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Francesco Alberti · Abraham R. Matamanda · Bao-Jie He · Adriana Galderisi · Marzena Smol · Paola Gallo *Editors*

Urban and Transit Planning

City Planning: Urbanization and Circular Development

Third Edition

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IEREK Interdisciplinary Series for Sustainable Development

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Preface

It is now 50 years since the first world Earth Summit held in Stockholm (1972) and 30 years since the Rio de Janeiro Conference on Environment and Development (1992), whose Declarations played a crucial role in shaping global awareness of sustainability issues and the risks associated with an extractive model of economic development that irreversibly impacts the environment and climate balance of our planet. The notion of sustainable development, i.e., an alternative model of development that integrates the economic dimension with the environmental and social dimensions, and "meets the needs of the present without compromising the ability of future generations to meet their own needs", was formulated and disseminated worldwide by the Brundtland Report *Our Common Future,* published by the UN Commission on Environment and Development some 35 years ago (1987). Starting from these cornerstones, the scientific debate and the political initiatives taken at various levels—international, national, and regional—have been highly articulated and enriched over time with a growing involvement of the media, public opinion, and, recently, a strong assumption of responsibility by the youngest (the "future generations" who have meanwhile been born and clearly see the threats to their future), claiming that these challenges are translated into concrete actions and policies to correct the course followed so far since the Industrial Revolution. And it is in fact to the pre-industrial era that the Paris Agreement (2016) refers in defining as a virtuous target a limit of the global average temperature increase to 1.5° by the end of the current century. An ambitious target (which in any case will not prevent serious consequences on territories and populations worldwide) to be pursued through national and transnational strategies of ecological transition of settlements, economic activities in all sectors (starting with energy production), mobility, and transport (from urban to intercontinental).

As we said, much progress has been made, with peaks of innovation that would bring immediate benefits in many decisive fields, if they became the current standard. But we cannot deny that over the last 50 or 30 years, the awareness of the risks we face has had very little impact on the development trajectories of both the most industrialized and emerging countries. And cities, even those that have developed the most in recent years, are far from achieving the targets set by UN Sustainable Development Goal No. 11—"Sustainable Cities and Communities". Not to mention mobility models, which in developing countries, where the demand for the transport of people and goods increases year after year at the highest rate, usually follow the bad examples of richer countries instead of exploring new, more sustainable paths. This confirms Enrique Peñalosa's remark: "Transport differs from other problems developing societies face, because it gets worse rather than better with economic development. While sanitation, education, and other challenges improve with economic growth, transport gets worse".

So, with each passing day, the challenge for a more sustainable future, instead of diminishing with the accumulated knowledge and awareness becomes greater. There is only one way to face it and make up for past and present mistakes: increase studies, spread knowledge, and good practices, so that they can take root faster. This is the mission that this publication and the series of which it is a part seek to respond to. The selected papers that form the chapters of the book constitute a small but significant repertoire of the best that is being done or could be done in the fields of urban and transport planning.

I sincerely thank all the authors, who, from different corners of the world, share the responsibility to ensure that the 50 years path toward a paradigm shift in our way of being-in-the-world continues, accelerates, and involves more and more fellow travelers, until it becomes a common path.

Florence, Italy Francesco Alberti

Acknowledgments We would like to thank the authors of the research papers that were selected for addition in this book. We would also like to thank the reviewers who contributed with their knowledge and constructive feedback in hopes of ensuring the manuscript is of the best quality possible. A special thanks goes to the Editors of this book for their foresight in organizing this volume and diligence in doing a professional job in editing it. Finally, we would like to express our appreciation to the IEREK team for supporting the publication of the best research papers submitted to the conference.

Contents

Development of New Bio-based Materials Derived from Sicilian Agri-Food Industry Waste

Simona Colajanni, Tiziana Campisi, Alfonso Senatore, and Marco Bellomo

Abstract

The key factors that are transforming the market landscape are the European Green Public Procurement (GPP) policies, the rapid spread of voluntary green building rating programs, and the increasing focus on reducing our dependence on raw materials through the principle of the circular economy. As a result, the need for bio-based and sustainable building material solutions has increased dramatically. This research explores possible ways to reuse bio-based waste material (such as dried fruit shells), derived from the agri-food industry, for the production of healthy new building materials aligned with the principles of circular economy. Previous case studies and researches have demonstrated the reuse of dry-fruit shells for the making of new building components. However, current trends also show that synthetic resins are commonly used as binder to glue the valuable renewable agriculture by-product. This has a negatively impact on actual circularity of the resulting building materials as well as on people health and well-being due to VOC emissions. This study demonstrates, throughout laboratory-based investigations, the reuse of dried-fruit shells coupled with natural binders leading to a number of potential applications and the creation of bio-based new materials for the building industry. The encouraging initial results show how unused waste may become a valuable "nutrient" for the industry by keeping the material value flowing constantly in a circular loop and allowing material reuse and recyclability as long as possible. While testbed and reference of this study are the Sicilian context, the project outcome could be easily transferred to other countries with dried-fruit industries, encouraging the creation of new business models that replace or integrate the current ones, and also pushing skills and new roles in the supply chains capable of guaranteeing enhanced circularity of natural resources.

Keywords

Waste • Biomaterial • Circular flow • Dried fruit • Sicily • New economy • Hazelnut shell • Almond shell • Reuse • Recycle • Sustainability

1 Introduction

One of the problems to be addressed in the coming years is the reuse of raw materials, creating new products that use elements coming from waste. A very high percentage of waste in the world come from agri-food production, producing actually an unsustainable energy deficit. The potential reuse of waste is very high and equal to the quantity of waste present in the territory and in the agri-food production companies. The research aims to give new life to waste coming from agri-food production, with a particular attention to dried fruit, very diffuse in the Italian and Sicilian territory. The waste from the agri-food production of dried fruit entirely derives from fruit shells; these shells can be used and mixed as aggregates or inert into a new mixture, verifying the new properties. The experimentation will be based on the reuse of these materials, mixing them with only natural binders, such as natural wine vinegar and potato starch, creating some possible raw materials, applied for the design of new natural products. The context is that of a rapidly expanding market that requires more and more low-consumption materials, advantaging of natural recycled elements. In particular, the research aims to find a possible use of walnut waste as a fundamental element for the realization of a building component, easily recoverable and

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recyclable at the end of its construction life cycle. This premise implies the necessary and beneficial transition from a linear economy model to an increasingly sustainable and close circular economy model. We have studied the reference context of scientific literature related to hazelnut, almond, and pistachio shells use researches. We have focused our research basing on different areas of scientific literature, such as essays about the chemical characterization of waste walnut shells, the recycle of walnut shells as aggregates useful for the production of wooden particle boards or as aggregates for sustainable plasters, finally as a mixture for 3D printers. We also have examined some articles presenting studies of natural binders, creating mixtures for new cements or new insulating panels. What we finally highlighted is that, nowadays, there is a huge presence of use of unsustainable materials that make impossible the recycle of some products. Therefore, the aim of this study is to give an answer to the market demand for the creation of innovative and sustainable products, constituting a natural blend as well as an efficient reuse of waste material coming from the agro-food production of walnut shells. The ultimate goal is to re-enter into the market in a very competitive way, realizing a second material.

2 Circular Economy and the Reuse of Bio-based Waste

A well-established paradigm nowadays is the "circular economy", from the simple combination of the use of raw materials that identifies a production, a use, and a waste, we go from production to use, collecting the waste and recycling it in order to reuse it. The mechanism of the linear economy provides for the infinite use of raw materials, but the concept of circular is precisely in the fact that the material is not extracted but reused as the extraction of new materials is no longer sustainable in any field of innovation. The commitment to the mitigation of these risks and the search for new tools to ensure an efficient use of resources has led organizations to undertake innovative paths by approaching in a different way the issue of sustainable use of resources, through an ever-decreasing waste and waste disposal and an increasing reuse in new production processes. A technical and scientific opportunity for environmental sustainability in various sectors is now the implementation of the circular economy, identified as a centripetal driver of innovation (Fan et al., 2019). So an agricultural company, or a company of building materials, is able to participate in this sustainable project by enhancing the value of waste materials by giving new capacity for technological and innovative use. In this general context, the research of reusing food production waste into innovative and sustainable materials is focused, which can be revitalized into a new reconfigurable form and function as materials needed for development. The mechanism of circular economy should be usable in all categories of production of materials and also services, the study is conducted in the context of agro-food production of dried fruit in Sicily, where today all the waste product is eliminated, or reused as biomass (Angelidaki et al., 2018). This pool of waste becomes a flywheel for the production context, as it would give strength to a new economy and sustainable technology. In our economic system, a protagonist of sustainability must be the reuse of natural raw materials, in this area, the dried fruit becomes very important, as it can fill many needs of the demand for biobased materials. The study aims to identify possible natural and sustainable solutions to give a new life to agro-food waste produced by dried fruit companies in particular. Within the mechanism of the circular economy, there are countless solutions, of these, however, it is necessary to evaluate those that are energy sustainable and of course one of the objectives of this study is to establish a working table on the reuse of agro-food production waste by investigating sustainable and reusable solutions within the various branches of product use. Agricultural waste, also citing study (Gothard et al., 2018), is a huge pool of untapped biomass resources that can also represent economic and environmental burdens. They can be converted to bioenergy and bio-based products through cascading conversion processes within the circular economy and should be considered residual resources. Furthermore, the promotion of business based on agricultural residues is discussed through industrial ecology to promote synergy, on a local basis, between different agricultural and industrial value chains.

3 Research Objectives

One of the problems to be faced in the coming years is the reuse of raw materials in order to create products with the majority of elements coming from waste. A very high percentage of waste in the world is constituted by waste coming from the agro-food production, whose production creates an energy deficit and for this reason not very sustainable at present. The potential for reusing waste is very high and equal to the amount of waste present in the territory and in the agro-food production companies. These wastes are at the center of the study presented, when it was thought to convert them to make new materials and even new products, and the latter to produce them in a completely sustainable, reusable, and recyclable, so as to fit into the concept of circular economy now present in our lives. The research aims to give new life to the waste coming from the agro-food production and in this case from dried fruit, very present in the Italian and Sicilian territory. The waste from the agro-food production of dried fruits is almost entirely the waste of fruit shells, these can be used and mixed as aggregates or inert within a new compound for a new reaction. The experimentation will be based on the possibility of reusing these materials by mixing them with only natural elements, such as wine vinegar and potato starch, present in nature, with which we can create new possible raw materials for the realization of new products of natural origin.

4 Materials and Methods

The research work on the possible reuses of waste materials from the agro-food production of dried fruit was organized in different programmatic phases of study. The research work was set up starting from the study of the state of the art, identifying various scientific researches and products in the same cultural context. The study of the state of the art on the reuse of products derived from food waste and in this case of dried fruit was followed by the study of quantities and presences in Italy and Sicily. It has been analyzed what are the most present elements within the Sicilian market, and what are the products that create the majority of waste within the production of dried fruit. Once the materials to work with have been chosen, a working process has been set up in the laboratory, where, using natural mixtures and natural binders, the response of the waste has been tested in various forms and with various compounds created. For the proposed study we followed a working methodology defined in the following steps:

- State of art evaluation and analysis of contextual literature;
- Analysis and characterization of waste material;
- Laboratory work;
- Analysis of results;
- Evaluations of possible prototypes.

Literature Review

Numerous past studies and case studies addressing the reuse of the by-product derived from the bio-based food industry, such as the reuse of dried fruit shells were identified and evaluated as part of this research project. The initial objective was to gather a solid foundation of knowledge on the studied subject, the state of the art on the reuse of agro-food waste in relation to the context of the green building materials and circular economy.

Many of the previous investigations and case studies discuss and evaluate the reuse of agricultural waste (i.e., hazelnut shell) as a pool of biomass for the production of bio-energy sources (Ahring et al., 2015) for generating both electricity and heat, or as potential renewable fertilizer (Bolzonella et al., 2017). Generating bio-fuel reusing agriculture waste seems to be the most logical way of valuing a residual resource like the dried fruit shells. It certainly represents a valid alternative to fossil fuels as well as a climate change mitigation measure. However, there are a number of constraints to be taken into account like the complexity and variability in the chemical composition of the waste feedstock, the presence of contaminants, and the degrading processes (Gontard et al., 2018), to just name a few. In addition, in all the energy processes considered above, the dried fruit shells are collected, treated, and then reused only once in order to be converted into usable bio-methane, bio-oil, bio-ethanol, or other forms of "sustainable" fuel. The material source is not constantly reused or recycled as required by the circular economy principles.

Another study suggests the reuse of hazelnut shells for the industrial production of particleboards and chipboards. In this case, a synthetic resin is used as binder to glue the valuable renewable agriculture by-product. According to the study, the resulting product may represent a valid wood substitute in panel production for the building industry (Cöpür et al., 2006; Senol, 2019). Similar studies explore the opportunity of using the structural strength of the shells to shape a novel material with an improved modulus of elasticity. The study shows that walnut shells can be used for the manufacturing lignocellulose and polyurethane-based panels while achieving enhanced strength performance (Cătălin Barbu et al., 2020). Dried fruit shells can also reused as a matrix for 3D printing (Singh et al., 2020). According to the study, the residual shells are powdered and reused to form a novel filament to be applied with 3D printers. The resulting polylactic acid (PLA)-reinforced almond husk powder is then used for the digital manufacturing of biomedical scaffolds.

The reuse of shell waste in the form of polymer–particle biocomposite is also explored by Muller. The study exploits the hazelnut (*Corylus avellana*) shells from a molecular point of view, demonstrating the possibility of using this waste in the area of polymer–particle composites with a low concentration of the filler based on hazelnut shell microparticles (5 wt%) and increased tensile strength. SEM analysis (Fig. 1) showed good wettability of the hazelnut shell microparticle-based filler. (Müller et al., 2018).

The use of synthetic resin and binders is a common characteristic of the identified past studies focused on the production of novel materials for the manufacturing of dried fruit shell base building products. However, the idea of reusing the agricultural waste in order to keep the reclaimed resource (the hazelnut shells) in use for as long as possible while extracting maximum value was one of the key drivers of our study. According to the principles of the circular economy, everything has to be designed to be constantly reused or recycled (Charlotte et al., 2019). On this basis, the investigation of published research and case studies was then stretched towards the reuse of dried fruit shells with natural

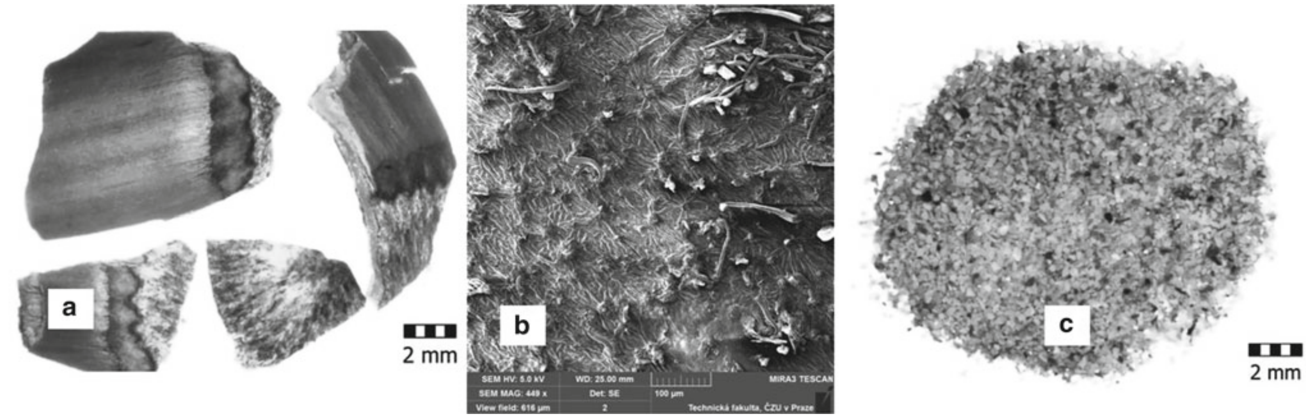

Fig. 1 SEM images of hazelnut shell © (Müller et al., 2018)

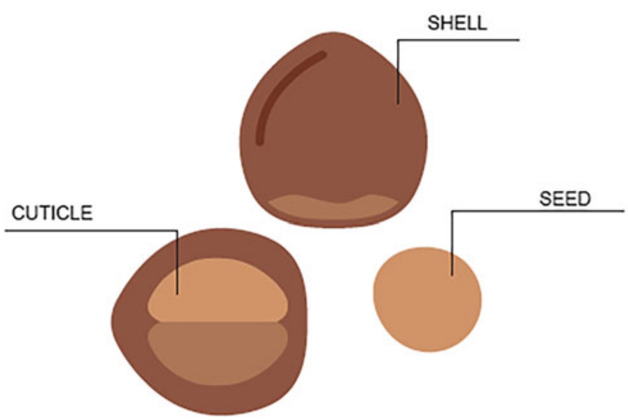

Fig. 2 Hazelnut scheme © (Manzella, 2020)

binders. An interesting contribution is represented by research on binders used for the production of glues for wood panels. (Müller et al., 2007). Due to the ecological and economic concerns, about harmful resins are replaced with natural binders for the production of wood binders. Pure bio-based binders or a combination of bio-based and conventional synthetic resins or chemical substitutes are also explored. Applications of natural binders depend on the properties of the binders and, most of all, by the "technique" used in the preparation of the glue adopted for the production of the boards. Chemical and physical properties of the resulting waste-based panels are directly affected by the strength of the binder. A further scientific research project, which served us as a basis for our exploration, is provided by the university's thesis called "Bùgia – Da scarto a risorsa" which was undertaken at the University of Turin (Ciancio et al., 2019–20). In this case, a novel bioplastic is produced by re-using hazelnuts and cocoa-based waste resources with natural binders. Researchers explore the use of glycerol, vinegar, potato starch, and water as natural binders together with hazelnut and cocoa cuticles.

On the basis of our literature review, it appears that very little has been done, to date, in evaluating the use of natural binders and fillers while exploiting the reuse the dried fruit shells. In fact, very few case studies were identified.

In response to the above knowledge gap, this research project has been building on previous studies and research projects to further explore the sustainable reuse of the dried fruit shell waste while keeping the material value flowing constantly in a circular loop, in order to allow reuse and recyclability as long as possible in order to extract maximum value (Salvador et al., 2019). In order to achieve the above, the exploration has been focused on the use of natural binders. The ultimate objective of the study was to advance the knowledge and qualitative data in relation to the reuse of the dried fruit shell waste coupled with natural binders aimed at the production of novel materials for the building industry.

Sicilian Dried-fruit Waste

Sicilian agriculture has always been described and narrated for the great variability of environments, climates, vegetation, and productions. From the North to the South of the island, from the Etna area to the one characterized by the salt pans of Trapani, each agricultural area has always had unmistakable always unmistakable elements of diversity that have made the region an environment of richness in the field of agricultural biodiversity widely recognized nationally and internationally, national and international levels. A substantial contribution has always been attributed to the sector of dried fruit, from which in Sicily are often derived elements of agricultural economy important that today important agricultural economy that today highlight timeless peculiarities with vivid contrasts in terms of development and perspective. Dried fruit is that sector which, in general, refers to the arboreal plant species producing fruits which, when ripe, are partially dried and which, after harvesting, undergo a process of complete drying before being marketed or subjected to post-harvest processing. All tree species for dried fruit are present in Sicily and many of them have contributed to a consistent agricultural development. Many of them have contributed to a consistent agricultural development in the island, especially in the past; some species are even of exclusive Sicilian interest, determining a national leadership and an important position on the international level. A fairly common feature in this sector is the extremely defined localization of the various species of the different species. As far as, in fact, the presence of almond, pistachio, hazelnut, and carob tree, is quite widespread throughout the island, it goes without saying that in the regional territory, over the centuries, have been consolidated areas with greater tradition, culture, and specialization for each species. The carob tree, for example, is a species that is found in the agricultural landscape of all Sicily, but it is unequivocal that the province of Ragusa, the Hyblean plateau, and the agrarian landscape typical of this area is inextricably linked with the presence of the carob tree indissoluble with the presence of the carob tree that is not only an element of continuity and presence but also a source of income and local economy. Or at least, it was very much so in the past. The same is true, for example, for the pistachio, which is historically present in the area of Bronte, in the province of Catania, where 90% of Italian pistachio cultivation is concentrated Italian pistachio cultivation, even though it is possible to find interesting experiences of cultivation of the although limited in surface, in the provinces of Caltanissetta and Agrigento.

In recent years, many companies have undertaken research and development initiatives for the production of materials starting from food waste, which in many cases identifies the specificity and territoriality of the food, giving the material a high environmental and social value. One of the fundamental productions of the Sicilian economy is that of agro-food sector, and more specifically, the production of dried fruit in the island is produced, for example, 84.600 tons of almonds and 150.000 tons of hazelnuts, the production context covers a very large basin (INSTAT, 2020).

Thanks also to creativity and technology, many of these materials have spread internationally to be used also by big fashion and furniture brands for clothing with double-digit prices. A path that is only at the beginning and that promises to arrive at the valorization of different types of food waste. In the field of reutilization of food production waste, one of the protagonists is dried fruit and all types of seeds whose production involves the formation of a large amount of waste (Senol, 2019). The waste represents today almost half of the agri-food production, it is identified by the shells of almonds, hazelnuts, walnuts, and pistachios. These dried fruit scraps are characterized and united by the presence of different percentages of cellulose, hemicellulose, and lignin, which characterize their chemical and physical behavior (Table 1).

All these productions, only in Sicily, form a large amount of waste that today is not exploited within a mechanism of circular economy. Thanks to the mechanical and physical characteristics of nut shells (Table 2), they can be reused in a variety of ways, in this study, we have investigated the possibility of reusing nut shells, using a completely natural and sustainable working methodology.

Most of the hazelnut installations in Sicily are distributed in the province of Messina, especially in the areas of Nebrodi and Madonie. It is possible to find cultivation not only in plain but also in mountainous regions up to 1,400 m of altitude. The cultivated surface, according to ISTAT amounts to a little more than 15,000 and is mainly located in the province of Messina (81% of the production). Followed by the province of Catania (9.9%), Enna (7.5%), and Palermo (1.6%) (INSTAT, 2020). Here, the hazelnut groves

Table 1 Dried fruit vegetal chemical characteristics

Shell	Hemicellulose (%)	Cellulose (%)	Lignin (%)
Pistachios	25.0	43.0	16.3
Hazelnuts	30.0	26.7	42.9
Walnuts	22.5	25.3	52.3
Almonds	34.6	48.4	17.0

Table 2 Dried fruit vegetal physical–mechanical characteristics

Shell	Density (kg/m^3)	Thickness (mm)	Modulus deformability (N/mm^2)	Heating power (kWh/kg)
Pistachios	320	0.3–0.5	180	3.2
Hazelnuts	360	1–1.2	250	4.2
Walnuts	250	1.6–1.9	220	4.8
Almonds	340	1.5–1.8	280	5.2

grow in sloping areas and are poorly mechanized, with objective agronomic difficulties in the execution of the processing. Walnut kernel belongs to the Betulaceae family, genus *Corylus* L. and is native to the temperate zones of the northern hemisphere (Europe, Asia Minor, Asia, and North America). Within the genus, Corylus are distinguished by about 15 species.

Corylus comes from the Greek "koris" = helmet, for the shape of the involucre covering the fruits. Avellana derives from Latin and refers to the city of Avellino. The hazel is a very common plant, from the Mediterranean area to the mountains, where it reaches up to 1,400 m above sea level. It participates in the constitution of mixed deciduous forests, also lending itself well to the colonization of marginal soils. Its bark is smooth, gray-brown in color and, with time, it flakes, like that of the birch, and its leaves, round or oval, turn yellow in autumn before falling (Cătălin Barbu et al., 2020).

The fruits of this plant are hazelnuts, hazelnut is counted among dried fruits, it is initially greenish in color and then brownish, as the degree of ripeness continues. The seed, placed inside, is edible and has a crunchy consistency (Fig. 2). It is very rich in lipids (about 50–60% of fats), proteins (20%), and water (11%). This composition makes hazelnut a rather caloric food. Gastronomical uses of this fruit are really numerous, among the various ones, there is also the production of an alternative oil to the extra virgin olive oil (Queiròs et al., 2020). Besides being consumed alone, hazelnuts are used for the production of sweets, nougat, chocolate, ice cream, and sweets, as well as "healthy" foods such as muesli. Hazelnuts are also used in macrobiotic diets and in some diets. After almonds, they are the fruit richest in vitamin E and are a source of phytosterols, an important substance for the prevention of cardiovascular diseases. Hazelnut is a dry fruit; they are large achenes enclosed in a woody brownish pericarp. The fruits grow in groups of 2–4 and each is partially enclosed by a dome of overlapping bracts, modified fringed, and tomentose leaves. Research has shown that 20% of the shell is composed of a prebiotic fiber called Axos with antioxidant properties and beneficial effects on the immune system, cardiovascular system, and lipid metabolism. Hazelnut shells also have a high calorific value and are currently used as an alternative biofuel to pellets to fuel stoves, boilers, fireplaces, industrial boilers, and cogeneration plants. The cuticle of the fruit is rich in polyphenols, valuable substances in the fight against free radicals, metabolic diseases, and cognitive degeneration.

The first stage of the Corili cultural chain is represented by agricultural producers, who directly collect and introduce their production in the distribution circuit through wholesalers or other brokers, or indirectly through fruit and vegetable producers' organizations (OP) which distribute it through commercial companies or first processors. The latter carries out a phase of first treatment and manipulation of the raw material which, depending on the destination of the product obtained, involves the processes of cleaning, drying, sizing of the product in shell and shelled, polishing, shelling, roasting, shelling, plasticizing, and packaging. Subsequently, these realities also provide for the placement of the product on domestic or foreign markets: it can then be sold on the fresh market or to confectionery industries that transform it to obtain other finished products. Following the processing carried out on the harvested hazelnuts, it is possible to identify the main types of final products that can be obtained: hazelnuts in shell, offered on the fresh market in various weights and in packages of different weights; shelled hazelnuts, placed on the market without any processing, or subjected to roasting, processing into paste or grain. In particular, among shelled hazelnuts, it is possible to distinguish between good quality shelled hazelnuts, destined for the confectionery or fresh produce industry, and those processed only with an initial roasting, packaged in vacuum packs destined for industry, wholesalers, and the rest of the supply chain.

The chemical analyses (Cruz Lopes et al., 2012) revealed that hazelnut shells are composed of lignin (30.2%), cellulose (28.9%), hemicellulose (11.3%), tannins (18.2%), and protein (6.7%). The chemical composition of the ashes (27.7% K and 16.9% Ca) makes them a possible substitute for feldspar in the ceramic industry. XRD showed that hazelnut shell has cellulose fiber I with high-quality crystalline cellulose fibers (69.1%).

Hazelnut shells have a high calorific value and low humidity, so they are used as an alternative biofuel to pellets to fuel stoves, boilers, fireplaces, industrial boilers, and cogeneration plants. Hazelnut shells are natural eco-fuels that are not subjected to any type of chemical process, but only mechanical (without the addition of additives or other chemicals). They are ecological fuels, non-polluting, with a calorific value of around 4.2 KWh/kg. Their main characteristics are good performance under the thermal profile, local availability, and considerable economic and ecological savings.

5 Analysis

The first experimentation concerns the use of waste hazelnut shells. This started from the realization of a mixture defined according to the proportions of 15% of shells, 20% natural binder, 20% wine vinegar, 5% glycerol, and the rest water (Fig. 3).

Our mixture involves the use of hazelnut shells in three different grain sizes of 1, 2, and 5 mm, because research has shown that it is much more important to use the shells than the cuticles because the shells represent 50% of the fruit,

Fig. 3 Starting working materials © by the Authors

while the cuticles represent 2%. The laboratory steps are as follows:

- transition to cuticles and creation of grain sizes;
- mixing with natural alloys;
- firing;
- mechanical considerations.

After weighing and evaluation, we baked and weighed them again. The tested mixtures were each time mixed with different percentages of hazelnut shell and then baked in an oven at 150° (Fig. 4).

All the materials produced and tested were mixed with natural elements such as potato starch and glycerol. The first step in the lab was to sift and pulverize the material to create different particle sizes (1, 2, and 5 mm) (Fig. 5). The objective in fact was to use as much waste as possible to obtain samples of material suitable for the realization of a new element. From here, the blends were reformulated and, while the process remains the same, the only change is the increase in firing time from 1 to 1 h and 30 min.

In the laboratory phase, we tested 17 samples for each type of natural waste (hazelnuts) in different paste percentages. The first test did not produce samples with characteristics suitable for our objectives. The waste shells and the binder did not mix: the former remained on the surface and the binder settled to the bottom. The product had poor mechanical strength capabilities and was jagged and uneven (Fig. 6). The firing times proved to be insufficient. In addition, the percentage of waste used was too low. By increasing the percentage of natural waste, hazelnut shells, much more stable and homogeneous samples were obtained from the point of view of consistency. Repeating the analysis with the percentages between 40 and 70%, we obtained the best results; beyond these percentages, we obtained unstable samples.

Compared to the research work above, the same materials and proportions between them were maintained but we replaced the waste. In the thesis, hazelnut and cocoa cuticles were used; instead, our blend foresees the use of hazelnut shells (in three grain sizes) because, from the research, it was more important to use shells than cuticles because shells represent 50% of the fruit, whereas cuticles represent 2%. Below we report the values of the blends that were obtained, with different percentages of hazelnut shell waste product, the best results (Table 3).

For each waste particle size, we made a sample (three specimens), from mixture 2 to mixture 5 to understand what the maximum possible amount of usable waste was. The maximum amount of usable reject in the mix to obtain homogeneous and strong samples is 70%. In sample 7, the low percentage of binder (80%) makes the material too brittle (breakage at the exit of the mold).

The same procedure has been applied to the manufacturing process for pistachio shells and almond shells. Always using as a working objective, the use of natural raw materials mixed with the waste from the agri-food production of dried fruit. In the laboratory tests with pistachio shells (Fig. 7), we worked on an experimentation of an organic resin with pistachio shells. In the study of pistachios, and in the reuse of the shell, it has emerged that, compared to other shells, this one is much denser and inclined to be used for materials subjected to higher stress. By analyzing scientific literature, we can say about pistachios that chemically, shells are made of triglycerides and cellulose without any trace of inorganic compounds. Cellulose concentrations vary according to the

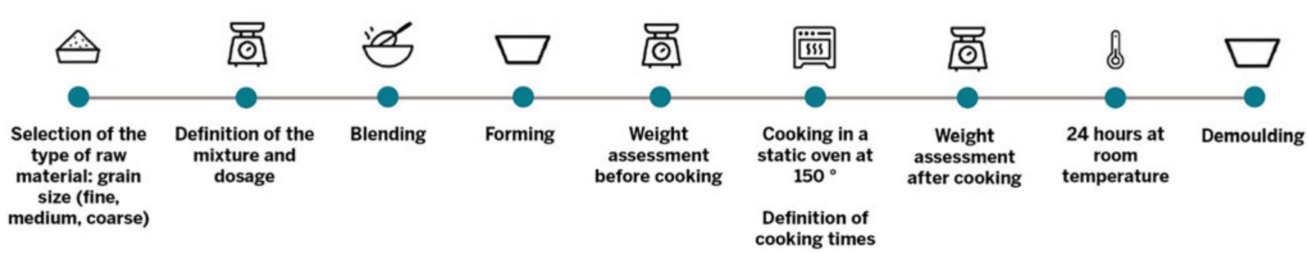

Fig. 4 Laboratory work phases © © by the Authors

Fig. 5 Pulverizing phases © (Manzella, 2020)

Fig. 6 Samples on hazelnut shells © (Manzella, 2020)

Table 3 Mixture experimentation

Mixture 2	Mixture 3	Mixture 4	Mixture 5
50% Waste	60% Waste	70% Waste	80% Waste
50% Binder	40% Binder	30% Binder	20% Binder
Hazelnut shells 50%	Hazelnut shells 60%	Hazelnut shells 70%	Hazelnut shells 80%
Potato starch 30%	Potato starch 24%	Potato starch 18%	Potato starch 12%
Glycerol 10%	Glycerol 8%	Glycerol 6%	Glycerol 4%
Wine vinegar 10%	Wine vinegar 8%	Wine vinegar 6%	Wine vinegar 4%
Water 70% (extra)	Water 70% (extra)	Water 70% (extra)	Water 70% (extra)

Fig. 7 Granulometry of pistachios © (Maniaci, 2021)

Fig. 9 Pistachio test samples © (Coniglio, 2021)

depth of the shell in accordance with the function of the shell at that depth (Piness, 2010).

In the laboratory, we carried out analysis on the particle size of the waste product, ground pistachio shells, and we obtained a particle size curve where there is the presence of elements from 1–4 mm up to 8 mm. About 1,500 gr of shells were taken, divided into three samples of about 500 gr and 1,000 cm3 each, calculating the respective densities, obtaining an average density of 0.50 gr/cm3. The three samples were screened individually through a stack of sieves, having diameters of 16, 12.5, 8, 4, 2, and 1 mm, as required by the ISO3310-1 standard (Fig. 8).

The latter has responded well to the experiments, the sample realized is homogeneous and very resistant, little smelling and compact. In addition to pistachio shells, the natural mixture consists of potato starch, glycerol, vinegar, and water (Fig. 9).

Regarding almond shells, the part of the fruit that is called "Almond Drupxa" was used in the analysis steps. Once crushed and passed through the sieve, the mixture was mixed to create a homogeneous mixture with the natural binder and water. In the same case of hazelnut shells, we had very good results in the composition of the element; in fact after several trials, we obtained a consistent product to be verified mechanically and physically. Regarding the almond shells, we had the best results with two grain sizes 1 and 2 mm of waste product at a percentage of 70% (Fig. 10).

Among the four samples, it can be noticed that the ones made with drupes are more likely to compact, this is because they have sugars which with heat should unify the material, whereas shells remain pulverized. The best sample of the two obtained from drupes is the one made from fine granules, i.e., 1 mm, this is because the finer granules allow the compound to compact more easily unlike the one made from thicker powder which finds it more difficult to compact

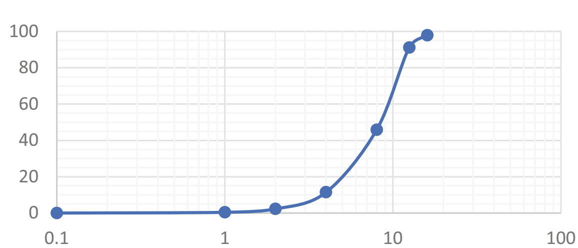

Fig. 8 Granulometric curve of pistachio shells

Fig. 10 Almond test samples mix 2 mm © © (Coniglio, 2021)

Fig. 11 Samples detail mixture n.5 © (Manzella, 2020)

(Fig. 11). The almond shell from sample 2 responded well in the experimental stages, it can easily be mixed with potato starch or glycerol, and a homogeneous mixture is created that can be used in a variety of ways.

6 Results

The experimentation, on hazelnut shells, allowed us to evaluate as the most suitable sample for our needs mixture n.4, containing 70% waste material and the remaining 30% potato starch, glycerol, and wine vinegar (Table 3). This amount turned out to be the maximum possible, because by increasing the amount of waste further (80%) the sample broke down with mechanical stress. Mixture n.4 allows the sample to be stressed without reaching breakage.

In addition, the sample at the end of the laboratory steps is well defined, the different colors of the waste are visible, the outside is homogeneous, the inside is dry and the edges are regular (Fig. 11). As for the mixtures with almond and pistachio shells, although treated only in the analysis phase, we can say that the same applies to them as to hazelnut shells. In fact, even in their experimentation with a very small particle size of waste product (1–2 mm) and with a percentage of 70%, we obtain a product workable and resistant, with homogeneous color and well-defined edges (Fig. 12).

Fig. 12 Almond test samples mix 1 mm © (Coniglio, 2021)

7 Discussion

The waste of hazelnut shells, as well as the reuse of waste from agri-food production, has a strong ability to repropose in the market, identified in a path of circular economy, very wide. The prototype created is perfectly preserved in all its characteristics, it does not present mold or signs of deterioration, even the smell remains unchanged. A number of suitable applications for the almond, hazelnut, and pistachio shells were identified as part of the investigation project, ranging from building material and construction components to cosmetics.

In particular, the bio-based waste material derived from the Sicilian agri-food industry was considered for the production of thermal insulation panels, sound absorption indoor coverings, and insulating plaster. The hazelnut and pistachio shells may also be used as an inert within the mixture of a mortar. The above hypothesis was based on the quality results obtained from the laboratory processing activities of the pistachio shells and the observations on the early prototypes. The qualitative studies have demonstrated that pistachio shells could be an excellent by-product suitable for building and construction applications. The technical characteristics of the raw material have shown excellent insulating capacity alongside a strong mechanical capacity and fire resistance. It is envisaged that the bio-based thermal insulation panel made of pistachio shells, would have an excellent thermal performance comparable to petroleum-based insulation material. Outcome of the laboratory processing activities on the almond shells has shown that this by-product could be very suitable for the production of wall plaster with high thermal performance. Additionally, once processed, the almond shells could also be used as an aggregate for standard plaster, or as an inert for the mortar.

Almond, hazelnut, and pistachio shells may also be considered for the manufacturing of indoor finishes, and specifically, acoustic plaster, sound absorption indoor cladding, and furniture. In addition, another possible use of the nut shells that was considered was for the production of pots for growing plants. in this case, one of the cons of these materials is that easy deterioration becomes the most important property of this type of product (Fig. 13).

The implementation of an integrated system that allows the valuable use of the bio-based waste material derived from the Sicilian agri-food industry would have positive impacts from the point of view of the supply–demand relationship in the construction market in terms of the qualification of existing resources and processes (De Curto et al., 2015). It is envisaged that this would encourage the creation of new business models that replace or integrate the current ones, skills and new roles in the supply chains capable of guaranteeing the circularity of material flows to boost the transition towards a resource-efficient circular model while converting unused food-waste in valuable nutrients for industry, products, components, and building technologies.

As part of this research project, the potential applications of the bio-based waste material derived from the Sicilian agri-food industry were also analyzed in the context of the fast-growing green building market. In particular, compatibility and compliance of the individual applications (i.e., thermal insulation panels, sound absorption indoor finishes, and insulating plaster) with the industry-accepted green building certification rating systems were assessed.

Fig. 13 Jars of hazelnut shells © (Manzella, 2020)

The green building rating systems (GBRS) such as LEED, WELL, BREEAM, Estidama, etc., provide project teams, building owners, and operators with a framework for identifying and implementing practical and measurable green building design, construction, operation, and maintenance solutions. Despite the GBRS are mostly voluntary tools, they are also widely adopted in more the 190 countries and territories worldwide and recognized by the industry as a mark of excellence for high-performance sustainable building and property industry.

Implementing the GBRS requires project teams to carefully select healthy building materials and products (i.e., indoor finishes, furniture, and ventilation systems). To be identified as eligible and installed in buildings pursuing green building certification, building materials and indoor finishes have to comply with a number of environmental criteria and standards as identified by the GBRS in use.

In particular, project teams and specifiers are asked to identify building materials that minimize the environmental impact, human exposure to hazardous chemical ingredients, and eliminate toxic compounds in indoor spaces. Thus, great emphasis is placed on the material ingredients that can impact human health and well-being as well as the environment and building carbon footprint.

The assessment was performed using Product MAP, a data-driven multi-criteria analytic software solution developed by On greening which considers a set of 11,000 sustainability criteria and 59 international GBRS to identify the strengths and advantages offered by the products in the field of certification of sustainability and, more generally, of the green building market.

The above aspects were considered critical in order to further explore and facilitate the future uptake of the Sicilian bio-based waste material-derived building applications in the context of the green building and the circular economy.

Outcome of the product compliance assessment study has highlighted the most important factors and criteria that should be considered while designing and manufacturing the potential building applications derived from the bio-based waste material of the Sicilian agri-food industry. They are summarised in Table 4, below.

The possible building applications, as identified during the early stage of the research project, were subdivided into two groups:

- Outdoor applications
- Indoor applications

In the context of the GBRS, requirements, selection criteria, and relevant standards may vary significantly according to the application of building materials and components.

As recently highlighted in the recent study by the World Green Building Council, many types of chemicals including volatile organic compounds (VOCs), both engineered and naturally occurring, are usually released into the air from numerous architectural finishes and building materials—

Table 4 Green building product criteria

Suitable Building Applications	Main Criteria					Impact
	Recycled Content (post-consumer)	**Recycled Content** (pre-consumer)	**Recyclability**	**LCA** (Life Cycle Assessment)	**VOCs** (volatile organic compounds)	
Outdoor applications						
Thermal insulation panels	n/a	■	■	■	n/a	Recycled content: Significant high recycled content embedded; Recyclability: hazardous treatment of the by-product to be avoided;
Insulating plaster (outdoor)	n/a	■	■	■	n/a	
Malta/agglomerate inert	n/a	■	■	■	n/a	
Indoor applications						
Insulating plaster (outdoor)	n/a	■	■	■	■	Recyclability: See above Manufacturing restriction: No added hazardous chemicals such as VOC and SVOC compounds, halogenated flame retardant treatments, urea–formaldehyde based binders, phthalates, etc
Thermal and acoustic insulation	n/a	■	■	■	■	
Sound absorption indoor finishes	n/a	■	■	■	■	
Indoor coverings	n/a	■	■	■	■	
Furniture	n/a	■	■	■	■	

some of them natural, human-made and plant-based (Alkerc, 2015). The prolonged exposure to high concentrations of some VOCs and other indoor air pollutants may significantly impact the health and well-being of the building occupants. For this reason, all GBRS impose rigorous requirements when it comes to select indoor finishes or building materials that may affect the indoor air quality, in order to reduce concentrations of chemical contaminants that can damage air quality, human health, productivity, and the environment.

In line with the principles of the circular economy, and the current EU action plan “Closing the loop”, all GBRS provide strong rewards to encourage the use of building materials and components produced with recycled materials (pre-consumer and post-consumer). In relation to this research investigation, a number of potential building products and components may be created by using a by-product, the nut shells, derived from the Sicilian bio-based food industry. The proposed new building products, for both indoor and outdoor building applications, have a significant high-recycled content (pre-consumer) ranging from 50 to 80%. For the purpose of this investigation, post-consumer recycled content was reckoned as not applicable at this stage. The percentage of the recycled content has to be evaluated according to ISO14021 (Environmental labels and declarations—Self-Declared Claims—Type II Environmental Labeling) and demonstrated in the form of self-certification confirmed by a third party certification body (Pacheco-Torgal et al., 2012).

Recyclability of the proposed building product, material, or component at the end of its useful life, was a further aspect that was considered. Alongside the recycled content, recyclability is an important aspect of the products that has to be carefully considered in order to promote the circularity of the material resources.

The raw material considered by this research is a by-product derived from the Sicilian bio-based food industry. If the bio-based material is treated by using hazardous chemical substances, it will be unlikely that that material is recyclable or reusable. Therefore, in order to ensure full recyclability, no harmful chemicals (i.e., formaldehyde-based binders, halogenated flame retardants, and phthalates) has to be added while manufacturing of the future nut shells-derived building products. Many building products and components currently available on the market are made as zero-VOC and free-formaldehyde products. Therefore, the above is not considered a real challenge. As introduced above, hazardous chemicals such as VOC and SVOC compounds, halogenated flame retardants, urea–formaldehyde, and so on, are also carefully considered by GBRS as critical indoor air pollutants that may significantly impact the health and well-being of the building occupants. As a result, the manufacturing process is a critical phase to consider, especially when producing building materials and components designed for indoor applications. Life Cycle Assessment (LCA) of the identified possible products is also a further subject that requires attention in order to drive carbon reduction in building. While the LCA assessment of the products was not included at this stage, gathering a good understanding of the impact of the product across its lifetime via LCA is reckoned as a critical step to design new building products that promote net zero carbon construction targets. Therefore, LCA will be included among the further investigation to be carried out in the future, even because LCA represents an additional aspect that is rewarded by all GBRS.

8 Conclusions

Today, the current construction legislation also requires the inclusion of percentages deriving from waste materials for the creation of new building products. This condition has meant that these materials, in order to be reused and explain the best-required performances, usually in past are mixed with synthetic binders. In most of the analyzed literature, it is clear that the best results are obtained through the use of materials that potentially also produce harmful emissions for living environments, being not very sustainable and difficult to recycle. From the study of the contemporary literature regarding this topic, it emerges that the experimentation of binders of natural origin with zero emission is still in the verification and validation phase. Today, the current construction legislation also requires the inclusion of certain percentages deriving from waste materials for creating new building products. This condition means that these materials, in order to be reused to reach the best performances, usually are mixed with synthetic binders. In most of the analyzed literature, it is clear that the best results are obtained thanks to the use of materials that potentially produce harmful emissions for living environments, making them not very sustainable and difficult to recycle over time. The study of the contemporary literature regarding this topic shows that the experimental use of natural binders with zero emission is still in a phase that is to verificate and validate.

This research focused on the feasibility of reusing waste coming from Sicilian and zero-km agri-food production, not currently reused in other sectors, using low energy-intensive laboratory processes and analysis. Laboratory experiments demonstrate that the best results mixture (in mechanical and physical terms) is made by the 70% of waste material and using also 20% of natural binder. A comparison between the different produced blends and the evaluation of the examined study cases shows how it is possible to overcome the limits of using synthetic binders meanwhile creating a prototype of a new building component, realized using hazelnut shells, glycerol, and potato starch.

The use of waste deriving from agri-food production, such as dried fruit shells for the creation of building components, it could solve the shortage of raw materials, as well as reduce the environmental problems that arise from this waste. Furthermore, the reuse of dried fruit waste could mean a further economic stream for both farmers and producers.

This research has currently reached a definition point that opens up new scenarios for the creation/production of new materials, having repercussions on various sectors. The proposed research on the reuse of dried fruit waste can be extended both to the wide range of waste from agri-food production and to the experimentation of mixtures, exploiting different and innovative natural binders, also transferred from other technological sectors. This can be done in many research contexts since the set of solutions able to revive a waste embraces a heterogeneous field of development, projected to achieve the same eco-sustainable result.

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