.00	0.158	0.00	1.660	0.08	17.378	0.76	181.970	3.07	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	0.10	19.953	0.84	208.930	3.36	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	0.12	22.909	0.92	239.883	3.74	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	0.14	26.303	1.00	275.423	4.23	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	0.16	30.200	1.09	316.228	4.80	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	0.19	34.674	1.20	363.078	5.38	3801.894	0.00
0.035	0.00	0.363	0.00	3.802	0.21	39.811	1.32	416.869	5.88	4365.158	0.00
0.040	0.00	0.417	0.00	4.365	0.23	45.709	1.47	478.630	6.18	5011.872	0.00
0.046	0.00	0.479	0.00	5.012	0.26	52.481	1.64	549.541	6.21	5754.399	0.00
0.052	0.00	0.550	0.00	5.754	0.29	60.256	1.83	630.957	5.89	6606.934	0.00
0.060	0.00	0.631	0.00	6.607	0.33	69.183	2.02	724.436	5.25	7585.776	0.00
0.069	0.00	0.724	0.00	7.586	0.37	79.433	2.21	831.764	4.34	8709.636	0.00
0.079	0.00	0.832	0.00	8.710	0.42	91.201	2.37	954.993	3.30	10000.000	
0.091	0.00	0.955	0.00	10.000	0.48	104.713	2.50	1096.478	2.23		
0.105		1.096		11.482		120.226		1258.925			

Operator notes:

Malvern Instruments Ltd.
Malvern, UK
Tel := +[44] (0) 1684-892456 Fax +[44] (0) 1684-892789

Mastersizer 2000 Ver. 6.01
Serial Number : MAL100704

File name: Mayıs-2018
Record Number: 12592
05.09.2023 12:23:00

Figure 5.29. Particle Size Analysis Test Result.

Shore A Test:

It is used to measure the hardness of rubber and similar PVC, leather, neoprene, and polyester materials. It penetrates to a depth of 0-2.5mm and gives measurement results from the shore value. Neoprene, Rubber and Cork isolation pads are used to isolate high frequency vibrations created by mechanical and industrial equipment. It is possible to choose materials in different surface sizes with Shore values of 30-70 for all Elastomer Insulation pads [39]. Shore value is a term used to express the hardness level of plastic materials. Hardness, which is generally defined as the material's resistance to deformation, is not a direct quantity but is calculated based on the deformation of a material with higher strength on another material with lower strength [39]. It can be evaluated that the smaller the deformation, the higher the hardness of the material.

Shore hardness value is used to measure the hardness of polymers, elastomers, rubbers, fabrics, and sponges. Shore-A and Shore-D are most commonly used in measurements [40]. They are classified according to the penetrating tip and the weight used. Using the Shore-A method; In general, the hardness of soft materials such as elastomer, vinyl, rubber, rubber, leather, PVC, silicone rubber, Teflon, neoprene, and polyester, ABS, nylon, polyurethane, polyamide, Kevlar, acrylic, wood, and polystyrene using the Shore-D method [40]. It is used to measure the hardness of more rigid materials. Shore-D method is used to measure the hardness of engineering plastics.

In this application, how much the hardness tip penetrates the material is measured. The diving tip is moved by a spring system with features determined by international norms. The greater the hardness value of the material, the less the immersion depth; but the applied force will be just as high. Measurement is generally made with a Durometer according to ASTM D2240 standard [40]. Shore units of the reference and the sample must be the same. While one is measured with Shore-A, the other is measured with Shore-D and should not be compared. Since hardness is a property specific to the material and also a function of temperature, looking at the reference and sample at the same ambient temperature will give more accurate results in comparison. In general, the hardness value of the product depends on the depth of the tip after it is applied for 15 seconds, on a flat surface, ~3 mm thick, with the sample's base adhered to a hard surface [39]. The shore has no units, it is dimensionless.

Figure 5.30. Shore Test Devices (Kori Durometer & Shore Leverloader).

For the Shore test, measurements were made in two different laboratories. The results obtained with the Leverloader device, one of which is used in TSE Konya Laboratory Directorate, were carried out at room temperature on samples of 2 different thicknesses. While the result obtained from the 3cm thick sample is 44.15 shore, the result obtained from the 1cm thick sample is 35 shores.

The other testing laboratory is a rubber company. Here, 2 samples were tested with the Kori Durometer device. While the result was 43 shores in the thick sample, it was 39 shores in the thin sample. The average was stated as 41 shores by the official who conducted the test. For the Shore test, it was informed that since there were gaps in the sample due to bubbles in some places, the result of the material in the test could be considered as +/-5.

SHORE A HARDNESS TEST							
INSPECTION AND TESTS							
SAMPLE	1. Measurement		2. Measurement		3. Measurement		AVERAGE
THICK SAMPLE	46	48	42	40	44	45	44,16
THIN SAMPLE	34	36	36	32	38	34	35

Figure 5.31. Leverloader Test Results.

Shore A test result between 35-45 indicates that the tested material is moderately hard. This means that the material has some flexibility, but also a certain amount of rebound.

The Shore A hardness scale ranges from 0 to 100. 0 represents the softest material and 100 represents the hardest material. A hardness value of 35-45 corresponds to the following materials:

- Rubber
- Silicon
- Polyurethane
- Soft plastics

A Shore hardness value of 35-45 indicates that the tested material has the following properties:

- moderately hard
- a little flexible
- a certain amount of recoil

These properties enable the material to be used in certain applications. For example, tires need a certain amount of elasticity to maintain grip and resistance. Rubber seals need a certain amount of rebound to prevent leaks [39].

Tension/Compression/Bending Test:

Tension test is used to determine the mechanical property of the material. It is used to measure the resistance against a static and slowly applied load. In the tension test, the ductility, strength, and rigidity of the material are determined. In addition to the test, compression and bending tests are also performed. Tests performed at room temperature.

A tension tester is an electromechanical testing system that applies a tension force to a material. During the tension test, the force applied to the device and the elongation of the sample are recorded. Measuring the force required to stretch or extend a material to permanent deformation or failure helps designers and manufacturers predict how materials will perform when used for their intended purpose.

In addition to the tension test, compression and bending tests are also performed. Tests are performed at room temperature. Compression test is used to measure the characteristic behavior of a material when compressive force is applied [42]. The test data results in the form of a tension strain diagram that also shows the elastic limit, proportional limit, yield point and compressive strength. This test is the opposite of the tension test. Common types of compression tests are compression testing, bending testing, and spring testing [42].

Rubber-like materials are characterized by being flexible and ductile. The desired results to be obtained in these tests for rubber-like materials are as follows:

- High yield point: It shows the material's resistance to plastic deformation.
- High breaking point: It shows the material's resistance to breaking.
- High elongation: It shows the material's resistance to deformation.
- High bending strength: It shows the resistance of the material against bending force.
- High hardness: It shows the resistance of the material during bending.
- High ductility: The amount of deformation the material shows during bending.

These results are used to predict how rubber-like materials will perform in an application. For example, a rubber-like material with a high yield point is suitable for an application designed to withstand high stresses. A rubber-like material with a high breaking point is suitable for an application designed to withstand high impacts. A rubber-like material with high elongation is suitable for an application designed to withstand high deformations.

In the test performed with the Zwick Roell Z250 machine of METU Central Laboratory, no valid result could be obtained because the surface was not flat and smooth due to the large particle size.

The main reason for not getting results from Tension/Compression/Bending tests is that the surfaces of the samples produced are not flat and smooth. In addition, due to the formation of bubbles in the samples during cooking, areas occur in some parts of the surface area, which will create inconsistency in the test results. In order to be more efficient, metal or glass molds can be used instead of epoxy and plastic molds. Additionally, the samples can be pressed before they have completely cooled down to minimize the voids remaining inside them.

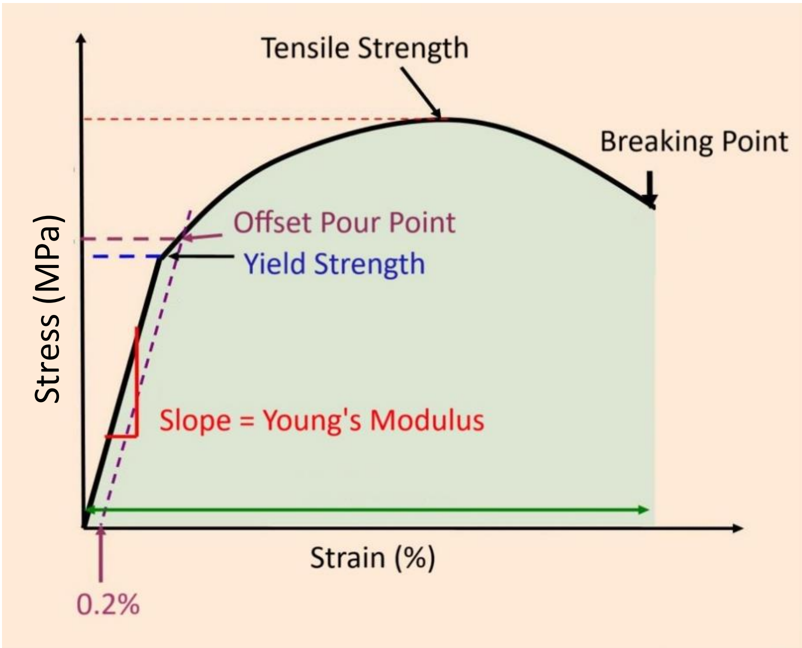


Figure 5.32. Zwick Roell Device & Strain/Stress Graphic.

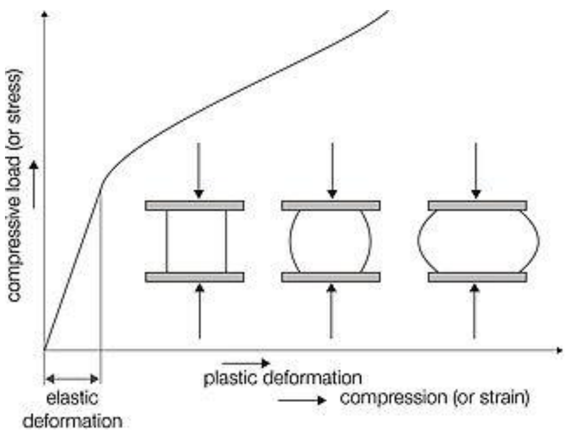


Figure 5.33. Compression Test Graphic.

Impedance Tube Test:

Impedance tube test is a test method used to measure sound absorption coefficient and sound transmission loss [24]. The test is measured by the sound pressure wave produced by the signal generator traveling through the tube and hitting the sample at the end of the tube. Samples to be prepared for impedance tube tests must be 28mm or 100mm in diameter [24]. Measurements can be made in the frequency range of 50Hz - 6400 Hz, at room temperature and under pressure [33].

Impedance tube values are analyzed using a computer program. This program analyzes the sound waves recorded by two microphones and determines values such as sound absorption coefficient and sound transmission loss [24]. The sound absorption coefficient, expressed as the difference between the energy of the incident wave and the energy of the reflected wave, is one of the basic values used in the production of acoustic materials [24]. It is a value that shows how well a material absorbs sound waves. This value is expressed as a number between 0 and 1. 0 indicates that the material does not absorb sound at all, while 1 indicates that the material absorbs sound completely [33]. Sound transmission loss is a value that indicates how well a material blocks sound waves [24]. The higher the sound transmission loss value, the better the sound wave blocking performance of the material. Some points to consider when analyzing impedance tube values are:

- The sample material must match the dimensions of the tube.
- The sample material should be placed flat in the tube.
- Measurements must be made in accordance with standards.

Impedance tube test is a test method used to measure sound absorption coefficient and sound transmission loss [24]. The test is measured by the sound pressure wave produced by the signal generator traveling through the tube and hitting the sample at the end of the tube. The sound absorption coefficient, expressed as the difference between the energy of the incident wave and the energy of the reflected wave, is one of the basic values used in the production of acoustic materials [33]. Samples to be prepared for impedance tube tests must be 28mm or 100mm in diameter. Measurements can be made in the frequency range of 50Hz - 6400 Hz, at room temperature and under pressure [24].

Figure 5.34. Impedance Tube.

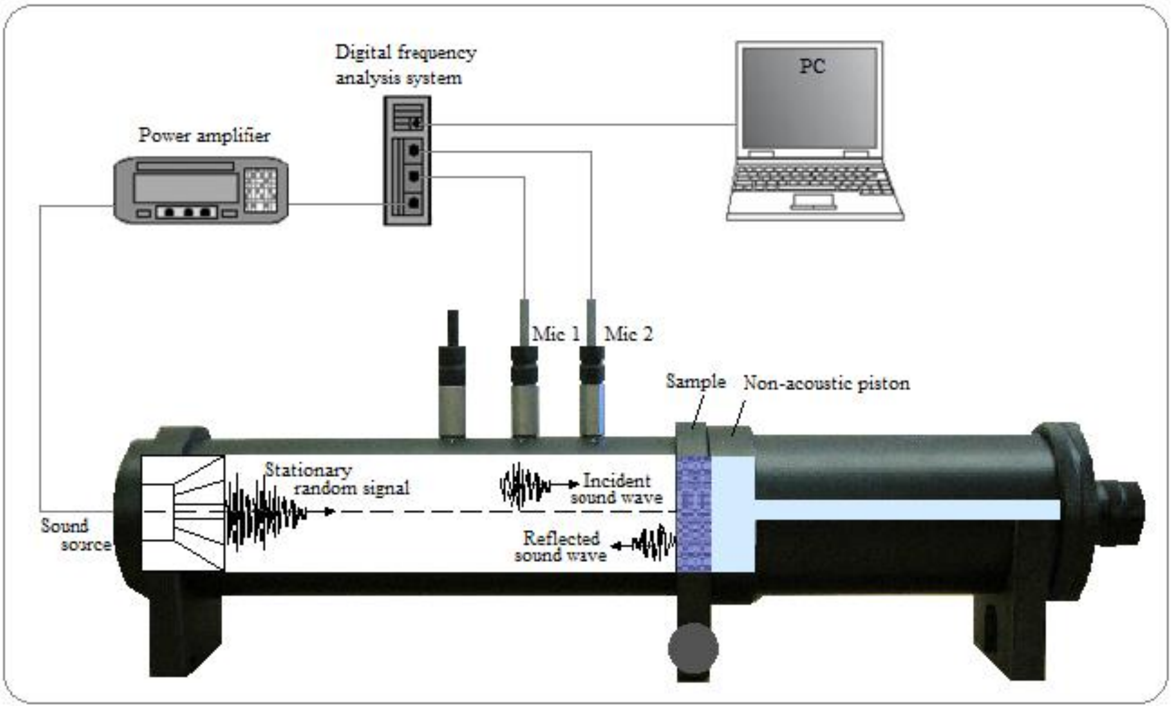


Figure 5.35. Visualization of the Working Principle of the Impedance Tube [33].

5.10. Discussion on Findings and Further Research

Processing nutshells can be challenging due to their complex structure and varying physical properties, which can affect the quality and consistency of the composite material. Therefore, it is important to note that the experimental research presented in this thesis is just an initial step in the process of exploring nutshells as a sustainable alternative to produce biomaterials for architectural design. More research, testing and development are needed to ensure their efficient use to replace elastomer material in floating floor systems and in other implementations in architectural design; and to address the problems associated with their processing and durability. Further experimentation and testing can help to improve our understanding of nutshell-based composites and their potential applications in the built environment. The durability and other physical and chemical properties of these materials need to be tested further before they can be used, with scientific testing methods, such as the followings:

- Compressive strength test.
- Flexural strength test.
- Tension/compression/bending test.
- Strength/Durability/Hardness test.
- Density test.
- Water absorption/Moisture resistance test.
- Heat/Fire resistance test.
- Fatigue test.
- Surface wettability test.
- Dimensional stability test.
- Biodegradation test.

Since all the components used in each experiment conducted within the scope of this research were biomaterials and the base material nutshells are biodegradable, the negative impacts that can be caused by the produced composite material on nature and environment are minimal. However, its durability in long-term as a building material is still unknown and needs to be observed over a long period of time. The strength, durability and elasticity characteristics also need to be improved to be used as an alternative material for the elastomer material found in floating floor systems. It is seen that the biomaterial samples produced in the experiments were affected by the amount of water and the following problems were observed:

- The biomaterial samples produced did not have homogenous smooth surface area.
- Due to sudden exposure to heat, the bubbles were formed by gelatin on the surface.
- Cracks were found in the nutshell-based composites after they were heated in oven. This is likely due to a decrease in their humidity when they are exposed to high temperatures during the manufacturing process.
- Brittleness caused as a result of reduced elasticity is another significant problem faced in the biomaterials produced, as they have natural fibers with various physical properties.

Laboratory test results of the biomaterial produced in this experimental study also revealed some problems associated with the use of nutshells to design an alternative composite material for elastomer material used in floating floor systems. As a result of the laboratory tests, it was seen that the composite structure of the biomaterial produced needs to be improved to have a more homogeneous structure. For this purpose, different bio-binders can be used for the composite structure. Moreover, impact of changes in the pH value on the characteristics of the biomaterial can be observed by modifying the elements in the composite structure in natural ways such as adding vinegar and lemon juice in further studies. In this way, the cross-linking feature can be achieved creating a balance also for water amount in the composite material. In addition, grinding walnut shell powder into smaller pieces would also contribute to the improvement of the homogeneity of the material. Moreover further research to identify processing and production techniques that can minimize the risk of cracking and other forms of damage to nutshell-based composites can also help to improve the composite structure. For instance, pressing can enhance the material to have a more homogeneous and flatter surface. Changing the heating source, method and tools can also improve the biomaterial's structure. Allowing time for the samples to solidify in room conditions before exposure of the material to heat may minimize bubble formation in further experimental studies.

It is also seen that thickness of the biomaterial affects the elasticity of the material. The thickness of a material plays a very important role in determining its flexibility. In materials science and engineering, elasticity is often a measure of the stiffness of a material. When it comes to thickness, it can be said that thinner materials tend to be more elastic than thicker ones. This is because thickness affects the density of atomic bonds and intermolecular forces within the material. Thicker materials have more bonds and interactions that resist deformation, making them less flexible and stiffer. Conversely, thinner materials have fewer of these bonds and interactions, allowing them to deform more easily under an applied force and thus exhibit greater flexibility. Understanding this relationship between thickness and elasticity is essential in designing and engineering materials for a variety of applications.

The produced biomaterial is also tested for sound absorption properties however the tests did not present significant results. Surface smoothness is a critical factor affecting the accuracy of many testing processes. One of the main reasons why test results may not be clear is surface irregularities. Surface irregularities or warps can affect the mechanical properties of a material, which can make test results misleading. Surface smoothing can help eliminate such problems and make test results clearer and more reliable. Therefore, special attention must be paid to surface smoothness to ensure the accuracy and reliability of testing procedures.

For future studies, not only walnut shells, but also other types of shells found on the outer surfaces of various shelled nuts that are unique to specific regions and have high consumption can be researched to develop bio-materials for architectural design. Textured or plain materials can be created in different sizes, shapes, and textures by using advanced tools and mixing and molding methods in more advanced laboratory studies. In addition, 100% bio dyes can be added to improve the aesthetic properties of the biomaterials according to their purpose of use. For this, leaves, seeds and skins/shells of plants and fruits can be used.

Finally, in order to ensure the required mechanical properties and resist cracking or other forms of damage, it is crucial to conduct further advanced experimental research and optimize the processing methods that can be used for upcycling nutshells and other bio-wastes to be used in the design of alternative architectural building materials.

6. CONCLUSION

Recent innovative research in the field of biomaterials supports architects and designers to create buildings that are not only functional, but also environmentally friendly and aesthetically pleasing. As sustainable design practices have become increasingly important in recent years, the development of alternative biomaterials such as composite materials produced from bio-wastes can play an important role in improving sustainability in the built environment. As a result of the literature review and meetings conducted with experts within the scope of this research study, it has been determined that large amounts of bio-wastes are produced from high nuts production and consumption in Turkiye. It is possible that these bio-wastes can be used for new purposes with the upcycling method. Within this context, this thesis study is focused on use of biomaterials in architectural design and investigated the potential of upcycling nutshells to produce a biomaterial as an alternative to the traditional elastomer material used in floating floor systems as an experimental case study.

The results of the research revealed that use of biomaterials in architectural design has potential for innovative and sustainable design solutions supporting the design of environmentally friendly and aesthetically pleasing building designs. However, there are many issues identified in the experimental study that need to be researched and developed in further advanced studies in future. It is found that biomaterial produced using walnut shells, which are one of the most produced biowastes due to their high production and consumption in Turkiye, can be a promising alternative for elastomer materials used in floating floor systems in architectural design with further advanced research. Although the biomaterial produced during the experimental study is renewable, biodegradable, and have unique physical and mechanical properties, it was seen during the testing phase that the biomaterial produced in the experimental study does not meet the material characteristics required and defined at the beginning of the experimental study. The findings in laboratory tests highlighted the problems associated with its composite structure and the need for further research to improve the elastic and sound absorbing characteristics of the composite material. If its elasticity is increased and rearranged with different molds and cracks are prevented, it can be reconsidered for use in floating flooring systems. Additionally, the biomaterial produced, which was aimed to have similar characteristics with traditional elastomer materials, can be developed for use in various other architectural systems and detail designs, such as a floor finishing material in indoor and outdoor children's playgrounds, bicycle paths, jogging, and walking paths, classrooms, playgrounds, and walking paths prepared for disabled people and raised floor systems. Further research on walnut shell-based composites can support development of innovative and sustainable alternative building materials to reduce the negative impact of the building sector on nature and health of people.

As a result, more and more construction projects are adopting this environmentally friendly approach to use biomaterials in architectural design. Biomaterials derived from renewable resources such as agricultural waste, wood, and even certain types of fungi, offer numerous benefits to the construction industry. This approach not only reduces the carbon footprint of buildings, but also promotes sustainable land use and minimizes the consumption of non-renewable resources. In order to highlight the importance of sustainable design methods that include biomaterials, living materials and materials derived from upcycled biowaste, it is crucial to encourage widespread adoption of these environmentally friendly alternatives and invest in research that facilitates their use. Integration of biomaterials into construction practices can lead to reduced energy consumption of buildings in both production and operation phases. This reduction in energy use, combined with the potential for improved indoor air quality, can result in healthier and more sustainable living and working environments. It is especially important to advance research on the life cycle and longevity of these materials. It is crucial to investigate how biomaterials degrade over time, their ability to withstand various environmental conditions, and the best methods for their recycling and disposal. Knowing in detail the stages that these biomaterials go through in their life cycle will instill confidence in their use. This information allows architects, engineers and builders to make informed decisions about the selection, use and maintenance of biomaterials in construction projects. Moreover, understanding the lifespan and durability of these materials enables them to contribute to long-term sustainability, reducing the need for constant replacement and minimizing waste in the construction industry. Another important step for encouraging the use of biomaterials would be developing guiding documents to define basic standards for safe and efficient use. Additionally, research should focus on the development of environmentally friendly production processes for biomaterials. Sustainable production methods can further reduce environmental impact and increase the feasibility of incorporating biomaterials into major construction. By exploring innovative ways to produce these materials and promoting their cost efficiencies, we can encourage their widespread use and help reduce the construction industry's negative impact on the environment.

Ultimately, the transition to biomaterials and sustainable design practices in construction is a vital step towards a greener and more environmentally responsible future. By promoting the use of biomaterials, conducting in-depth research, and developing environmentally friendly production methods, we can ensure that the construction industry plays an important role in reducing negative environmental impacts and promoting a more sustainable built environment for future generations.

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