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Circular economy in a domestic environment

- From coffee grounds to coffee boards -

Relatore
prof. Elena Piera Montacchini

Correlatore
Anita Ollár (PhD candidate)

Candidato
Carlotta Fasano

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In collaboration with:

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of
Architecture and Civil Engineering

I would like to dedicate a few lines to thanks who, in one way or another, allowed me to reach this important goal.

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ABSTRACT

The increase of waste is leading the development of a new economic system based on the idea of restoration and re-utilization of the materials. In particular, food waste represent an alarming matter since it causes the depletion of limited natural resources and it produces almost 8% of Global Greenhouse Gas Emissions. To mitigate these problems it is important to act at different scales (global, local and domestic), to involve an increasing number of people and to allow everyone to take part in the necessary change.

This project aims to act at a domestic scale to find a system to recycle and re-use spent coffee grounds directly involving people. The idea to transform the household coffee waste in a building material allows generating a circle where the waste produced in the houses comes back to the houses themselves as an architectural element.

On the basis of theoretical research and the users' behavior investigation, the achievability to produce a building material from the spent coffee grounds has been evaluated.
The samples have been produced mixing different percentages of spent coffee (70%, 80% and 90%) with diverse binders, in particular potatoes starch and maltodextrin.
The mixture has been pressed in various moulds to obtain different texture on the surface, and it has been fired at a temperature ranging from 120°C to 200°C depending on the thickness of the sample.
This study found that the mixture with 70% of coffee ad 30% of maltodextrin was the most performing in terms of material cohesion and long-term resistance, proving the potential of the spent coffee to be converted in tiles and panels.
Some post-production treatments with bee wax as a coating have also been taken in order to increase the material strength and water resistance.

Finally, five different application proposals have been developed (tiles, flooring, wall panels, furniture boards and insulation panels) in order to emphasize the potential of the coffee material as an architectural element.

L'aumento della quantità di rifiuti sta portando allo sviluppo di un nuovo sistema economico basato sull'idea di ripristino e riutilizzo dei materiali. In particolare, i rifiuti alimentari rappresentano un problema allarmante in quanto essi causano l'esaurimento delle risorse naturali, già limitate, e producono circa l'8% delle emissioni globali di gas serra. Per ridurre questi problemi è importante agire a scale differenti (globale, locale e domestica), al fine di coinvolgere un numero sempre maggiore di persone e permettere a tutti di prendere parte a questo inevitabile cambiamento.

Questo progetto agisce a scala domestica e mira a trovare un sistema in grado di riciclare e riutilizzare la polvere di caffè esausto coinvolgendo gli utenti in modo diretto. L'idea di trasformare i rifiuti domestici di caffè in un materiale da costruzione permette di generare una circolarità nella quale i rifiuti prodotti all'interno delle abitazioni ritornano nelle case stesse come elementi architettonici.

Basandosi su una ricerca teorica e sullo studio dei comportamenti degli utenti, è stata valutata la possibilità di produrre un materiale da costruzione a partire dalla polvere di caffè esausto.
I provini sono stati sviluppati mescolando diverse percentuali di caffè (70%, 80% e 90%) con vari leganti, in particolare l'amido di patate e la maltodestrina.
La miscela è stata pressata in stampi differenti tra loro per poter ottenere più texture sulla superficie del materiale. In seguito, il composto è stato cotto a temperature comprese tra 120°C e 200°C a seconda dello spessore del provino.
Da questo studio è risultato che la miscela formata per il 70% da caffè e per il 30% da maltodestrina rappresenta la combinazione più performante in termini di coesione e di resistenza nel lungo periodo, dimostrando il potenziale che il caffè esausto ha nell'essere trasformato in piastrelle e pannelli.
Inoltre, alcuni provini sono stati trattati con un rivestimento a base di cera d'api, il quale ha migliorato la forza e la resistenza all'acqua del materiale.

Infine sono state sviluppate cinque differenti applicazioni del materiale a base di caffè (piastrelle per pareti, piastrelle per pavimenti, pannelli decorativi, ante per armadi e pannelli isolanti) al fine di enfatizzarne il potenziale come elemento architettonico.

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INTRODUCTION

In a world where the amount of waste is increasing even more and the raw materials cannot keep up with the consu-mption my questions are:

- How can food waste be re-used in architecture?
- How can old coffee grounds be converted in building elements?

RESEARCH QUESTIONS

Education

2019 - 2020
Master's programme in Architecture,
second year of master
Chalmers School of Architecture

2018 - 2019
Master's programme in Architecture for Sustainable Design
first year of master
Politecnico di Torino

2015 - 2018
Bachelor's programme in Architecture
3 years
Politecnico di Torino

Employment

2018
Internship
4 months
Arch. Fabio Maina - vicolo dei Macelli n.2, 10023 Chieri (TO)

In a period where the amount of waste is increasing in a rapid way, it is important to explore new economic systems, such as circular economy, to try to reduce and re-use waste.
Especially waste that is disposed on landfills represent a significant issue, every year around 1,3 billion tonnes of solid waste are discarded and this number is expected to double in the next twenty years.[1]

Within these problematics, food waste is an alarming matter. Every year in the EU, around 88 million tonnes of food waste is generated with associated costs estimated at 143 billion euros.[2]

Wasting food is a large sustainability challage since it depletes the environment of limited natural resources, it generates about 8% of Global Greenhouse Gas Emissions and it is one of the causes for hunger and malnutrition.[3]

To mitigate these problems it is important to act at different scales (global, local and domestic), to involve an increasing number of people and to allow everyone to take part in the necessary change.

This project starts from the idea of acting at a domestic scale to help and encourage people to participate in a domestic circular economy, through household waste recycling.

More specifically, this research is focused on one type of food waste: old coffee grounds, since coffee is the most consumed drink, after water, all over the world[4] and it produces a great quantity of waste that potentially could be re-used.

NOTES

[1] C. S. Burke, E. Salas, K. Smith-Jentsch, & M. A. Rosen, *Measuring macrocognition in teams: Some insights for navigating the complexities* in “Macrocognition Metrics and Scenarios: Design and Evaluation for Real-World Teams”, 2012.

[2] Å. Stenmarck, C. Jensen, T. Quested, G. Moates, M. Buksti, B. Cseh, S. Juul, A. Parry, A. Politano, B. Redlingshofer, S. Scherhaufer, K. Silvennoinen, H. Soethoudt, C. Zübert, & K. Östergren, *Estimates of European food waste levels. Reducing food waste through social innovation* in “Fusions”, 2016.

[3] https://ec.europa.eu/food/safety/food_waste_en accessed from 10/03/2020 to 27/04/2020.

[4] ICO, *Coffee Development Report. Growing for prosperity. Economic viability as the catalyst for a sustainable coffee sector*, 2019.

This research aims to find a system to recycle and re-use spent coffee grounds in an architectural context. The thesis will investigate how a circular loop can be developed around coffee: from brewing a drink in the kitchen, through collecting and upcycling the produced waste, to reutilising it in the same domestic environment in a form of a newly created material.

In fact, the idea to focus on old coffee grounds to create new sustainable building materials is intended to close the circle of one part of domestic circular economy in fact the new developed construction elements will become the physical evidence of the efforts made to recycle waste, that everyone could see in their homes.

Furthermore re-used old coffee grounds allow to reduce the amount of waste and limit aquatic ecotoxicity and eutrophication due to coffee disposal.[5]

NOTES

[5] R. Salomone, *Life Cycle Assessment applied to coffee production: investigating environmental impacts to aid decision making for improvements at company level* in “Journal of Food Agriculture and Environment”, 2018.

In un periodo nel quale la quantità di rifiuti è in rapido aumento, è importante sviluppare nuovi sistemi economici, come ad esempio l'economia circolare, per ridurre e riutilizzare i rifiuti. In particolare, i rifiuti che vengono gettati in discariche rappresentano un problema significativo, infatti ogni anno circa 1,3 miliardi di tonnellate di rifiuti solidi vengono dismessi e si stima che questo numero possa raddoppiare nei prossimi vent'anni.[1]

Tra questi, i rifiuti organici rappresentano un problema allarmante. Ogni anno, nell'Unione Europea, vengono prodotte circa 88 milioni di tonnellate di rifiuti alimentari il cui costo è stimato attorno ai 143 miliardi di euro.[2]

Lo spreco di cibo è un'importante sfida della sostenibilità dal momento che esso impoverisce l'ambiente delle sue materie prime, già limitate, genera circa l'8% delle emissioni globali di gas serra e rappresenta una delle cause di fame e malnutrizione.[3]

Per ridurre questi problemi è necessario agire a scale differenti (globale, locale e domestica) al fine di coinvolgere un numero sempre maggiore di persone e permettere a tutti di prendere parte a questo inevitabile cambiamento.

Questo progetto parte dall'idea di agire a scala domestica per aiutare ed incoraggiare le persone a partecipare ad un'economia domestica circolare, attraverso la raccolta differenziata dei rifiuti domestici.

In particolare, questa ricerca si focalizza su un particolare tipo di rifiuto organico: la polvere di caffè esauto, dal momento che il caffè, dopo l'acqua, rappresenta la bevanda più consumata al mondo[4] e che produce una grande quantità di rifiuti che potenzialmente possono essere riutilizzati.

NOTES

[1] C. S. Burke, E. Salas, K. Smith-Jentsch, & M. A. Rosen, *Measuring macrocognition in teams: Some insights for navigating the complexities* in "Macrocognition Metrics and Scenarios: Design and Evaluation for Real-World Teams", 2012.

[2] Å. Stenmarck, C. Jensen, T. Quested, G. Moates, M. Buksti, B. Cseh, S. Juul, A. Parry, A. Politano, B. Redlingshofer, S. Scherhaufer, K. Silvennoinen, H. Soethoudt, C. Zübert, & K. Östergren, *Estimates of European food waste levels. Reducing food waste through social innovation* in "Fusions", 2016.

[3] https://ec.europa.eu/food/safety/food_waste_en accessed from 10/03/2020 to 27/04/2020.

[4] ICO, *Coffee Development Report. Growing for prosperity. Economic viability as the catalyst for a sustainable coffee sector*, 2019.

Questa ricerca mira ad individuare un sistema che permetta di riciclare e riutilizzare i fondi di caffè in un contesto architettonico. La tesi investiga come poter sviluppare il concetto di circolarità attorno al tema del caffè: dal consumo di caffè come bevanda in cucina, attraverso la raccolta e la valorizzazione del rifiuto prodotto, fino al suo riutilizzo nello stesso ambiente domestico in forma di un nuovo materiale.

Infatti, l'idea di concentrarsi sul caffè esausto per sviluppare un nuovo materiale da costruzione sostenibile permette di chiudere il ciclo di una parte dell'economia circolare domestica, dal momento che il nuovo elemento costruttivo rappresenterà l'evidenza fisica, che tutti potranno vedere nelle propie case, degli sforzi effettuati nella raccolta differenziata.

Inoltre, il riutilizzo dei fondi di caffè permette di ridurre la quantità di rifiuti e di limitare l'ecotossicità acquatica e l'eutrofizzazione dovuta al loro smaltimento.[5]

NOTES

[5] R. Salomone, *Life Cycle Assessment applied to coffee production: investigating environmental impacts to aid decision making for improvements at company level* in "Journal of Food Agriculture and Environment", 2018.

This thesis is characterized by theoretical research, user behaviour examination, materials investigation and a hypothetical design proposal.

I started from a literature study to have a clear vision of the situation regarding the waste issue and to know which are the possible solutions to control this problem.

Furthermore, to study properly the recycling problem, a survey was prepared, that was shared online, to investigate people's habits concerning household recycling. This has been used to find some solutions to adopt in the kitchen design and to start to understand how people deal with spent coffee grounds since the idea was to re-use this waste to develop a new building material.

Therefore, the second step was focused on looking for some references of projects and objects made using old coffee grounds. Then, research and interactions with experts allowed me to find some possible binders to use with coffee.

The third part of my work consisted of tests where different binders were tried to find the best mixture. The judgment parameters were based on the mechanical resistance assumed from the literature and on architectural qualities of samples.

As the last step, I drew my design proposals to show how and where this new building material could be used.
These proposals have been influenced by the strength, the shape and the aesthetic qualities of the elements.

This work was characterized also of some delimitations.

Starting from the online survey, the population of my survey was composed of 504 elements covering only 10 countries, with a great number of answers coming from Italy. This caused a disproportionated and limited overview of issues.

Meanwhile, concerning the experimental part, the lack of access to the labs has prevented the possibility to test different types of binders and techniques that would give the material different features. It was not possible to perform tests to try out the mechanical strength and insulating properties.
Therefore, the samples have been evaluated only for their aesthetic characteristics and their resistance in the long run.

Lastly, also in the design application proposals, it was necessary to rely on existing literature regarding certain features that the material can and should have.

Despite the listed limitations, the thesis represents an interesting starting point for more in-depth later researches on coffee materials.

La tesi è stata caratterizzata da studi teorici, valutazione dei comportamenti degli utenti, ricerche sui materiali e sviluppo di ipotetiche proposte progettuali.

Partendo dallo studio della letteratura preesistente, è stato possibile ottenere un quadro generale sul problema dei rifiuti in generale e sulle possibili soluzioni applicabili per risolvere tale problema.

Inoltre, per valutare accuratamente il fenomeno del riciclaggio, è stato preparato un questionario, distribuito online, al fine di analizzare le abitudini delle persone per quanto riguarda la raccolta differenziata in ambito domestico. I risultati sono stati utilizzati per selezionare alcune soluzioni da adottare nella progettazione degli ambienti domestici, in particolare della cucina, e per iniziare a comprendere come le persone si approcciano ai fondi di caffè, dal momento che l'idea è quella di riutilizzare questo tipo di rifiuto nello sviluppo di un nuovo materiale da costruzione.

Il secondo step è stato improntato sulla ricerca di studi e sperimentazioni precedenti nell'utilizzo della polvere di caffè esausto. In seguito, ulteriori ricerche e il confronto con degli esperti, hanno permesso di individuare possibili leganti da usare con il caffè.

Nella terza parte di questo lavoro, invece, sono stati prodotti alcuni provini utilizzando diversi leganti da aggiungere alla polvere di caffè al fine di individuare la miscela più performante. I criteri di giudizio si sono basati sulle propietà meccaniche e fisiche indicate dalla letteratura preesistente e sulle qualità architettoniche osservabili dei diversi provini.

Infine, sono state sviluppate cinque proposte di applicazione del materiale per mostrare come e dove si può adottare.
Queste proposte sono state influenzate dalle caratteristiche meccaniche ed estetiche degli elementi sviluppati.

Questo lavoro è stato caratterizzato anche da alcune limitazioni.

Partendo dal questionario online, la popolazione, composta da 504 elementi, copriva soltanto 10 Paesi, con un elevato numero di risposte provenienti dall'Italia. Ciò ha portato ad una visione sproporzionata e limitata del problema.

Inoltre, per quanto riguarda la parte sperimentale, l'impossibilità di accedere ai laboratori a causa del Covid-19 ha impedito di sperimentare diverse tecniche e diversi leganti che avrebbero potuto influire sulle caratteristiche del materiale.
Anche la verifica, mediante prove meccanicche e fisiche, delle proprietà del prodotto ottenuto non è stata possibile. Pertanto i provini sono stati valutati solamente in relazione alle loro caratteristiche estetiche e per la loro durabilità.

Infine, anche per quanto riguarda le proposte progettuali, è stato necessario fare affidamento sulla letteratura esistente per poter considerare le proprietà che il materiale dovrebbe possedere.

Nonostante queste limitazioni, la tesi rappresenta un interessante punto di partenza per future ricerche più approfondite sui materiali a base di caffè.

CIRCULAR ECONOMY

“ Circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models. The overall objective is to enable effective flows of materials, energy, labour and information so that natural and social capital can be rebuilt ”[6]

Ellen MacArthur Foundation, 2015

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[6] E. MacArthur & McKinsey, *Towards the circular economy - Economic and Business Rationale for an Accelerated transition*, Report by the Ellen MacArthur Foundation, 2012, p. 7.

ABSTRACT CHAPTER 1

A partire dalla Rivoluzione industriale il modello economico di riferimento è sempre stato di tipo lineare (take-make-dispose). Negli ultimi anni però, ci si sta approcciando sempre più frequentemente al sistema descritto e sviluppato dalla Ellen MacArthur Foundation: l'economia circolare. In questo sistema l'idea di base consiste nel mantenere i prodotti in uso il più a lungo possibile e, una volta arrivati al termine della loro vita di servizio, trasformarli in nuovi materiali da re-inserire nel ciclo produttivo.
Il passaggio da economia lineare a circolare richiede però l'adozione di due differenti approcci: quello reattivo e qiello proattivo. Il primo si focalizza sullo sviluppo di sistemi in grado di allungare la vita dei prodotti già presenti sul mercato, mentre il secondo mira alla definizione di nuovi elementi che rispondano ai criteri dell'economia circolare.
I tre principali presupposti per un'economia circolare sono:
- riscoprire i rifiuti come fonte principale di materie prime;
- ridurre lo spreco d'uso degli oggetti;
- limitare la morte prematura dei prodotti.

A partire dagli anni 2000 anche la Commissione Europea ha investito risorse sul tema della circolarità. Negli ultimi anni infatti sono stati prodotti piani di azione con linee guida sia in ambito pubblico che privato per incentivare una crescita sostenibile e portare l'Europa ad essere il primo continente "*climate-neutral*" entro il 2050.

Importante è distinguere l'economia circolare dalla bio-economia. Come spiegato in precedenza infatti, lo scopo dell'economia circolare è allungare la vita utile dei prodotti e ridurre la quantità di rifiuti prodotti, a tal fine essa considera tutti le tipologie di materiali ed elementi presenti nella catena. La bio-economia invece, come dice la parola, pone la sua attenzione sulle materie organiche e sui sistemi di produzione ad essi collegati. Diventa perciò interessante far convergere i due metodi nella bio-economia circolare sfruttando i vantaggi di entrabe migliorando l'uso delle risorse, riducendo le emissioni di CO_2 e la domanda di materie prime naturali e valorizzando i rifiuti.

Come anticipato in precedenza, diventa di fondamentale importanza considerare l'economia circolare a diverse scale, essa infatti non si basa solo sui processi produttivi ma considera anche i sistemi di consumo, per questo motivo è possibile traslare questo concetto dall'ambiente industriale a quello domestico considerando la circolarità

come una modalità di pensiero e adottando atteggiamenti responsabili.
A stretto contatto con l'ambiente domestico si trova il settore delle costruzioni. Esso è responsabile del 40% dello sfruttamento di materie prime e del 25-40% emissioni di carbonio. Per ridurre questi problemi ed ottenere una piena transizione all'economia circolare, si deve agire su tre livelli. Macro interventi sono già stati realizzati, essi riguardano piani a livello regionale e urbano. É però importante agire anche a livello di edificio (meso scala) progettando sistemi in grado di essere trasformati nel corso del tempo per adattarsi alle necessità degli utenti. Infine non vanno trascurati i micro interventi che si concentrano principalmente sullo sviluppo di materiali ad alte prestazioni derivati da elementi di scarto.

1.1 A SUSTAINABLE ECONOMY

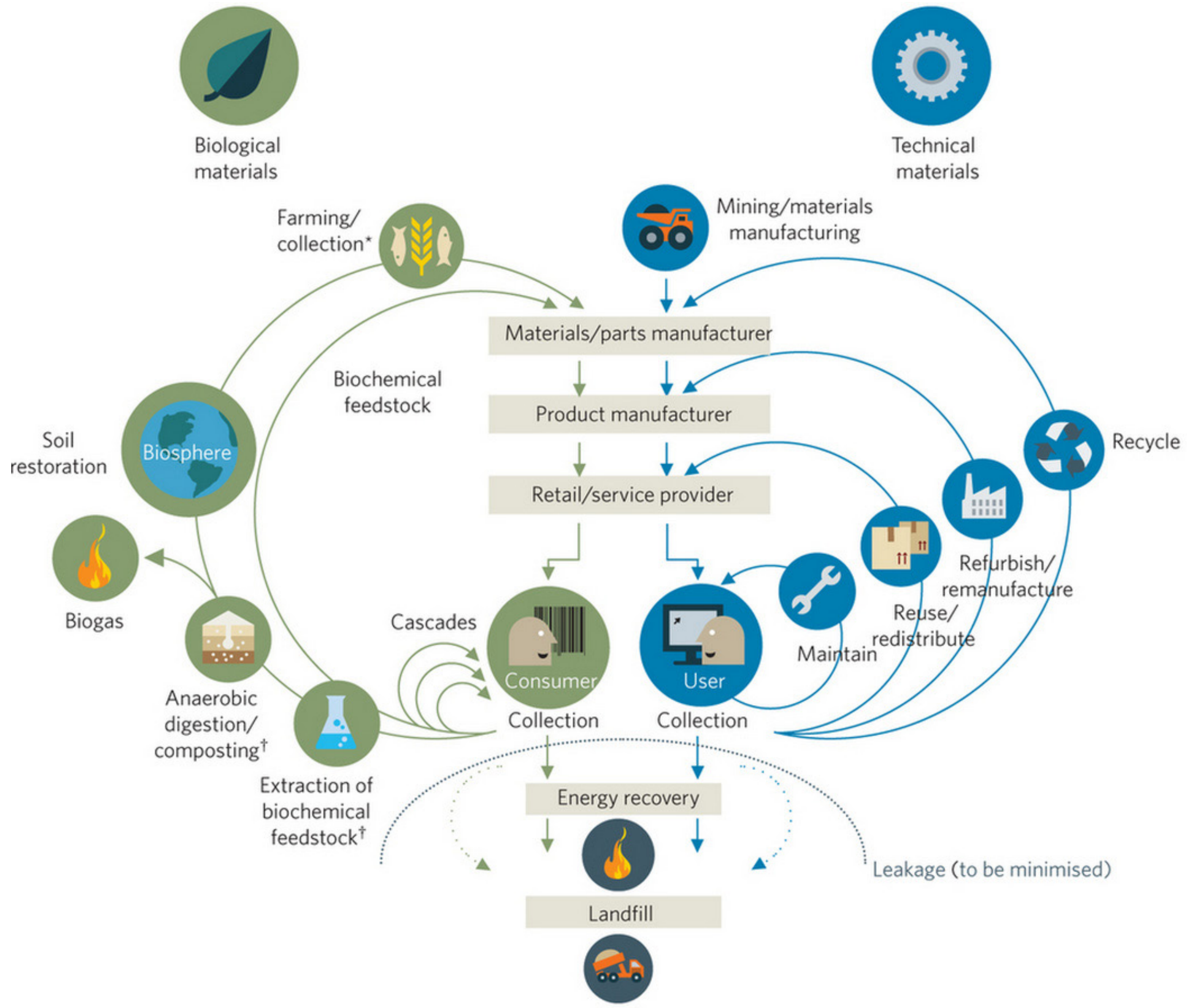

Fig. 1 - Outline of a circular economy, butterfly diagram by Ellen McArthur Foundation
https://www.ellenmacarthurfoundation.org/circular-economy/concept/infographic

1.1.1 From linear to circular economy

Since the early days of industrialization and almost until the 90s of the 20th century, industrial economic growth has always been based on the same fundamental characteristic: linear economy.[7] This "take-make-dispose" model is built on the idea of extracting new raw materials to use once and which immediately becomes waste at the end of their service life. This is why this economic pattern could be defined as a model from cradle to grave. This system is very dangerous for the earth. It is one of the factors which determine global warming and all its consequences: sea and land contamination, waste problem, greenhouse gas emissions, wars to control raw materials and strong social inequality.

For these reasons, prominent researchers, such as the architect Walter Stahel, the physicists Amory and Hunter Lovins, the designers William McDonough and Michael Braungart, the green-economist Nicholas Georgescu-Roegen, developed an alternative method called circular economy presented as a more environmentally sustainable alternative to the existing linear economy.[8]

The new system aims to build long-term resilience, create economic opportunities and generate social benefits. The main idea consists of re-using the most of an object, utilizing as little energy as possible. Therefore recycling, seen as the transformation of an object in a raw material to use as base for a new item, becomes the last resort. It is very important, instead, to try to repair and remanufacture materials, always giving them new functions, without completely transforming them.

Ellen MacArthur Foundation has also explained this circular system in a diagram (fig. 1), showing four different levels of re-use, taking into account the different stakeholders for each considered level:

"• recycle to reclaim base materials (parts manufacturers);
• refurbish and remanufacture (product manufacturers);
• facilitate re-use and redistribution (service providers);
• maintain and prolong useful life (individual users)".[9]

NOTES

[7] E. MacArthur & McKinsey, *Towards the circular economy - Economic and Business Rationale for an Accelerated transition*, Report by the Ellen MacArthur Foundation, 2012.

[8] https://www.ellenmacarthurfoundation.org/circular-economy/concept accessed from 02/03/2020 to 20/04/2020

[9] A. Twigger Holroyd, *Reknit Revolution: Knitwear Design for the Domestic Circular Economy* in "Journal of Textile Design Research and Practice", 6(1), 2018.

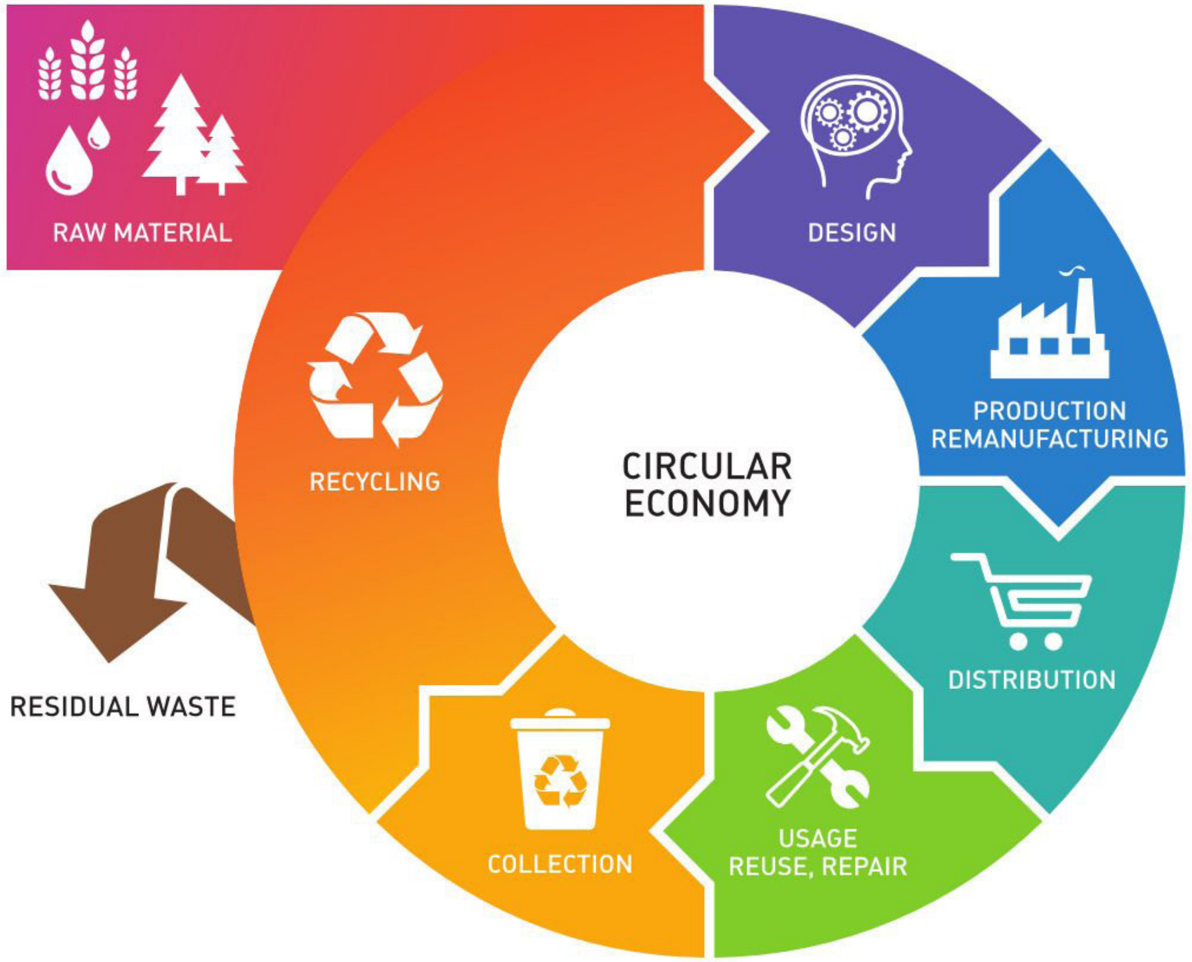

Fig. 2 - Circular economy diagram - https://www.ideegreen.it/economia-circolare-definizione-ed-esempi-95289.html

Furthermore, in 2014 Kate Goldsworthy[10] underlined two different approaches to re-use and recycling: re-active approach and pro-active approach. The first one is a reaction to the amount of waste generated by the linear economy, while the pro-active approach considers the high-quality base materials starting from the design.
Of course, two approaches are needed nowadays in order to handle the materials that are already in circulation and at the same time to start developing a stronger circular regime (fig. 2). This will allow to "keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life".[11]

As Emanuele Bompan said in his article,[12] circular economy is based on three fundamental principles:

1. Rediscover the deposits of materials as resource materials.
The main idea showed by this principle is the importance to see waste materials as a "second raw material" instead of as garbage.
Taking inspiration from the natural world, where every kind of waste becomes a resource to feed other organisms, a way to reintroduce even more waste materials in the production chain must be found with waste coming both from industry and from the private sphere.
According to this idea, cities can be seen as the main (urban) deposits for second raw materials; a place where it is possible to collect resources useful to produce new objects. For this reason, it is important to start to see containers and recycling stations as a system to extract raw materials and not as a point where waste is collected.
One of the several examples of this principle is Wineleather, the first 100% vegetable leather made from grape marc and made in Italy by the company Vegea founded by Giampiero Tessitore.[13] This vegetable material is made by transforming

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[10] K. Goldsworthy, *Design for Cyclability: pro-active approaches for maximising material recovery* in "Making Futures", 3, 2014.

[11] WRAP and the Circular Economy, 2016.
http://www.wrap.org.uk/about-us/about/wrap-and-circular-economy, accessed on 20/04/2020

[12] https://www.ideegreen.it/economia-circolare-definizione-ed-esempi-95289.html, accessed from 17/02/2020 to 20/04/2020.

[13] https://www.treedom.net/en/blog/post/wineleather-the-first-leather-made-from-wine-2094, accessed on 11/03/2020

Fig. 3 - Wineleather by Vegea - https://www.materially.eu

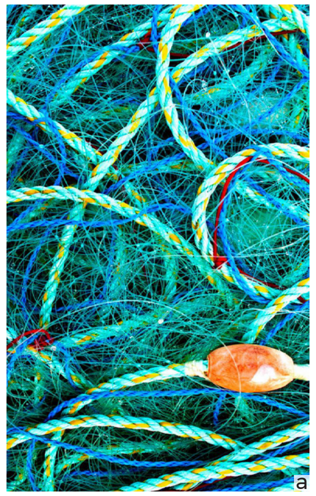

Fig. 4 - Econyl, from fishing net (a) to new yarn (b) by Aquafil
(a) https://www.livingcircular.veolia.com/en/industry/econyl-infinitely-recyclable-nylon-yarn
(b) https://professionals.tarkett.com/en_EU/node/econyl-recycled-yarn-5248

fibers and vegetable oils present in the grape marc into an ecological material with the same mechanical, aesthetic and sensory characteristics of a normal leather using zero water and zero petrol avoiding every kind of impact on the ecosystems (fig. 3).
Sometimes it is also possible to talk about "up-cycling". This happens when the waste, used as a new material, has a higher value compared with the value that it has in its previous life. An example, in this case, is Econyl,[14] a system developed by Aquafil spa to valorize the waste nylon. They take nylon from old fishing nets and use it to produce a high-performance synthetic thread for vinyl and carpet collections and other objects (fig. 4a and 4b).

2. End of unused values.
In this case, the attention goes on all those objects that are neglected even if they are working perfectly.
Just consider all dresses that people bought and only used once or twice, the factory machines which have to be changed and all the assets whose value is not exploited. All these behaviors cause a useless waste of matter. To avoid it should be started to assimilate and use a new commercial process called "Product-as-a-service", this means that instead of owning an object, it can be used as a service with some other consumers. One of the most famous examples of this way of acting is the car-sharing, in this case, user can pay only for the time that he effectively uses the car and at the same time, the cars are more exploited during their life period. Another example is the Michelin Fleet Solutions,[15] they give the possibility to take their tyres in leasing. In this manner, tyres can have a longer life through frequent checks and small fixing actions.
There are then organizations like Vigga[16] which work in the clothes field. When people subscribe immediately get 20 pieces of children's clothing, once they become too small it is possible change them with some bigger clothes. This helps to avoid waste of clothes and makes companies design high-quality, long-lasting clothes that directly serve their bottom line.

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[14] https://www.econyl.com/blog/case-studies-design/interfloor-collection/, accessed on 11/30/2020

[15] https://www.michelintruck.com/services-and-programs/michelin-fleet-solutions/, accessed on 13/03/2020

[16] https://www.goodnet.org/articles/5-companies-that-embrace-concept-circular-economy, accessed on 13/03/2020

3. Stop the premature death of matter.
This principle puts the focus on all those objects thrown away before the end of their life.
Often only a small part was broken in the object, or in other cases, the excuse is that our clothes or objects are out of fashion.
It is very important to try to avoid this waste by repairing, upgrading and reviewing the programmed obsolescence of the objects.
The producers of Fairphone[17] are working on this line. They create the first phone designed to ensure longevity and reparability of the product to maximize the average life of the phone. In fact, it is easy to repair, change some parts, and to disassemble at the end of its life (fig. 5).

Fig. 5 - Fairphone 3, a modular phone by Fairphone - https://www.mobil.se/fairphone-3

1.1.2 Circular Economy and European Plan

Every year, in the European Union, each person produces more than 4.5 tonnes of waste and half of that is disposed of in landfills.[18] These data are expecting to increase of 70% in the next forty years, while the global consumption of raw material is expected to double by 2050.[19]

NOTES

[17] https://circulareconomy.europa.eu/platform/en/good-practices/fairphone-created-worlds-first-ethical-modular-smartphone, accessed on 13/03/2020

[18] R. Effi, *THE CIRCULAR ECONOMY Connecting, creating and conserving value* in "Public Relations Review", 33(1), 2007.

[19] Herdiana, *Communication from the commission to the European Paliament, the Council, the European economic and sicial committee and the committee of the regions* in "Journal of Chemical Information and Modeling", 53(9), 2013.

For these reasons, the European Union started to draw developing plans based on the idea to turn waste into a resource, preparing the ground for the transition from the linear to the circular economy.
Since the first years of XXI century, they developed initiatives to use resources in a more responsible way in order to move towards sustainable growth and jobs.[20] Several promising business areas are already defined by the European Resource Efficiency Platform (EREP) to achieve new trade models. They have also established new financial and accounting frameworks to promote the efficiency and the circularity of resources. They consider incentives, research and innovation, regulation, information exchange, support for voluntary approaches and market-based instruments in these core areas. Furthermore, EREP invited the European Union to set a target which guarantees resources productivity growth by more than 30% by 2030, in order to connect these elements to the resource efficiency agenda.

In the last years, the European Commission has introduced a new Circular Economy Action Plan[21] that represents one of the main parts of the European Green Deal, the new agenda for sustainable growth in Europe. This new Circular Economy Action Plan indicates measures along the entire life cycle of products, such as the promotion of circular economy processes or a sustainable consumption that aims to keep used resources in the EU economy for as long as possible. These actions seek to modernize the economy protecting the environment and, at the same time, they allow citizens "*to take full part in the circular economy and benefit from the positive change that it brings about*".[22]
According to European Green Deal, all the investment plans, covering both the public and private sectors, will allow the European Union to become the first climate-neutral continent by 2050.[23]

NOTES

[20] R. Effi, *THE CIRCULAR ECONOMY Connecting, creating and conserving value* in "Public Relations Review", 33(1), 2007.

[21] https://ec.europa.eu/environment/circular-economy/index_en.htm, accessed on 12/03/2020

[22] European Commission & switch2green, *Circular Economy Action Plan*, March, 4, 2018.

[23] European Commission, *Investing in a Climate-Neutral and Circular Economy*, January 2020.

1.2 CIRCULAR BIO-ECONOMY

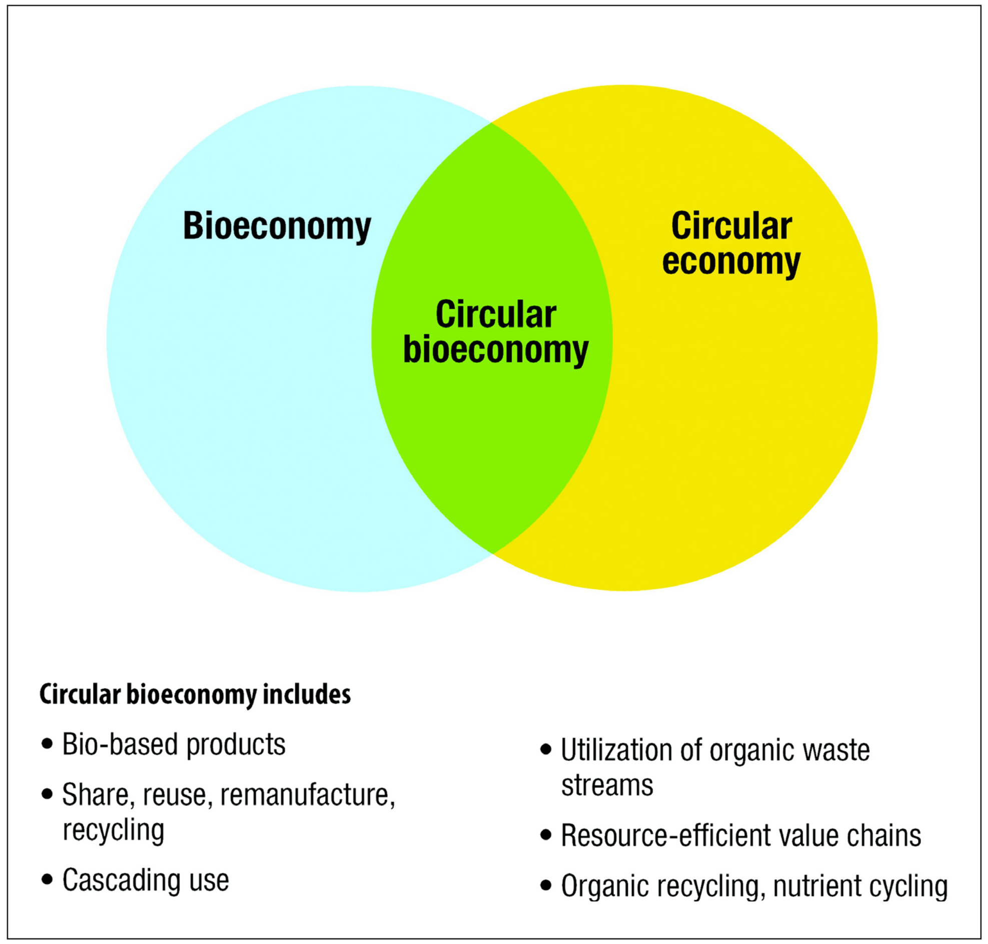

Fig. 6 - Circular bio-economy diagram: an overlapping of circular economy and bioeconomy
M. Carus, & L. Dammer, *The Circular Bioeconomy - Concepts, Opportunities, and Limitations* in "Industrial Biotechnology", 14(2), 2018, p. 86.

1.2.1 Definition of Circular Bio-Economy

The circular bio-economy is defined as the overlap of circular economy and bio-economy (fig. 6). It aims at improving resource use, lowering CO_2 footprint, reducing demand in fossil carbon, and valorizing waste as a resource.[24]
Therefore, although they have similar targets, circular economy and bio-economy are two different concepts that can be combined and overlap but neither is fully part of the other nor embedded in the other.

1.2.2 Circular and bio -economy similarities and differences

As it was previously mentioned, circular economy and bio-economy have some common targets such as improved resource and eco-efficiency, low GHG footprint, reduce the demand for fossil carbon or the valorization of waste and side streams, but they have also some differences.
Talking about fossil carbon, for example, we can see that they have two different approaches.[25] The circular economy aims to decrease the emission of additional fossil carbon in manufacturing and extraction processes improving the performance of resource utilization and restoration of waste materials. On the other hand, the bio-economy focuses its attention on renewable biomass generated by agriculture, forestry, and marine environment as an element to replace fossil carbon. This means that almost 95% of fresh biomass is used to produce bioenergy while only 15% is adopted for the production of bio-based chemical materials exploiting the cascading use promoted by circular economy.[26]

To be able to overlap the two economic systems and exploit better biomaterials it would be necessary to start to use fresh biomass in chemical materials production and only later consider their bio-waste to produce bioenergy by applying the cascade mechanism in the best possible way.

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[24, 26] M. Carus, & L. Dammer, *The Circular Bioeconomy - Concepts, Opportunities, and Limitations* in "Industrial Biotechnology", 14(2), 2018.

[25] T. M. W. Mak, X. Xiong, D. C. W. Tsang, I. K. M. Yu, & C. S. Poon, *Sustainable food waste management towards circular bioeconomy: Policy review, limitations and opportunities* in "Bioresource Technology", 297, 2020.

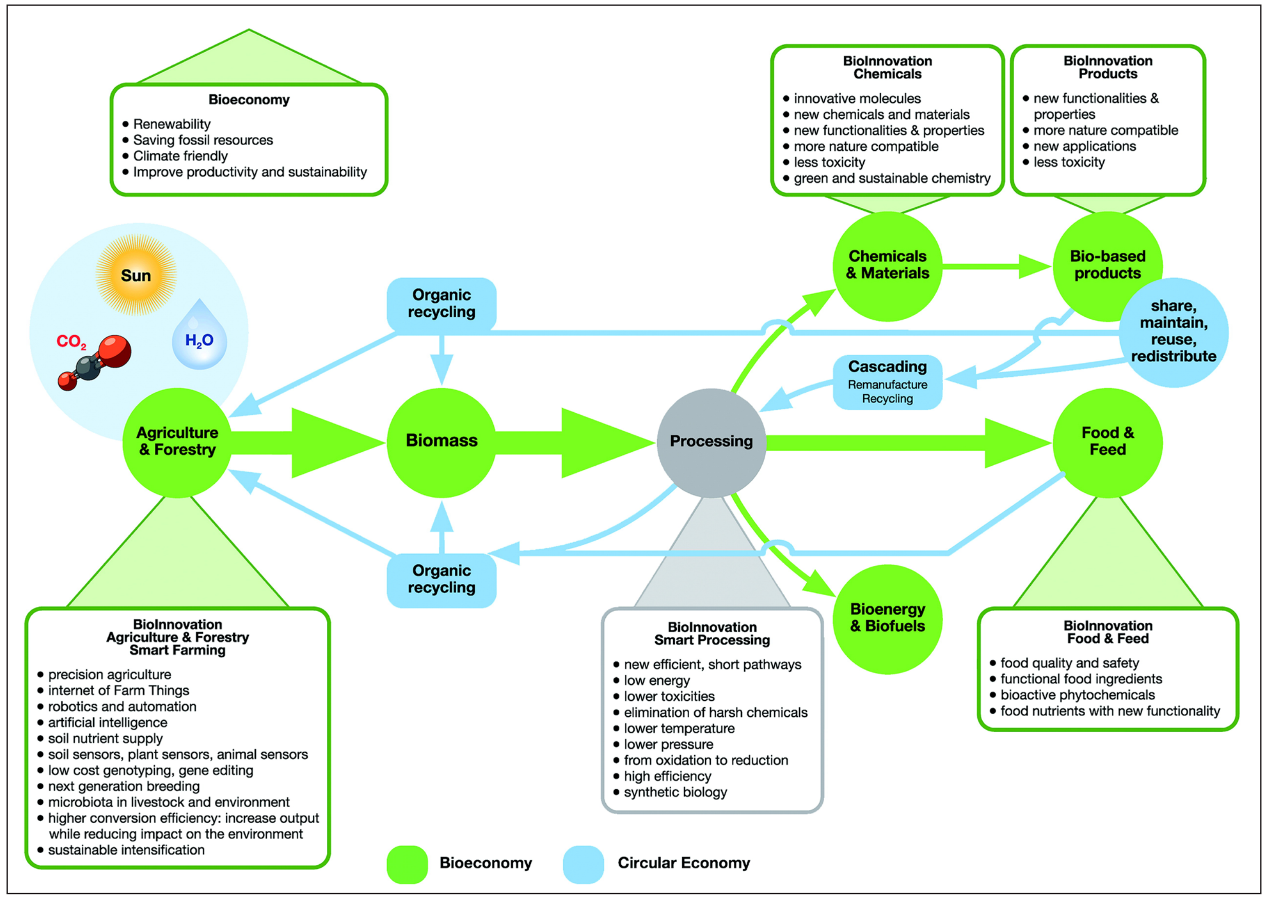

Fig. 7 - Biomass flow diagram. Only when by-products and biowaste are reintroduced in the chain you can talk of "Circular bioeconomy"
M. Carus, & L. Dammer, *The Circular Bioeconomy - Concepts, Opportunities, and Limitations* in "Industrial Biotechnology", 14(2), 2018, p. 86.

Bio-economy is more than a part of the circular economy. In fact, many aspects of the bio-economy overtake the circular economy's goals. It considers also aspects that are related to services and product functionality like precision farming, gene editing, new processing pathways with lower toxicity, materials with new properties and functionalities and products more nature-compatible and healthy bio-based (fig. 7).

In conclusion, these two different thinking, complement one another[27] because all the bio-waste from architecture, forestry, fishery, can be introduced in circular economy processes only thanks to bio-economy. On the other side, the bio-economy can also get advantages from circularity. Improving links between bio-economy and other industrial areas it will be possible to create a stronger circular economy.

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[27] M. Carus, & L. Dammer, *The Circular Bioeconomy - Concepts, Opportunities, and Limitations* in "Industrial Biotechnology", 14(2), 2018.

1.3 DOMESTIC CIRCULAR ECONOMY

Fig. 8 - Responsable consumption actions by Zero Waste Arlington Committee
https://www.arlingtonma.gov/town-governance/all-boards-and-committees/recycling-committee

1.3.1 A domestic mentality

As has been mentioned, it is important to consider the circular economy in all stages and scales. Not only big industries, small start-ups or designers can be part of the circular economic system but this movement can take place also in the household environment. In fact, circular economy is based both on production models and on consumption systems.
The circular economy is, first, a way of thinking where the disposal of the product in a landfill must be the last action, when nothing else can be done. Consequently, it is possible to pursue a responsible consumption and try to make the life of the product as long and efficient as possible. This will be possible through reduce, re-use, repair and recycle of the items (fig. 8).
To support responsible consumption is it necessary to buy and use environmentally friendly products and services. This means buying local food, eating fruit and vegetables that are in the season, buying products with little packaging and trying to avoid the single-use items. Another important action is collaborative consumption. This principle is based on the idea that usage is predominant over ownership promoting, in this way, the sharing of products and services in the neighborhoods.

1.3.2 Circular economy designed at meso and micro levels

One of the sectors that have the greatest influence on the natural environment is the building industry. Since the 1990s, the construction sector represents the largest consumer of raw materials in the world, around 40%, and it is responsible for 25-40% of global carbon dioxide emissions.[28] For these reasons it is essential to make the transition to the circular economy.
Many initiatives have already interested the macro scale of the building sector; this means regional or urban plans, redefinition of big quartiers or design of eco-parks. However, it is also important to think and design for the meso (buildings) and micro (assemblies and components) levels. In fact, it has been demonstrated that it is necessary to improve relations between technological and social challenges designing simple-usage solutions, in order to involve even more people and, hopefully, the whole society in this transformation.

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[28] F. Pomponi, & A. Moncaster, *Circular economy for the built environment: A research framework* in "Journal of Cleaner Production", 143, 2017.

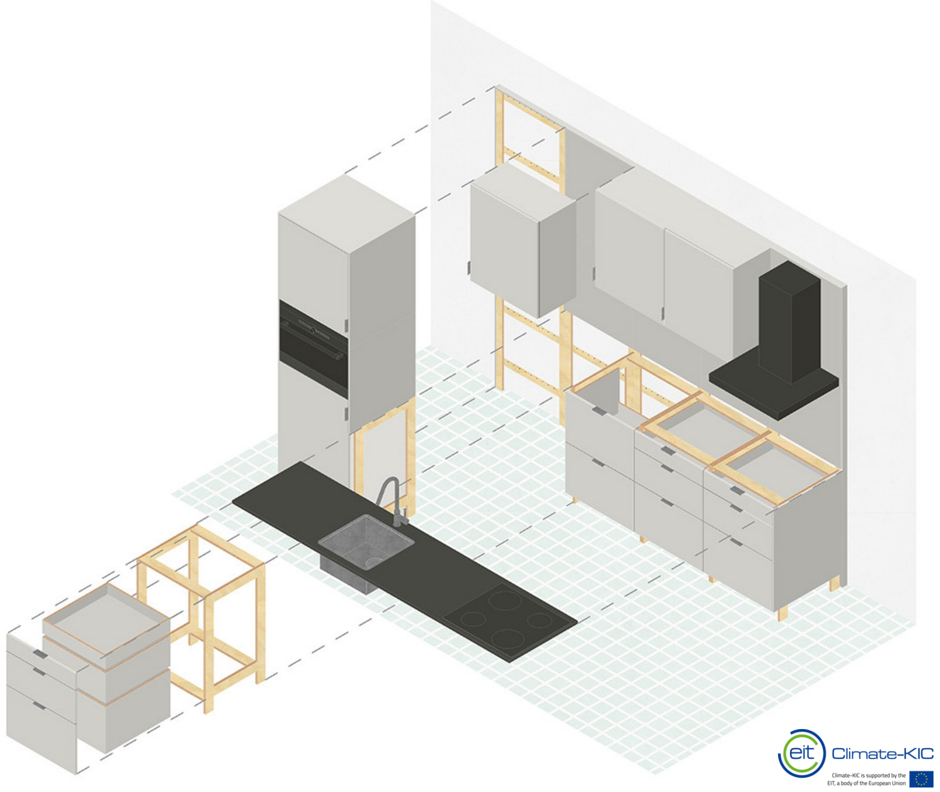

Fig. 9 - CIK project, a circular kitchen designed Delft University of Technology (Academic, Netherlands) - https://www.tudelft.nl

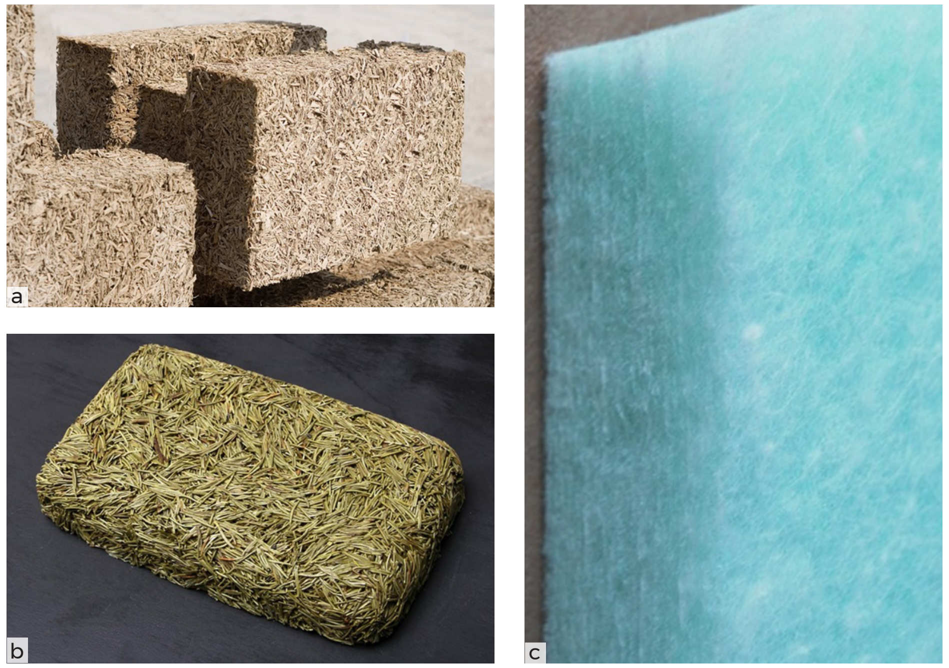

Fig. 10 - Bricks from hemp's fibers (a), brick from pine needles (b) and insulating panel from recycled PET (c) - https://www.matrec.com/

Concerning meso level, it is essential to start to design circular buildings designed, planned, built, maintained and deconstructed following the principles of circular economy. This means thinking about the possibility to choose natural or re-used materials, adopting systems able to involve people who live in the house doing sustainable actions as simple as possible, providing the possibility to re-adapt the plan according to the family's needs and designing separated changeable elements.
An interesting example in this field is CIK, a circular kitchen.[29] The idea shows how building component could be "circular", which means that they can be changed, fixed or replaced during the entire life of the building. In fact, CIK is a modular kitchen where the different elements can be added, removed and replaced in case of in breakage or changes of tastes or family's needs (fig. 9).
There are countless the examples of cases concerning the micro scale. In fact, in the last years, many research took place to produce materials from waste. From bricks built with hemp's fibers (fig. 10a) or with pine needles (fig. 10b) to insulating panels created by fibers of polystyrene coming from plastic bottles[30] (fig. 10c), through flooring made by alpine hay[31] (fig. 11a) to drainage panels made by recycled tyre [32] (fig. 11b).

Fig. 11 - Alpine hay flooring system (a) drainage panel from recycled tyre (b)
(a) https://www.matrec.com/
(b) https://www.organoids.com

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[29] https://www.tudelft.nl/bk/onderzoek/onderzoeksthemas/circular-built-environment/projects/cik-the-circular-kitchen/, accessed on 20/02/2020

[30, 32] https://www.matrec.com/materiali-circolari, accessed from 24/02/2020 to 26/05/2020

[31] https://www.organoids.com/produkte/branchen/, accessed from 13/03/2020 to 21/04/2020

FOOD WASTE

"Food loss is defined as 'the decrease in quantity or quality of food.' Food waste is part of food loss and refers to discarding or alternative (nonfood) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to end household consumer level"[33]

Food and Agriculture Organization (FAO), 2016

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[33] M. F. Bellemare, M. Çakir, H. H. Peterson, L. Novak, & J. Rudi, *On the Measurement of Food Waste. American Journal of Agricultural Economics*, 99(5), 2017, p. 1151.

ABSTRACT CHAPTER 2

È stato stimato che circa un quarto del cibo prodotto a livello mondiale ogni anno venga sprecato, del quale circa il 53% deriva dal settore domestico. Questi sprechi hanno un forte impatto sui sistemi economici, sociali e ambientali a livello mondiale. Per questo motivo, diversi Stati hanno già attuato misure per ridurre gli sprechi sulla base degli *Obiettivi di Sviluppo Sostenibile* descritti nell'Agenda 2030.

Nel considerare gli sprechi di cibo è molto importante distinguere tra perdite, sprechi e surplus. Il primo indica le perdite di qualità e quantità durante le prime fasi della filiera, il secondo considera le quantità di cibo destinate al consumo ma che per vari motivi sono state scartate, infine il surplus consiste negli alimenti che sono stati preparati e serviti ma che per svariate ragioni non vengono consumati.
Questa gerarchia può essere a sua volta suddivisa in sei categorie che tengono conto della commestibilità o meno dei vari rifiuti di cibo considerati.

Questi sprechi hanno un forte impatto sull'ambiente che riguarda le emissioni di carbonio, il consumo di suolo e il consumo di acqua. Per queste ragioni è indispensabile sviluppare strategie in grado di gestire e convertire i rifiuti alimentari in risorse a valore aggiunto.
Diverse soluzioni sono già state adottate nella produzione di energia elettrica, biodisel, bio-plastiche o fertilizzati organici attraverso processi termochimici, di digestione anaerobica e di compostaggio.
Anche nel campo delle costruzioni si è incominciato ad utilizzare i rifiuti alimentari nella produzione di materiali edili. In questo caso si possono trovare due diversi approcci: in alcuni casi i rifiuti alimentari vengono impiegati come materia principale del nuovo materiale, mentre in altre sperimentazioni si aggiungono piccole quantità di scarti di cibo a composti già esistenti per migliorarne le proprietà fisiche e mecchaniche.

Tra i rifiuti organici si può trovare anche la polvere di caffè esausto. Il caffè infatti rappresenta la seconda merce di scambio al mondo dopo il petrolio ed è stato stimato che in un anno vengono consumate circa 9500 tonnellate di polvere di caffè. Questo genera una grande quantità di rifiuti lungo tutta la catena produttiva: polpa, buccia, pellicola argentea e polvere di caffè esausto il cui smaltimento in discarica contribuisce attivamente alla produzione di CO_2.

Numerose rierche si concentrano su questo problema sviluppando sistemi in grado di riutilizzare questi rifiuti nell'industria alimentare, nella produzione di fertilizzanti, di bio-combustibili e di energia. Inoltre, i fondi di caffè sono stati impiegati nella produzione di diversi oggetti quali: lampade, gioielli, piccoli elementi d'arredo e stoviglie.

Nonostante ciò, tutti questi studi sono ancora ad una fase embrionale che non prevede il pieno utilizzo dei rifiuti di caffè in ambito edilizio. Pertanto è necessario approfondire questo tema al fine di sviluppare startegie e metodi di valorizzazione del caffè nel campo delle costruzioni.

2.1 PROBLEMS AND CLASSIFICATION

Fig. 12 - The diagram shows how a correct management of produced food allows to reduce food waste and loss
http://www.fao.org/resources/infographics/infographics-details/en/c/414196/

2.1.1 Definition and numerical data

Food waste is recognized as all "*the leftovers or precooked food, which generates biodegradable organic waste*".[34]

The United Nations Food and Agriculture Organisation has estimated that almost one-quarter to one-third of the food produced in the world is wasted[35] (fig.12). Furthermore, the European project FUSION[36] has declared that, in the European Union, every year, almost 88 million tonnes of food waste are produced, including both edible and inedible parts of the food. This generated a cost estimated around 143 billion euros of which, two-third have been produced by the household sector. This sector, together with the processing, contributes most to food waste, generating around 72% of EU food waste.
This is an important global issue because it has an environmental, economic and social impact that produces global consequences. For this reason, many countries have already taken some political measures to reduce food loss and waste according to the SDGs of the Agenda 2030,[37] for example in France supermarkets are not allowed to throw out food, they are obliged to donate unsold and expiring products to no-profit associations.
Indeed the SDG Target 12.3 plans to halve per capita the global food waste by 2030, in the retail and consumer sectors. It also establishes to reduce food losses during the production processes and along the supply chains, considering also post-harvest losses.
Furthermore, all the efforts made to reach the SDG Target 12.3 could help to meet other SDG targets such as achieving Zero Hunger. However, despite the domestic sector is the main responsible for food waste generation, most of the regulatory efforts focus on production and sales sectors.

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[34] P. Sharma, V. K. Gaur, S. H. Kim, & A. Pandey, *Microbial strategies for bio-transforming food waste into resources* in "Bioresource Technology" 299, 2020, p. 3.

[35] M. F. Bellemare, M. Çakir, H. H. Peterson, L. Novak, & J. Rudi, *On the Measurement of Food Waste* in "American Journal of Agricultural Economics" 99(5), 2017, p. 1148.

[36] Å. Stenmarck, C. Jensen, T. Quested, G. Moates, M. Buksti, B. Cseh, S. Juul, A. Parry, A. Politano, B. Redlingshofer, S. Scherhaufer, K. Silvennoinen, H. Soethoudt, C. Zübert, & K. Östergren, *Estimates of European food waste levels. Reducing food waste through social innovation* in "Fusions", 2016.

[37] Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*, 2019.

2.1.2 Hierarchy and classification

A great variety of terms is used to identify waste that comes from food. “Food waste” is often used as a general definition but it is important to make a distinction between “food loss”, “food waste” and “food surplus” because they belong to different moments of the food supply chain.[38]
Food loss is “*the unintentional decrease in edible food quantity or quality before consumption, including postharvest losses*”.[39] It concerns production, post-harvest and processing moments of the food supply chain. Some examples of food loss are the edible crops left in the fields or the food damaged during the transportation from factory to retailer.
Food waste, instead, consists of all “*food originally produced for human consumption that was discarded or was not consumed by humans. Including still edible food that is deliberately discarded*”.[40] For example, plate waste or food spoiled because of poor storage in retail or households. In this case, they may cover the whole food supply chain, but primarily retail, and consumer stage services included.
Lastly, food surplus is defined as “*the edible food produced, manufactured, retailed or served that has not been consumed by humans (mainly due to socio-economic reasons), including food produced beyond nutritional needs*”.[41] As for food waste, this may cover the whole food supply chain but is more common in the retail and consumer stage. Food surplus considers only edible food, it doesn’t consider inedible food or food use for feeding animals. Examples of food surplus are the overproduction of food during production, retail waste such as fresh fruits and vegetables or canned goods.
This waste hierarchy, defined in the EU’s legislation[42], comes from two strategies identified in the 1970s by the European Parliament’s Directive on Waste in 1975 and the European Commission’s Second Environment Action Program in 1977. It represents a guide to identify the best end-of-life treatment in terms of environmental efficiency.

NOTES

[38] D. A. Teigiserova, L. Hamelin, & M. Thomsen, *Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy*, Science of the Total Environment, 706, 2020.

[39, 40, 41] D. A. Teigiserova, L. Hamelin, & M. Thomsen, *Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy*, Science of the Total Environment, 706, 2020, p. 3, table 1.

[42] European Parliament Council, 1989.

The hierarchy of food surplus, waste and loss is related to the concepts of edibility and avoidance (fig. 13).
This allows splitting food surplus, waste and loss in six different categories.[43] In category I it is possible to find all edible food that is good to eat for humans, which means the surplus food. Category II includes food waste that cannot be avoided due to food’s natural inedibility. Category III, on the other hand, encompasses all the food waste that can be minimized through a process optimization, though it also cannot be prevented fully. In categories IV and V there are cases where inedibility cannot be eliminated completely. Category IV includes inedible food caused by high perishability while in category V there is inedible food that is the result of unpredicted conditions such as damages by weather or pests. Category VI, finally, is about food loss and amounts not accounted for.
As it has been stated before, categories II and V represent the inedible fraction of food. They have a big potential for material recycling so they can be seen as a resource for the industrial sector able to generate economic and environmental benefits.

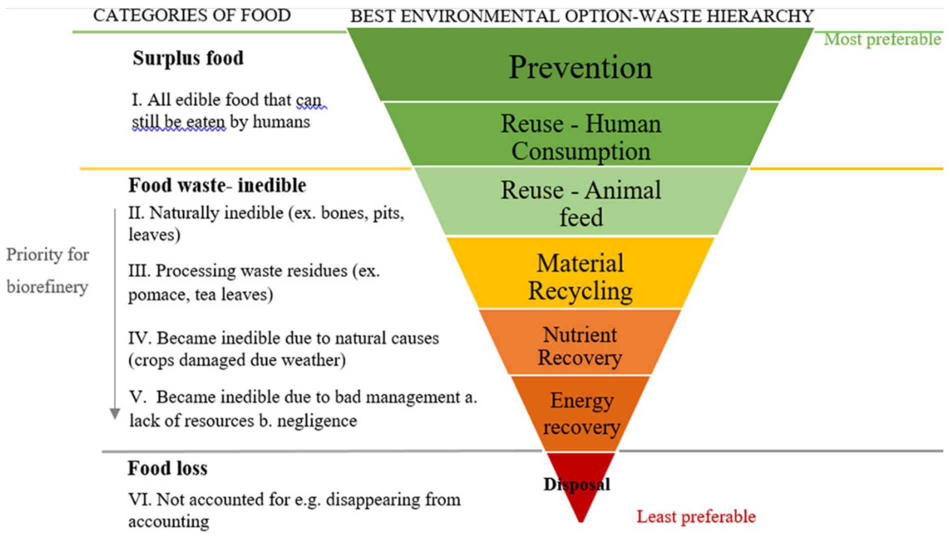

Fig. 13 - Food surplus, waste and loss hierarchy and categories
D. A. Teigiserova, L. Hamelin, & M. Thomsen, *Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy*, in “Science of the Total Environment”, 706, 2020.

NOTES

[43] D. A. Teigiserova, L. Hamelin, & M. Thomsen, *Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy*, Science of the Total Environment, 706, 2020.

2.1.3 Food loss and waste environmental footprint

Attempting to feed the world's population sustainably is becoming even more challenging due to population and income growth. This sense of wellness increases the global demand for agricultural outputs, in fact, an increase by 35–50 percent of food demand is expected between 2012 and 2050.[44] This may lead to environmental damages that are already oppressing the Earth such as climate change, land degradation, water scarcity and loss of biodiversity.
Furthermore, producing food that becomes waste because it is not consumed causes further damage since it reduces the quantity of available food and represents a big waste of economic and environmental resources. For these reasons, a reduction of food loss and waste could help to have an environmental sustainability in the food sector.

FAO, in The State of Food and Agriculture 2019, illustrates that food loss and waste produce three different types of environmental footprints: carbon footprint, land footprint and water footprint. Carbon footprint consists especially of the greenhouse gas, expressed in CO2 equivalent, emitted during all the food's life cycle, starting from the production, through transportation, processing, distribution, consumption and up to disposal. In fact, disposal is one of the main problems; often food waste is left in landfills where it starts to release greenhouse gases. As it has been explained, the CO2 emissions come from all moments of the supply chain. Both in developed and in developing countries there is a production of greenhouse gas already in the primary production steps. While moving forward the steps of the supply chain, the greenhouse gas' production increases and accumulates to the one produced in the previous stages ensuring that the food loss and waste at the end of the chain are characterized by increased greenhouse gas production.
The land footprint concerns the pressure on land resources. Since the first agricultural expansions, the land occupation occurred at the expense of forests, causing changes and damages in environmental equilibrium. With population growth, changes in diet and food consumption and demand for bioenergy will increase the exigency of land to cultivate producing a higher quantity of land footprint. This has measured as the surface of land needed to produce that food, which means that almost all the land use is concentrated in the primary production phase of the food's life cycle.
Lastly, the water footprint is related to the pressure on water resources. Almost 70% of the global water consumption is used by the farming sector, while the other 30% concerns the industry sector and domestic water supply.
The water footprint is defined by the amount of freshwater used to produce and supply the food production to its final consumer, through all phases of the supply chain. Most of that water is used for irrigation but a large part is also required in the processing of some types of food products.
Three different components generate water footprint: blue water that includes groundwater or surface water, green water that indicates the rain and grey water that is the one used to dilute pollutant concentrations to acceptable levels.
All these footprints quantity vary considerably from one type of food to another and depending on the characteristics of a country's food production system.

NOTES

[44] Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*, 2019.

2.2 EXAMPLES OF HOW TO REUSE FOOD WASTE

2.2.1 Why re-use food waste

The European project FUSION estimated that in 2012 have been produced around 173 kilograms of food waste per person in the EU-28 including both edible and inedible food.[45]
Furthermore, the University of California researchers have shown that food waste produces dioxins when it disposed of through incinerators because of its high moisture content, whereas, when food waste is dumped in open-air landfill it may cause health and environmental issues.[46] Starting from these data it has been estimated that food waste releases into the atmosphere approximately 3.3 billion tonnes of CO2 every year, contributing to the formation of greenhouse gases.[47]
For these reasons, it is important to find new and appropriate methods to manage food waste in order to give them a new value and re-use them.

2.2.2 How to re-use food waste

Searching on websites such as Science Direct or Google Scholar with keywords like "food waste", "re-use food waste" or "food waste valorization" it is very easy to find studies and proposals on how to re-use food waste in different sectors.
The most common usage of food waste consists in convert it in value-added resources such as electric power generation, biodiesel, bio-hydrogen, ethanol, butanol, biosurfactants, bio-plastics or organic fertilizers.[48] This can happen through phenomena as anaerobic digestion, thermochemical process and composting.
Anaerobic digestion is a process that consists in the degradation of organic materials in the absence of oxygen.

NOTES

[45] Å. Stenmarck, C. Jensen, T. Quested, G. Moates, M. Buksti, B. Cseh, S. Juul, A. Parry, A. Politano, B. Redlingshofer, S. Scherhaufer, K. Silvennoinen, H. Soethoudt, C. Zübert, & K. Östergren, *Estimates of European food waste levels. Reducing food waste through social innovation* in "Fusions", 2016.

[46] T. Katami, A. Yasuhara, & T. Shibamoto, *Formation of Dioxins from Incineration of Foods Found in Domestic Garbage* in "Environmental Science and Technology" 38(4), 2004, pp. 1062–1065.

[47] K. Paritosh, S. K. Kushwaha, M. Yadav, N. Pareek, A. Chawade, & V. Vivekanand, *Food Waste to Energy: An Overview of Sustainable Approaches for Food Waste Management and Nutrient Recycling* in "BioMed Research International", 2017.

[48] P. Sharma, V. K. Gaur, S. H. Kim, & A. Pandey, *Microbial strategies for bio-transforming food waste into resources* in "Bioresource Technology", (299), 2020.

During the process are produced biogases, for this reason, the technique is largely adopted in food waste disposal.[49]
Anaerobic fermentation is a developing technology that allows the generation of hydrogen and methane, two important gaseous fuels that can be used in the automotive industry. Moreover, these gases can be converted into heat or electricity for the machines of many industries.[50]
Thermochemical processes, such as, for example, pyrolysis, are becoming more and more interesting thanks to their capacity to reduce the waste volume more than 80%, reduce the reaction times and increase the number of wastes that can be treated. Furthermore, they allowed producing gases, bio-oil, biochar and biochemical products.[51]
The other interesting way of re-use food is composting. This technique is very useful for the soil because it reduces greenhouse gas emissions, improves soil health and generates the perfect soil environment for the microorganisms.
There are two different types of composting: aerobic and anaerobic. The first one is made at open air or in closed in-vessel or container systems, in both cases, however, there is the presence of air. The second category of composting, instead, is characterized by the presence of inoculated bran for the fermentation to convert food waste into compost; a famous anaerobic system is the Bokashi method.[52]
Another field concerning food waste re-use is the bio-plastics one. In fact, during the last years, biodegradable packagings are becoming even more popular to replace the synthetics ones. Different studies have shown that it is possible to create food biodegradable packaging adding natural antioxidants in biopolymers. One of these biopolymers is gelatine that, thanks to its biodegradable properties, can produce a biofilm. The gelatine may be taken from the waste coming from the industrial processing of oil nutraceutical capsules. This process represents two benefits: it allows the re-use of food

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[49] M. J. Rogoff, F. Screve, *Waste-To-energy Technologies and Project Implementation* (Third Edition), 2019, pp. 29-56.

[50] N. Bao, D. Thi, C. Lin, & G. Kumar, *Waste-to-wealth for valorization of food waste to hydrogen and methane towards creating a sustainable ideal source of bioenergy* in "Journal of Cleaner Production", (122), 2016, pp. 29–41.

[51] S. Kim, Y. Lee, K. A. Lin, E. Hong, E. E. Kwon, & J. Lee, *The valorization of food waste via pyrolysis* in "Journal of Cleaner Production", (259), 2020.

[52] Z. Xiang, S. Chong, C. Guan, N. Izzati, S. Hanson, G. Pan, P. Li, C. Vimala, & A. Singh, *Community-scale composting for food waste : A life-cycle assessment- supported case study* in "Journal of Cleaner Production", (261), 2020.

waste material to generate a high-value product and, at the same time, it helps the industrial waste disposal, reducing the cost of waste treatments.[53]

2.2.3 Re-use food waste in building sector

The re-use of food waste as a resource is becoming increasingly important also in the field of materials and construction. In fact, there are several studies focuses on this topic.
In some cases, food waste is used as the main component to design a new material, as in research carried out by Rowan Minkley and Robert Nicoll.[54] The two designers developed a system to transform potato peelings into MDF and chipboard substitute to use as a furniture or building material. This study, in addition to re-use waste potato peelings, allows creating a material that, at the end of its life, can be biodegraded into fertilizer.
In other cases food waste represents only a small addition to an existing material, to increase its properties. An example is Bruna D'Agata's research.[55] In her thesis, she added a small quantity (< 20%) of almond shells in an already existing thermal plaster. Her study shows that by adding almond shells, the plaster's thermal properties and the building's energy efficiency improved, not to mention the environmental and economic benefits obtained giving this waste a new value.
Furthermore, by consulting online materials databases, such as Matrec,[56] or other websites oriented on materials sustainability, like Organoid,[57] it is possible to find a huge number of building materials produced from food waste. These materials cover a great variety of functions: from

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[53] T. De Moraes, T. Maria, H. Costa, A. De Oliveira, & S. Hickmann, *Valorization of food-grade industrial waste in the obtaining active biodegradable films for packaging* in "Industrial Crops & Products", (87), 2016, pp. 218–228.

[54] Natashah Hitti, *Rowan Minkley and Robert Nicoll, Recycle potato peelings into MDF substitute* in "Dezeen" (online version), 2018.

[55] B. D'Agata, *Almond shells as natural aggregates in thermal plaster - Product development and theoretical-experimental analysis of the energy-environmental performance,* Master's thesis, Turin, 2016, Serra V., Giordano R., Dutto M.

[56] https://www.matrec.com/, accessed from 24/02/2020 to 26/05/2020

[57] https://www.organoids.com/en/products/raw-materials/, accessed from 13/03/2020 to 21/04/2020

thermal and acoustic insulation to decoration panel, from flooring products to plaster coating. They result from several types of food waste such as rice or other cereal husks and hulls, coconut shells and fibers, almonds, walnuts or hazelnuts shells and banana or other fruit fibers, to mention only some examples.
This is a constantly expanding field, which always needs new research and discoveries to increase innovation and reduce the waste amount.

2.3 OLD COFFEE GROUND

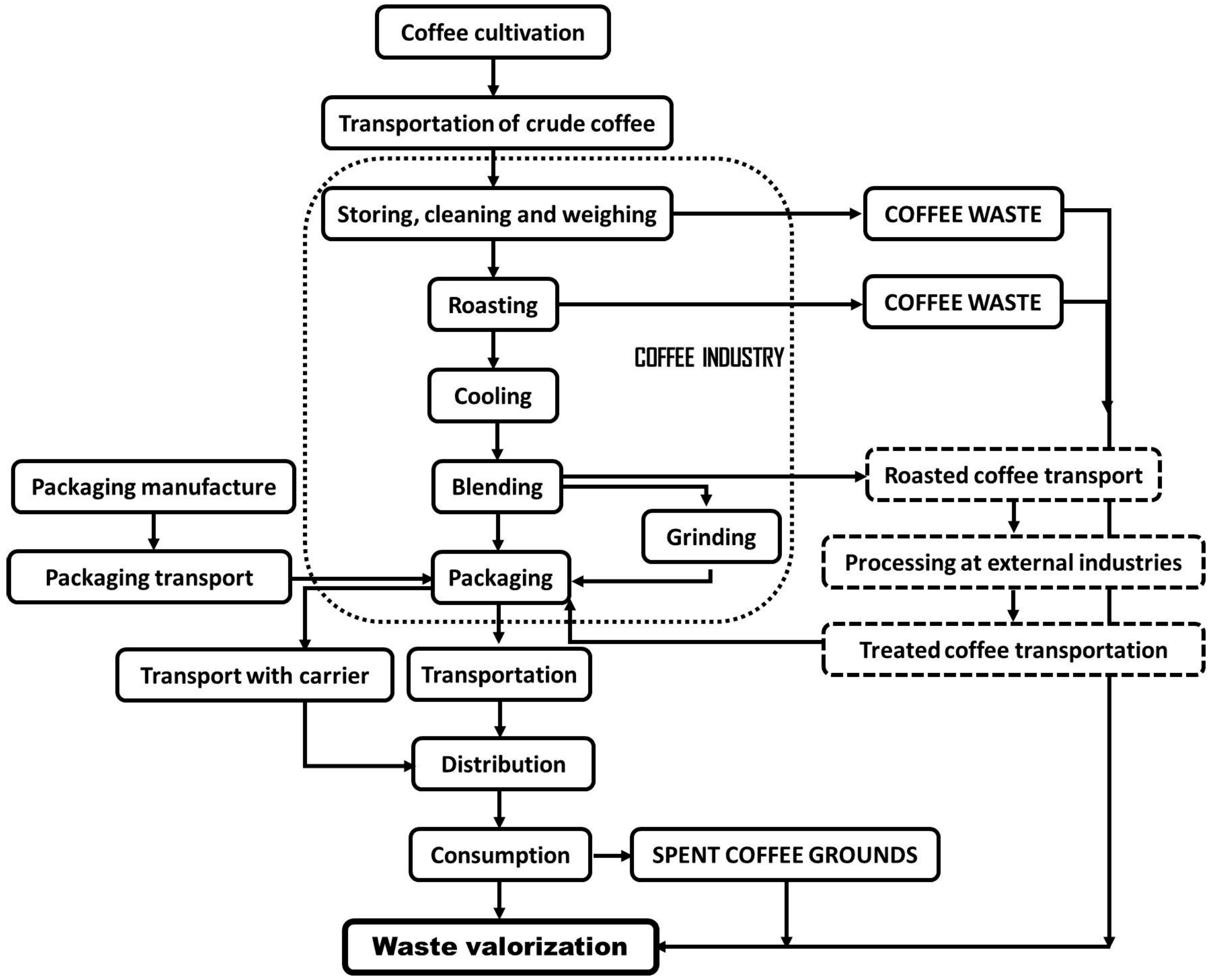

Fig. 14 - Coffee supply chain and production of coffee waste
S. K. Karmee, *A spent coffee grounds based biorefinery for the production of biofuels, biopolymers, antioxidants and biocomposites* in "Waste Management", (72), 2018, p. 242.

2.3.1 Numerical data

Coffee is one of the most requested tropical products and the second common trade commodity in the world, after petrol.[58] In fact, worldly coffee production covers almost 16,34 billion pounds per year, making this food an essential agricultural product. Its great demand in the world market brings economic benefits at each level of the supply chain, by connecting producers and consumers.
The ICO (International Coffee Organization) established that since 1990, the consumption, and consequently the production, of coffee has grown by more than 65%[59] transforming coffee in the second most drunk beverage in the world, after water. The highest worldly coffee consumption was reached in 2016/2017, it consisted of 157382 bags of 60 kg.[60] It has been estimated that in the world there is an average of 4,5 kg of coffee consumed per capita every year.[61] However, this quantity varies a lot from country to country in the USA, for example, the average consumption is around 4 kg per person while in Italy it is 6 kg. The major coffee drinkers are the Scandinavian countries, starting from Swedish with an average of 8 kg each up to the Finns that, with their 12 kg of coffee per person each year, represent the country with the highest consumption of coffee in the world.

The two favorite coffee species in the world are Arabica (70%) and Robusta (30%).[62] They are cultivated in more than 50 countries, among which we found Brazil, Vietnam, Colombia, Indonesia and Ethiopia.

During the entire coffee's life cycle, however, large quantities of waste are produced: coffee pulp, coffee husk, coffee silver skin and spent coffee grounds (fig. 14). Just preparing 1kg of soluble coffee around 2kg of wet spent coffee grounds are produced.[63]

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[58, 62] J. Rajesh Banu, S. Kavitha, R. Yukesh Kannah, M. Dinesh Kumar, Preethi, A. E. Atabani, & G. Kumar, *Biorefinery of spent coffee grounds waste: Viable pathway towards circular bioeconomy* in "Bioresource Technology", (302 January), 2020.

[59] ICO, *Coffee Development Report. Growing for prosperity. Economic viability as the catalyst for a sustainable coffee sector*, 2019.

[60, 63] M. Stylianou, A. Agapiou, M. Omirou, I. Vyrides, I. M. Ioannides, G. Maratheftis, & D. Fasoula, *Converting environmental risks to benefits by using spent coffee grounds (SCG) as a valuable resource* in "Environmental Science and Pollution Research", 25(36), 2018.

[61] https://www.quickcaffe.com/consumi-caffe-italia-e-mondo/, accessed on 14/04/2020.

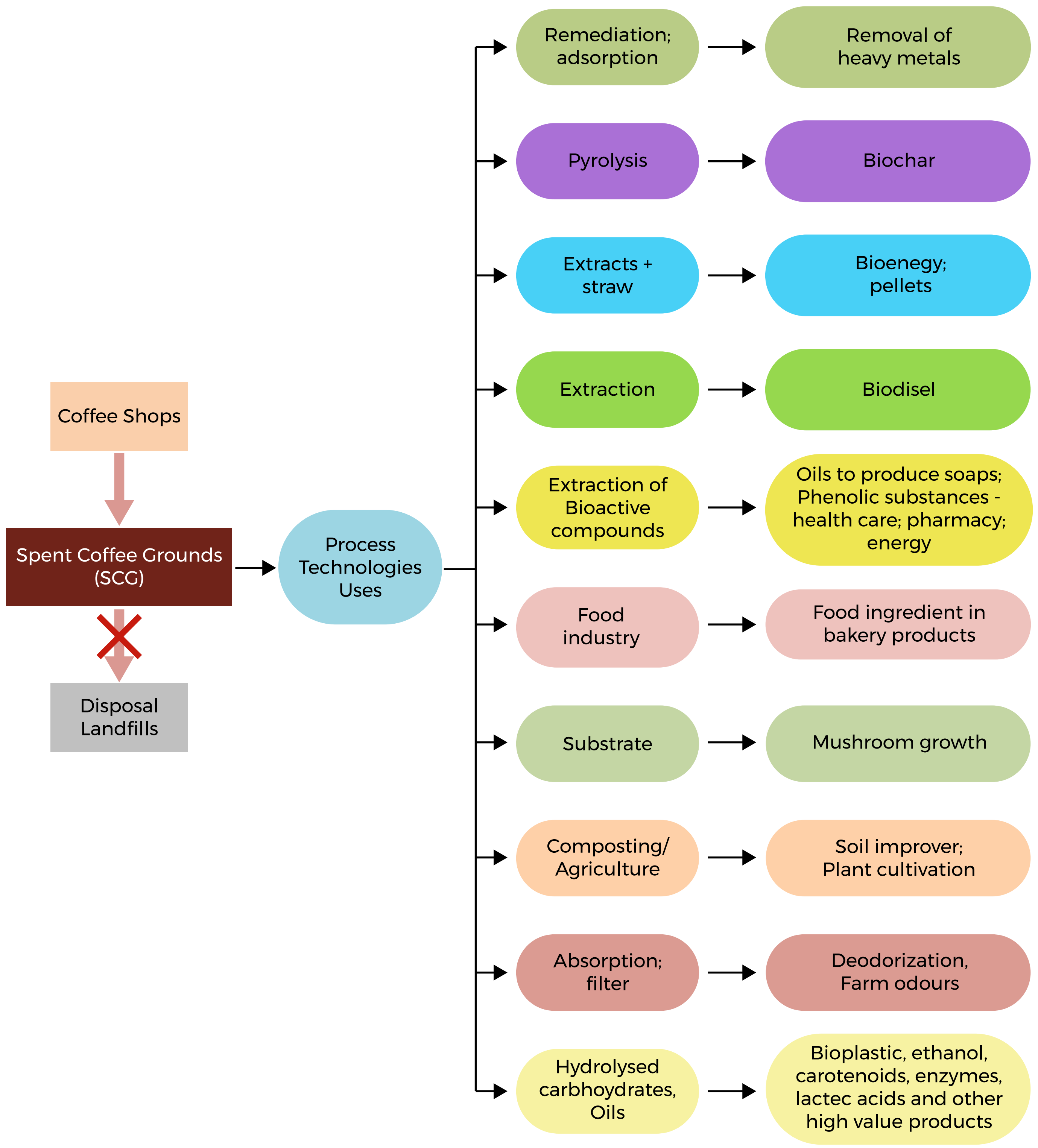

Fig. 15 - Potential uses of spent coffee grounds
M. Stylianou, A. Agapiou, M. Omirou, I. Vyrides, I. M. Ioannides, G. Maratheftis, & D. Fasoula, *Converting environmental risks to benefits by using spent coffee grounds (SCG) as a valuable resource* in "Environmental Science and Pollution Research", 25(36), 2018, p. 35778.

In Italy, every year, around 360000 tons of spent coffee grounds are produced. These are dumped in landfill, producing 131400 tons of CO_2.[64] Worldwide, in 2014 more than 9 million tonnes of old coffee grounds were generated and discarded in dumps.[65] The numbers show that in the last five years the consumption of coffee increased. Hence, it is easy to imagine the enormous environmental impact that the spent coffee grounds pose on the planet.

2.3.2 Spent coffee grounds' valorization

Spent coffee grounds are considered a valuable and promising material for a great variety of applications (such as for the production of mushrooms, pellets for biomass, biochemicals, biodiesel and for furniture), thanks to its content of rich nutrients, oil, phenolic compound, protein and fibers.[66]
Several studies are already dealing with the problem of how to re-use and enhance coffee waste. In fact, through a proper use of technologies, it is possible to manage coffee waste with a holistic approach considering the different possibilities of valorization of the material (fig. 15). It has been shown that spent coffee grounds contain phytochemicals, substances capable of producing benefits to the human body, with antioxidant,[67] prebiotic and antimicrobial[68] properties. This means that spent coffee grounds have been considered as an important agricultural by-product for scientific applications for medical, healthcare and pharmaceutical purposes. In fact, phenolic compounds would have a protective action against cardiovascular and degenerative diseases and cancer, as well as having anti-allergic properties.[69] Furthermore, these

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[64] http://www.finanzialatuaidea.it/dal-riciclo-all-impresa-fare-business-con-i-fondi-del-caffe-547, accessed on 14/04/2020.

[65] S. K. Karmee, *A spent coffee grounds based biorefinery for the production of biofuels, biopolymers, antioxidants and biocomposites* in "Waste Management", (72), 2018.

[66] M. Stylianou, A. Agapiou, M. Omirou, I. Vyrides, I. M. Ioannides, G. Maratheftis, & D. Fasoula, *Converting environmental risks to benefits by using spent coffee grounds (SCG) as a valuable resource* in "Environmental Science and Pollution Research", 25(36), 2018.

[67] J. Bravo, C. Monente, I. Juániz, M. P. De Peña, & C. Cid, *Influence of extraction process on antioxidant capacity of spent coffee* in "Food Research International", 50(2), 2013.

[68] C. Severini, A. Derossi, & A. G. Fiore, *Ultrasound-assisted extraction to improve the recovery of phenols and antioxidants from spent espresso coffee ground: a study by response surface methodology and desirability approach* in "European Food Research and Technology", 243(5), 2017.

properties allow re-using old coffee grounds in the food sector as nutritional supplements. An interesting research concerning this field was conducted by Severini et al. who have demonstrated that it is possible to produce muffins replacing part of the flour with spent coffee grounds as an unconventional integrator of fibers and antioxidant.[70]
Another interesting feature of the old coffee ground is its heat value (almost 6000 kcal/kg dry) that is similar to coal,[71] for this reason, it can be used as a fuel in industrial boilers. Furthermore, ashes derived from combustion are rich in phosphorus, calcium and magnesium that make them excellent fertilizers. However, it should also be noted that the combustion of this type of fuel has produced atmospheric pollutants and volatile organic compounds. To reduce these effects Limousy et al.[72] developed specific densified logs made by 20% of spent coffee grounds and 80% of pine sawdust that could become a promising biofuel for residential heating.
Among the others, another common technique used to produce biodiesel from old coffee grounds is the transesterification.[73] This process allows extracting the oil from spent coffee grounds and replacing the normal diesel with this biofuel.
Lastly, Tsai et al.[74] conducted a study for the production of biochar, as a coal substitute for energy production, from exhausted coffee residues through the pyrolysis process. The research's results show that biochar from spent coffee grounds has a higher calorific value compared with coal. This

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[69] M. Stylianou, A. Agapiou, M. Omirou, I. Vyrides, I. M. Ioannides, G. Maratheftis, & D. Fasoula, *Converting environmental risks to benefits by using spent coffee grounds (SCG) as a valuable resource* in "Environmental Science and Pollution Research", 25(36), 2018.

[70] C. Severini, A. Derossi, & A. G. Fiore, *Ultrasound-assisted extraction to improve the recovery of phenols and antioxidants from spent espresso coffee ground: a study by response surface methodology and desirability approach* in "European Food Research and Technology", 243(5), 2017.

[71] O. Box, *The use of biomass residues in the Brazilian soluble coffee industry*, (14), 1998.

[72] L. Limousy, M. Jeguirim, S. Labbe, F. Balay, & E. Fossard, *Performance and emissions characteristics of compressed spent coffee ground/wood chip logs in a residential stove* in "Energy for Sustainable Development", 28, 2015.

[73] N. Kondamudi, S. K. Mohapatra, & M. Misra, *Spent coffee grounds as a versatile source of green energy* in "Journal of Agricultural and Food Chemistry", 56(24), 2008.

[74] W. T. Tsai, S. C. Liu, & C. H. Hsieh, *Preparation and fuel properties of biochars from the pyrolysis of exhausted coffee residue* in "Journal of Analytical and Applied Pyrolysis", 93, 2012.

allows using biochar as a solid combustible in the industry sector.
Concerning biofertilizer, instead, several studies have been conducted to develop the use of spent coffee grounds in the manufacturing of these products because they could improve soil structure, aeration and fertility. However, the addition of old coffee grounds in the soil produces different effects depending on the type of plant because of their phytotoxic properties.[75] These effects can be reduced through composting spent coffee grounds with some other organic compounds. Jayapriya & Ravi,[76] for example, shown the possibility to generate value-added product thanks to the co-composting of yard (fallen dry leaves, grass residues or wood debris) and canteen (fruit and vegetable waste, spent coffee ground or spent tea leaves) waste.
Remaining in the biofertilizer's field, spent coffee ground can be also used as a substrate to grow edible mushrooms, as the study carried out by Fan et al.[77] shows. In their research, it is possible to understand that, unlike what happens for coffee pulp and other residues, spent coffee grounds do not need pre-treatment allowing their direct use.
A very interesting feature of spent coffee grounds is their great adsorbing abilities. Generation of biochar or pellets from old coffee grounds allows the absorption of many elements such as heavy metals,[78] organic and inorganic pollutants,[79] pharmaceutical compounds,[80] and indoor paints.[81]
Lastly, spent coffee grounds were also used in the design sector for the production of several objects, from lamps

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[75] M. Stylianou, A. Agapiou, M. Omirou, I. Vyrides, I. M. Ioannides, G. Maratheftis, & D. Fasoula, *Converting environmental risks to benefits by using spent coffee grounds (SCG) as a valuable resource* in "Environmental Science and Pollution Research", 25(36), 2018.

[76] K. M. S. J. Jayapriya, & J. H. Ravi, *Evaluation of in-vessel co-composting of yard waste and development of kinetic models for co-composting* in "International Journal of Recycling of Organic Waste in Agriculture", 4(3), 2015.

[77] L. Fan, A. Pandey, R. Mohan, & C. R. Soccol, *Use of various coffee industry residues for the cultivation of Pleurotus ostreatus in solid state fermentation* in "Acta Biotechnologica", 20(1), 2000.

[78] M. S. Kim, H. G. Min, N. Koo, J. Park, S. H. Lee, G. I. Bak, & J. G. Kim, *The effectiveness of spent coffee grounds and its biochar on the amelioration of heavy metals-contaminated water and soil using chemical and biological assessments* in "Journal of Environmental Management", 146, 2014.

[79] E. Loffredo, & E. Taskin, *Adsorptive removal of ascertained and suspected endocrine disruptors from aqueous solution using plant-derived materials* in "Environmental Science and Pollution Research", 24(23), 2017.

Fig. 16 - DECAFE lamps collection by Raúl Laurí Pla
https://www.yatzer.com/DECAFE-Raul-Lauri-Pla

Fig. 17 - Java Ore collection by Rosalie McMillan
https://www.trendhunter.com/trends/coffee-and-silver

Fig. 18 - Nero furniture collection by Xavier Loránd
https://www.dezeen.com/2018/10/22/nero-xavier-lorand-coffee-waste-concrete-inedito-design-week-mexico

Fig. 19 - Organic sunglasses made of natural coffee grounds by Ochis coffee
https://www.kickstarter.com/projects/ochis/ochis-first-organic-sunglasses-made-of-coffee

designed by Raúl Laurí Pla (fig. 16) to the jewels of Rosalie McMillan (fig. 17) and from the side-table and a stool of the Nero furniture collection by Xavier Loránd (fig. 18) to organic sunglasses designed by Ochis company (fig. 19). One of the most famous design objects is the invention of Julian Lechner who developed a system to produce coffee cups from coffee waste.[82] Combining natural glues and sustainable wood particles, he was able to produce a liquid to inject in moulds in order to create cups. Once dry, this material is hard and waterproof, thus allowing cleaning in the dishwasher (fig. 20).

All these studies, aimed at turning coffee waste into a new resource able to cover number of applications, but they are still uncommon and not well known. Furthermore, there are some fields that have not yet been fully considered such as the building sector. The purpose of this thesis, therefore, is to develop new methods to re-use spent coffee for architectural purposes.

Fig. 20 - Coffee cups from coffee waste by Julian Lechner
https://www.dezeen.com/2015/05/22/kaffeeform-recycled-ground-coffee-waste-cup-julian-lechner/

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[80] S. Y. Oh, & Y. D. Seo, *Sorption of halogenated phenols and pharmaceuticals to biochar: affecting factors and mechanisms* in "Environmental Science and Pollution Research", 23(2), 2016.

[81] S. Sangpongch, T. Prueksasit, *Adsorption efficiency of the activated charcoal produced from spent coffee ground for removal of the BTEX released from indoor paint* in "Environment Asia", 10, 2017.

[82] Dirk E. Hebel, Marta H. Wisniewska, Felix Heisel, *Building from waste*, Birkhauser Verlag GmbH - Basel, 2014, p. 146.

HOUSEHOLD WASTE RECYCLE

"Contemporary lifestyle pushes us to produce waste at any time of day, thus feeding a huge and complex mechanism of different professions which contribute to a common objective: reducing waste production and improving their recycling. [...]
The very close relationship between waste and space - private and public – raises some important issues in tomorrow's city design. Design and architecture are thus, central disciplines in the process of a new economic and environmental approach, becoming bases for a successful waste cycle."[83]

Arch. Stefano Boeri & Comieco, 2018

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[83] S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p.9

ABSTRACT CHAPTER 3

Nell'economia circolare domestica i principali attori sono i cittadini stessi, pertanto è importante coinvolgerli e valutare le loro necessità per poter progettare sistemi a loro funzonali. Per questo motivo è stato svolto un questionario on-line che ha indagato le principali abitudini degli utenti per quanto riguarda la raccolta differenziata, con un particolare focus sullo smaltimento del caffè esausto.

La popolazione dei partecipanti al questionario è stata composta da 504 elementi provenienti da 10 Stati europei con un'elevata percentuale di italiani. Mentre per quanto riguarda l'età degli intervistati sono state coperte tutte le fasce dai 18 anni 65 e oltre.

Dai risultati del questionario sono emersi tre principali problemi: organizzare il sistema di raccolta differenziata nelle abitazioni private, capire come poter trattare con i rifiuti organici per evitare che essi interferiscano negativamente sul comfort dell'ambiente domestico e sviluppare un sistema di riciclaggio attorno al tema del caffè esausto.

Per rispondere alle prime due problematiche sono state selezionate alcune soluzioni presentate nell'Atlas sulle nuove pratiche per la gestione dei rifiuti prodotto dall'architetto Stefano Boeri in collaborazione con Comieco.
Tra le soluzioni individuate, alcune riguardano la gestione diretta dei rifiuti in termini di volume e organizzazione dei vari bidoni di raccolta come nel caso di "Totem", "Humus, modular bags" o del "Compattatore". In altri casi invece si tartta di veri e propri sistemi di riciclaggio integrati nel design della cucina come nel caso di "Ekokook".
In particolare, per far fronte al problema dei rifiuti organici, molto interessanti sono gli innovativi sistemi di compostaggio, i quali, oltre ad avere speciali filtri di controllo degli odori, sono dotati di sistemi wireless che permettono il controllo da remoto.

Per quanto riguarda il terzo problema invece, essendo esso direttamente connesso alla ricerca sperimentale che caratterizza la tesi stessa, sono state individuate soluzioni su diversi livelli. In primo luogo si è pensato alla possibilità di raccolgliere la polvere di caffè esausto in appositi contenitori dotati di un sistema di aerazione che permetta al caffè, ancora umido, di asciugare senza la formazione di eventuali muffe. In seguito è stata proposta una soluzione di raccolta del caffè esausto a scala territoriale. L'idea riprende il sistema di raccolta di bottiglie di plastica e lattine adottato in alcuni Paesi nord-europei ed è basata sull'idea di "ricompensa per lo sforzo effettuato". In pratica viene data la possibilità ai consumatori di restituire al punto vendita cialde usate o polvere di caffè esausto in cambio di un compenso economico da spendere per l'acquisto di nuovi prodotti all'interno del punto vendita stesso. Questo sistema è già stato adottato da alcuni negozi di caffè, come per esempio Nespresso, ma potrebbe essere ampliato anche ai supermercati attraverso l'installazione di appositi collettori all'ingresso facilitando il processo di raccolta. Ciò permetterebbe di intraprendere il processo di trasformazione e rivalorizzazione di tutti i rifiuti di caffè, compresi quelli provenienti dall'ambiente domestico.

3.1 SURVEY AND RESULTS

3.1.1 Survey

Citizens are the fulcrum of the domestic circular economy. Therefore, it is important to design strategies and solutions starting from their opinions.
For this reason, an online survey has been prepared to better understand the habits and the needs of people concerning household waste recycling.
The partecipants were asked 16 questions organized in 2 parts. The first one, consists of 5 questions, concerns demographical data such as age-group, living country, number of people and number of children living in the house and type of house they live in. The second part, aims to discover specific informations about people's recycling habits and difficulties. This section ends with 2 questions about coffee, which represent a first attempt to gain insight to users' habits regarding buying coffee and the willingness to sort coffee separately, in order to choose and propose appropriate coffee collecting methods that would allow the re-use of spent coffee grounds.

3.1.2 Survey results

The data collected from the survey are referred to a population of 504 elements.
Starting from demographical data it is possible to see that the sample of respondents is various because it covers all age groups with a small majority of answers from age-group 35-44 and age-group 45-54 as it is showed in fig. 21.

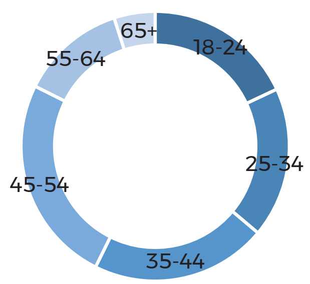

Fig. 21 - Age-goup percentage

Furthermore there is also a variety of countries. In fact, although the predominance of Italian partecipants is evident, there are also respondents from Belgium, Finland, France, Germany, Netherlands, Spain, Sweden, Switzerland and United Kingdom (fig. 22).

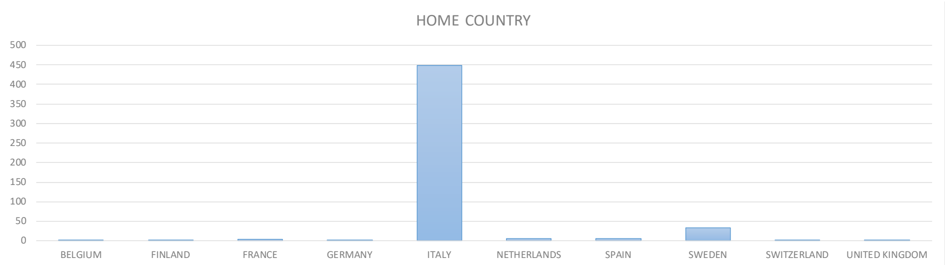

Fig. 22 - Interviewees home country

Moving on to recycling questions, the first query concerned the importance of recycling. In this case, respondents had to answer giving a score from 1 to 5 where 1 indicates that recycling is not important at all while 5 means that it is very important.
As shown in fig. 23, more than 80% of participants gave it a score of 5 out of 5.
This result, however, might be questionable bacause people may have been influenced by the survey tipoc.

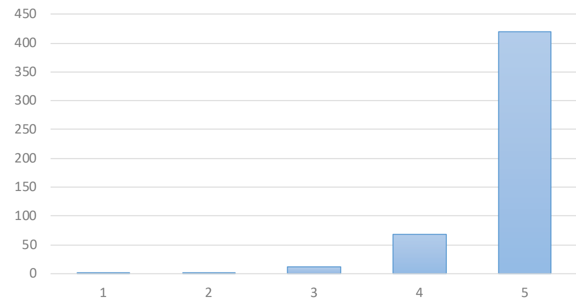

Fig. 23 - Recycling importance

The respondents were asked what were the most challenging things about recycling for them.
The most popular answers were: investing time to separate the materials within one waste item (53%), find enough space in the flat where to put the different recycling bins (42%) and understand which bin to throw the different waste in (36%) (fig. 24).

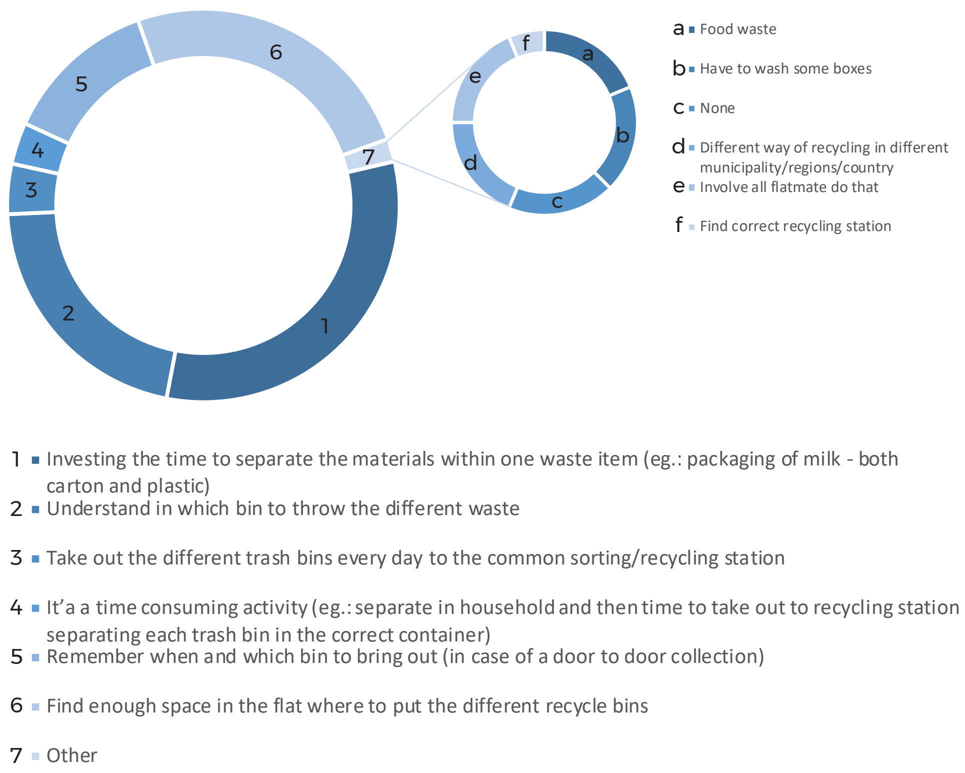

Fig. 24 - Major recycling challenges

Some participants also suggested other difficulties, including food waste. These results indicate that it is important to try to find a solution for food waste recycling since it appears as one of the most challenging things about recycling.

Another difficulty highlighted is the lack of space in the flat to keep the different trash bins.
Although, at the specific question, only about 30% of the respondents declared of not having enough space in their houses (fig. 25), the lack of space is a problem that could be solved with an appropriate and better design of living spaces.

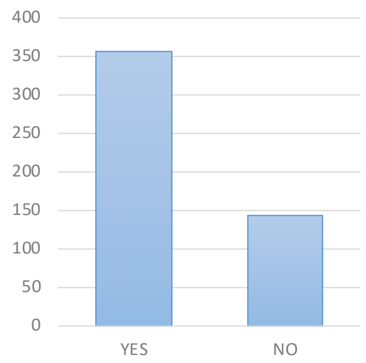

Fig. 25 - People feeling to have enough space for the trash bins

The next question investigated habits and preferences of the waste bins location in the house to choose the best recycling solution which meets aesthetic and comfort needs of the people. In this way, it is possible to involve and encourage even more people to separate waste.
Analyzing the results it is clear that the six waste categories can be grouped two by two according with the type of responses obtained: food and general waste, paper and plastic, glass and metals (appendix B).

Another question was related to the waste bins location. Respondents were, in fact, asked to judge on a scale from 1 to 5 if a recycling system, integrated with kitchen design, might be helpful for recycling.
Answers are distributed over the whole range: around 41% of interviewees selected 5 and another 22% selected 4 while 14% completely disagree (fig. 26).

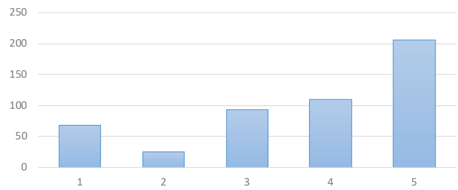

Fig. 26 - Usefulness of a recycling system integrated in the kitchen design

Carrying on with the coffee argument, the last two questions were focused on the old coffee ground. First, the partecipants participants were asked weather they were willing to recycle coffee in a separate bin.
The response is remarkable, more than 90% of people agree with a separate bin for coffee (fig. 27). This answer could come from the necessity to have a place where to throw old coffee grounds or pods, as we saw in the previous answers but it may also be influenced by the survey itself.

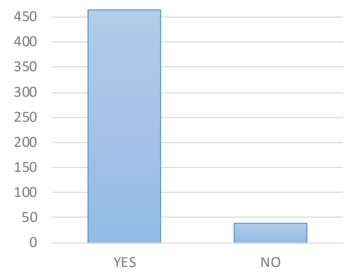

Fig. 27 - People willingness to collect old coffee grounds

The second question aims to investigate where people usually buy coffee to be able to design collecting strategies in order to exploit household coffee waste. It is interesting to see that there is a great variety of answers to this question, including “fair trade market” (1%), “market” (2%) and directly from the “factory” (1%), but also “small grocery shop” (8%), “online shop” (8%), and “door to door sellers” (2%). Nevertheless, the most popular answer is “supermarket” with almost 69%, followed by “specific coffee shop” (21%) (fig. 28).

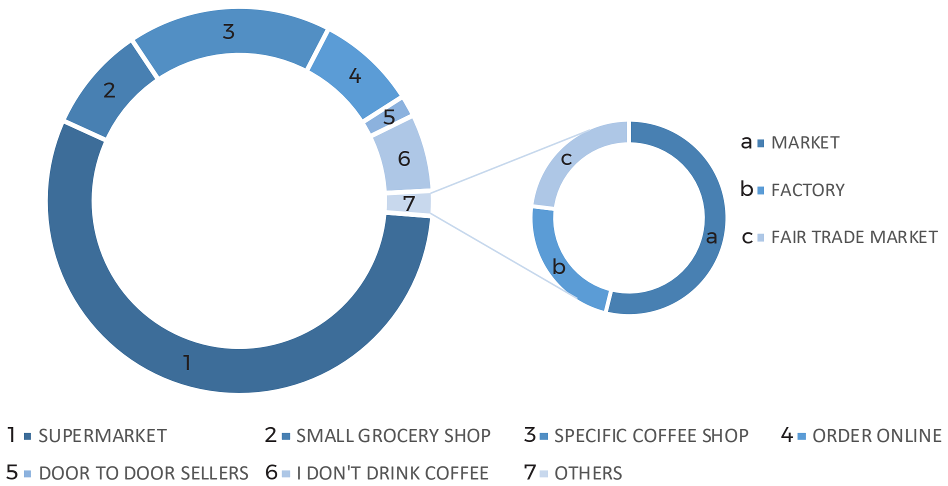

Fig. 28 - Places where the interviewees buy coffee

In conclusion, in the light of the survey results, three main problems were identified, that need to be addressed:
- solving better the waste sorting system in the home;
- understanding how to deal with food waste;
- developing solutions for creating a recycling system around spent coffee.

3.2 COMIECO AND BOERI'S ATLAS

3.2.1 Boeri and Comieco's research

The famous architect Stefano Boeri in collaboration with the association Comieco made an interesting research about recycling solutions.[84] In their Atlas, they investigate new ways of recycling considering three different scales: kitchen, apartment building and neighborhood. In each case, they show a variety of problems that lead to rough recycling and consequently hinder the whole cycle. In particular, they consider the kitchen as the fulcrum of personal waste collection and the starting point of the long and complex waste recycle chain. For this reason, it is necessary to evaluate the different solutions in terms of hygiene for example regarding insects and pests, bad smells or cleaning of the waste, aesthetics both inside the flat and on the façade, accessibility because waste bins must be easily movable and adaptability concerning differentiation, storage and waste difficult to compress.

As regards kitchen, they show nine different proposals, with various features, to adopt in household recycling.
Six of these systems have been selected in order to respond to the problems come out from the survey:
- "Humus, modular bags" is an idea of Muungano and it consists of modular containers made by recycled plastic (fig 21a);
- "Totem" was devised by Joseph Joseph and it consists of only one big bin with different compartments (fig. 21b);
- "Compactor" is developed by Ecopod and it is a solution which allows to reduce by 80% the space occupied by waste (fig. 21c);
- "Composter" is a system to produce fertilizer from food waste. In the Atlas are shown two modern types of composter monitorable from mobile phone designed by Zera Whirlpool and Smart Cara Weimar Enterprise (fig. 21d);
- "Flow" is a sustainable cooking plan devised by Studio Gorm (fig. 21e);
- "Ekokook", developed by V. Massip, L. Lebot, is a recycling system made of variouse bins with different functions, integrated into the kitchen design (fig. 21f).

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84 S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018.

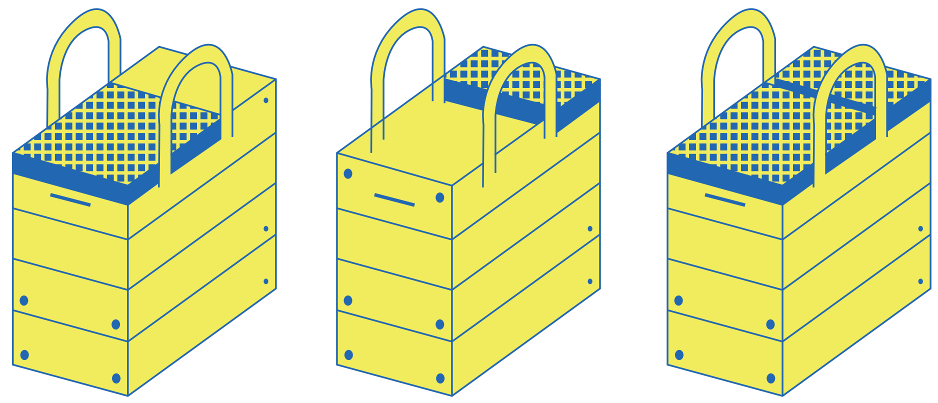

Fig. 21a - Humus, modular bags
S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p.47.

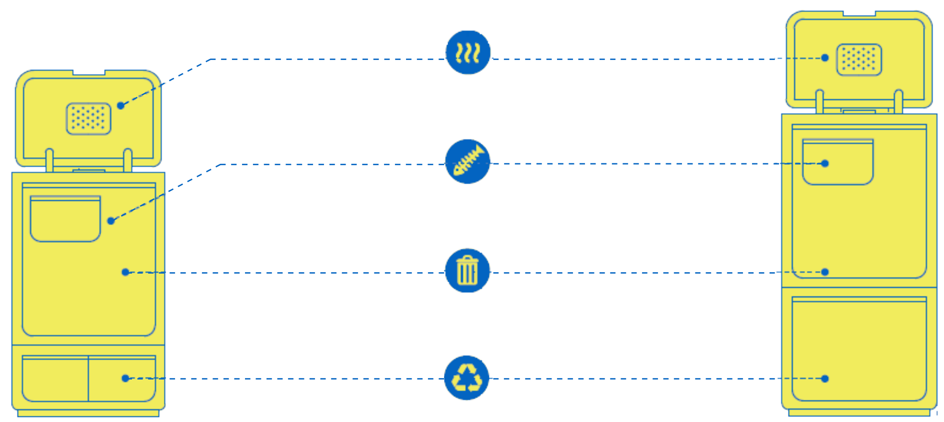

Fig. 21b - Totem
S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p.55.

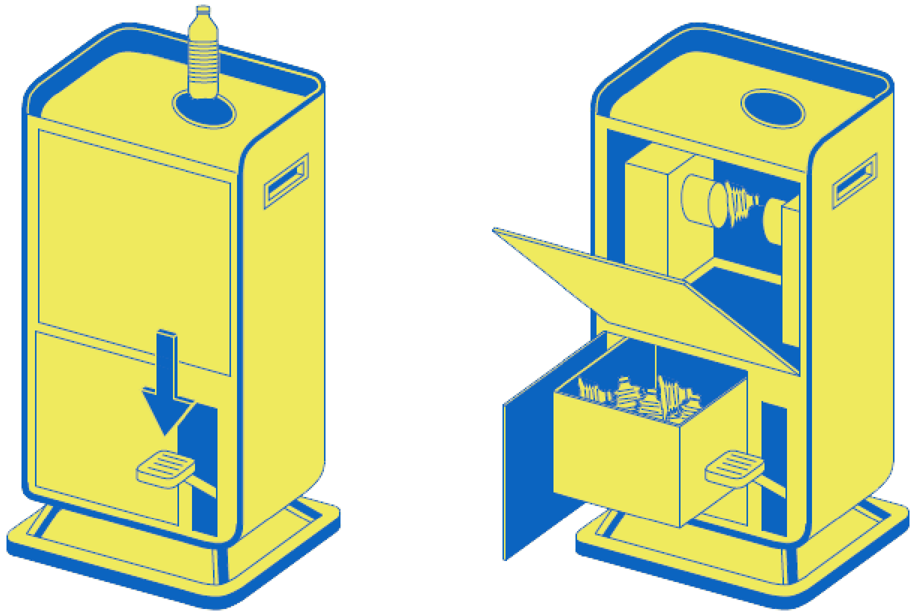

Fig. 21c - Compactor
S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p.59.

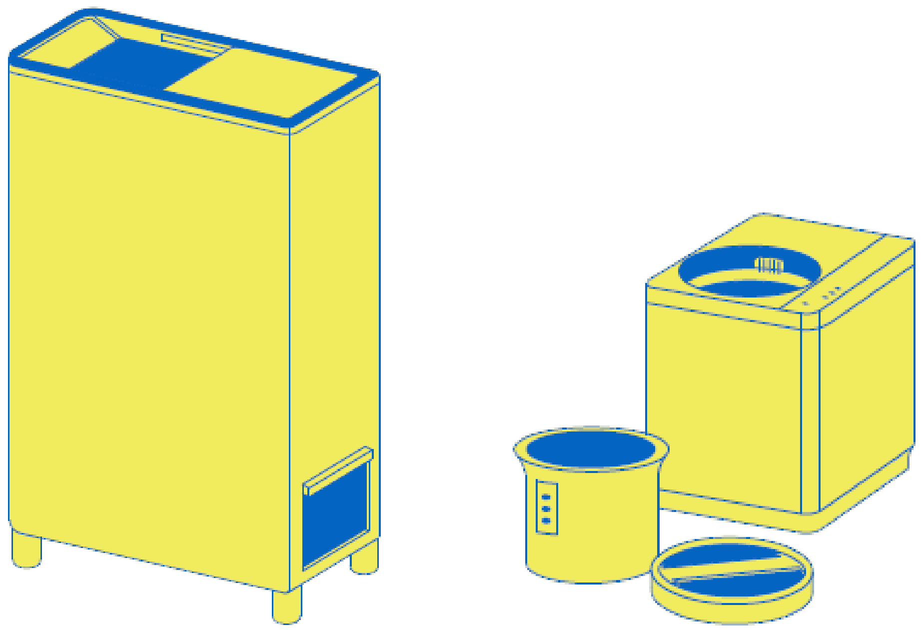

Fig. 21d - Composter Zera Whirlpool and Smart Cara Weimar Enterprise
S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p.64.

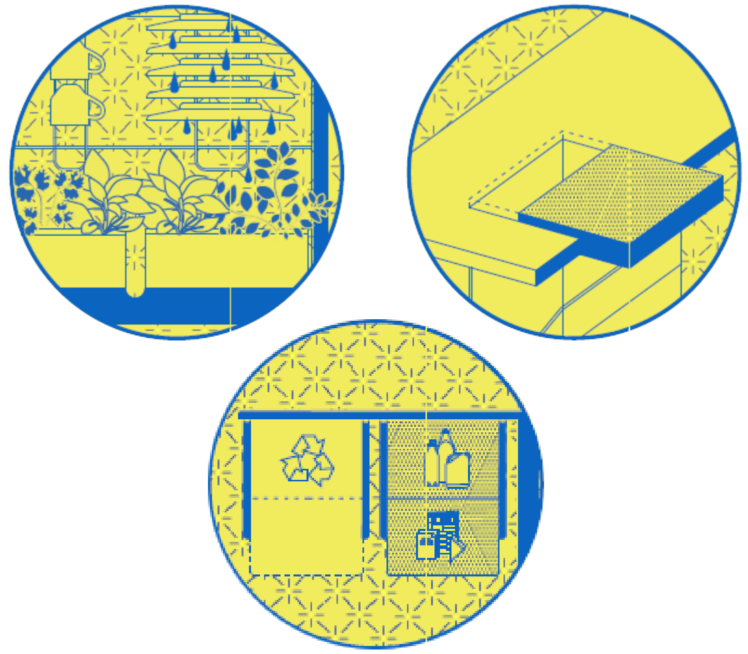

Fig. 21e - Flow
S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p.68-69.

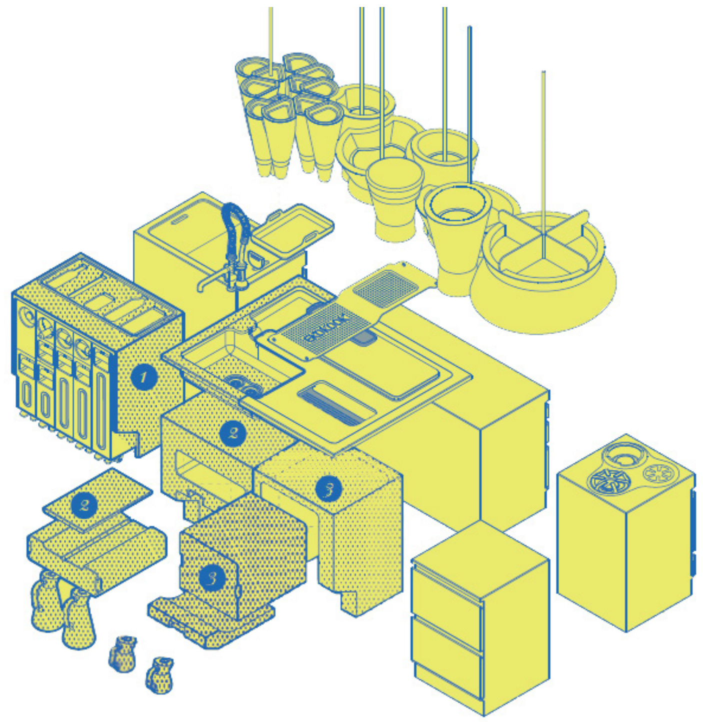

Fig. 21f - Ekokook
S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p.73.

3.3 SOLUTIONS

3.3.1 Waste sorting system in the house

The data collected with the survey allow to analyse better the different solutions showed by the Boeri and Comieco's Atlas[85] and select some of the best ones according to people needs.
According to the survey respondents, the most challenging problem was to "find enough space in the flat where to put the different recycling bins". This problem can be solved by using modular solutions like "Totem" (fig. 21d) or "Humus, modular bags" (fig. 21b). Thanks to their numerous compartments it is possible to have different bins in the same place saving space. In the case of "Humus, modular bags" is also possible to hide them inside one of the kitchen modules effectively removing the problem of lack of space. These systems are also able to cope with another of the problems highlighted: "investing time to separate the materials within one waste item". Having all the compartments together saves time when you have to throw the divers materials from the same waste item in different bins, encouraging the recycle to be carried out in the correct way.
Another useful solution in the case of lack of space may be the "Compactor", this system allows to reduce the volume of waste saving space, expecially concerning plastic and paper that are the ones that we usually sorage in bigger bins.
The survey also revealed that there are couple of waste that can be stored in different place. For example, people prefer to keep food and generic waste under the sink, that means hidden but close to the cooking place. For this reason "Flow", with its synergy between technology and nature, may be a perfect solution. In fact, this system is designed to have all the recycled bins integrated in the kitchen, minimizing the efforts to throw away waste without showing the bins. Furthermore with its compostable system it is possible to control better and reduce the food waste problem, which represents another big challenge in recycling.
Finally, people seem very interested in having a recycling system completely integrated in the kitchen design. The "Ekokook" presented is the perfect example of what people are looking for. A solution where every bin is easy and im-

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[85] S. Boeri, & Comieco, Atlas, Nuove pratiche per una migliore gestione dei rifiuti, 2018, pp. 35-83.

mediat to reach, but hidden enough not to interfer with the room design. In addition, in this system, each bin covers a specific function connected to a certain type of waste. For paper, plastic, glass, metal and generic waste, there are big bins able to compact the volume of the waste, completely included in the kitchen modules. As regards to food waste, a specific bin is placed under the cooking plane where it is possible to collect all the organic scraps and put them in a small composter to produce fertilizer. A particular importance it that it was connected to the water cycle, in fact, it has been designed as a system of two containers placed under the sink to collect separately clean and dirty water in order to re-use them for different purposes.
Furthermore, this system also represents the answer for those who have small flats without a space where keep recycle bins.

3.3.2 Deal with food waste

As shown by the survey's answers, another major problem in recycling is deal with food waste. Bad odours and fluids released by organic remains make this type of waste difficult to menage. Despite this all of us, every day, produce a huge quantity of food waste. It was estimated that in a year, in the European Union, are produced almos 92 kg pro capita of food waste, considering only the household portion.[86]
Therefore, this large amount of waste must be disposed of. As showed in chapter two, there are several methods to recycle food waste in order to produce energy, biofuels, biochemical products, bio-plastics or also building materials. Regrettably, however, these tecniques need only one specific type of food waste by time. This allows to re-use waste coming from food industries but not the household part because it cointains a mix of food scarps, without mentioning piece of paper or other materials due to an unresponsable recycling.
Furthermore, to be able to re-use the food waste it is important that it is not deteriorated. This represents another problem, since the path from houses to recycle and re-use centres is not immediat but it can take several days, during which food waste can rot.

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[86] Å. Stenmarck, C. Jensen, T. Quested, G. Moates, M. Buksti, B. Cseh, S. Juul, A. Parry, A. Politano, B. Redlingshofer, S. Scherhaufer, K. Silvennoinen, H. Soethoudt, C. Zübert, & K. Östergren, *Estimates of European food waste levels. Reducing food waste through social innovation* in "Fusions", 2016.

Therefore, the most probable usage is the production of biomass aimed at energy and compost production.
Consequently, concerning composting, have been developed several domestic composter which allow to re-use food waste in the household environment. One of the most common model is the already mentioned Bokashi method based on anaerobic fermentation thanks to the inoculated bran.
Nevertheless, in recent years, have been developed smart composting systems capable of being controlled remotely through a wireless tracking. Two of the most famous smart composting systems are showed in the Atlas.[87] In contrast to traditional composting, these solutions are smaller, therefore they are easy to integrate in the kitchen. Furthermore, they are able to convert organic waste in compost ready-to-use in almost 24 hours. In this way they encourage a circular economy also in the domestic environment, helping in organic waste collection and closing the waste cycle correctly.

3.3.3 Coffee recycling solutions

Spent coffee grounds represent a particular type of food waste. In fact, if dry enough, they do not rot and they are also easy to collect separtely from the rest of organic scrap. Nevertheless, from the survey's results, it is evident that both old coffee grounds and old coffee pods are a problem since most of the time it is hard to find where to throw them away. As it is already mentioned, the majority of people are willing to collect this kind of waste in a specific bin. For this reason it is important to develop a special bin which permits the air circulation to avoid the development of molds to include in the recycling systems. Some examples of how to include it might consists in adding a specific small compartment for coffee in systems such as "Totem" or "Humus, modular bags" or introducing a coffee collector directly in the kitchen design adding new functions in solutions such as "Flow" or "Ekokook".
Another problem is how companies can collect coffee from private to transform it into new materials. The solution, in this case, might come from the study of where people buy coffee. The survey shows that around 60% of people buy coffee in the supermarket and almost 20% acquire it in specific coffee shops. Some of these coffee shops have already introduced an old coffee collecting system. Nespresso, for example, gives some discount for the subsequent purchase to who brings back old coffee pods. This is an interesting system that allows collecting big quantities of coffee from households. Furthermore, taking inspiration from some plastic bottle collecting systems, it might be possible to design coffee collectors at the entrance of the supermarket. In this way, people can bring their old coffee there and receive a small volchure for the subsequent shopping. This will encourage people to collect and recycle old coffee ground and will allow companies to collect even more coffee and re-use it. This solution can be easy and useful also for the ones who are used to buy coffee in a place other than a supermarket since everyone goes to do shopping in supermarkets.
These proposals represent an important starting point for this research. Based on these hypotheses, it was possible to develope the studies around old coffee grounds, one of the food waste more difficult to place,[88] and their possible usage in the construction field. Always considering the idea of a domestic circularity, where the rests of coffee drank at home become an element for the house itself.

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[87] S. Boeri, & Comieco, Atlas, Nuove pratiche per una migliore gestione dei rifiuti, 2018, pp. 62-67.

[88] Answer to question 13 of the survey.

"Women and men started drinking coffee many centuries ago and traces of "formal" cultivation and trading of coffee go back as far as the 15th Century. Nowadays, coffee is commercially produced in more than 50 countries and the world drinks over 3 billion cups a day either alone or with family, friends or colleagues. Some drink it at home, others at work or in coffee shops. People even drink coffee in outer space." [89]

José Sette - Executive Director, ICO, 2019

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[89] ICO, *Coffee Development Report. Growing for prosperity. Economic viability as the catalyst for a sustainable coffee sector*, 2019, p. 6.

ABSTRACT CHAPTER 4

Prima di poter iniziare a produrre provini del nuovo materiale a base di caffè è stato necessario svolgere una ricerca sulla letteratura esistente rispetto all'uso di questo elemento in ambito architettonico. I risultati emersi sono stati raccolti e schedati. Durante il processo di schedatura gli articoli sono stati suddivisi in due gruppi principali:
- Gruppo A contenente gli articoli che riguardano i vari rifiuti derivati dalla produzione di caffè come pellicola argentea, i gusci e la pula del caffè:
- Gruppo B con gli articoli riguardanti strettamente i fondi di caffè. Questo gruppo è stato suddiviso in tre sottogruppi a seconda dell'applicazone della polvere di caffè esausto.

Da questi articoli è emerso che il caffè esausto possiede buone proprietà di isolamento termico che riducono il fabbisogno energetico dell'edificio portando a una diminuzione della produzione annua di CO_2 equivalente.
Inoltre i fondi di caffè presentano anche ottime proprietà acustiche che li rendono un materiale a valore aggiunto da utilizzare nella produzione di pannelli fonoassorbenti.

Dal momento che questi articoli considerano principalmente il caffè come elemento da aggiungere a composti pre-esistenti, è stata svolta un'ulteriore ricerca per valutare che tipo di legante a base naturale adottare nel caso di utilizzo dei fondi di caffè come elemento principale del composto.
Uno dei leganti più performanti in questo senso è la bio-resina, purtoppo però, a causa delle limitazioni dovute al Covid-19, si è dovuto optare per leganti facili da utilizzare anche in ambiente domestico come l'amido e la destrina. Quest'ultima è un derivato dell'amido ottenuta attraverso un processo di idrolisi che ne aumenta le qualità di legante.

Infine, è stata effettuata una ricerca sui trattamenti protettivi da applicare al materiale per migliorare la sua resistenza all'acqua. Tra la possibili soluzioni trovate, la cera d'api è risultata quella più adatta anche in relazione al suo consolidato utilizzo come impermeabilizzante nell'edilizia naturale.

La realizzazione dei provini ha seguito differenti passaggi. In primo luogo è stata preparata la miscela unendo le polveri asciutte, caffè e legante, alle quali è stata aggiunta l'acqua.
Una volta che il composto è diventato omogeneo, è stato pressato in stampi di forme e dimensioni diverse, ai quali sono state aggiunte delle basi per stampare sul provino varie texture. Inoltre, per compattare in modo adeguato la miscela è stato adottato un sistema di morse mobili. Il tutto è stato cotto in un forno per circa due ore a temperature comprese tra i 120°C e i 200°C, a seconda dello spessore del provino. Infine, alcuni degli elementi ottenuti sono stati trattati con un rivestimento a base di cera d'api per migliorarne le proprietà.

Il processo di produzione dei provini è avvenuto in 4 fasi.
La fase A consiste nelle prime sperimentazioni sul materiale. In questo passaggio sono stati utilizzati due leganti: amido di patate e amido di mais, in diverse percentuali. I risultati ottenuti hanno portato ad escludere l'amido di mais dalla ricerca in quanto ha portato ad un provino caratterizzato da una superficie completamente crepata.
Durante la prima fase si è notato che gli stampi lasciavano un segno sulla superficie dei provini, pertanto la fase B è stata dedicata alla sperimentazione delle texture da applicare sul materiale. Per fare ciò, basi con disegni differenti sono state inserite all'interno degli stampi.
Nella fase C invece sono stati prodotti provini di dimensioni maggiori. Il primo tentativo, composto per il 70% da caffè e per il 30% da amido di patate, ha iniziato a creparsi pochi giorni dopo la sua realizzazione, rivelando la scarsa funzionalità dell'amido di patate. Visti i risultati, si è deciso di sostituire l'amido con la maltodestrina, ciò ha permesso di ottenere risultati favorevoli. Anche la temperatura di cottura e lo spessore dei provini sono stati modificati durante i vari tentativi infatti, per produrre un elemento di dimensioni 23x23cm è necessario uno spessore di almeno 2cm affinchè il provino non si crepi durante il raffreddamento.
Infine, nella fase D, alcuni dei provini ottenuti sono stati trattati con la cera d'api. Questa operazione ha permesso di impermeabilizzare e rafforzare il provino e di conseguenza di sviluppare elementi di spessore ridotto rispetto a quelli non trattati.

Gli esperimenti hanno dimostrato come i fondi di caffè siano un valido scarto da valorizzare e da usare nel settore edile.
Nonostante i risultati promettenti ottenuti, però, non è stato possibile testare le reali proprietà fisiche e meccaniche del materiale a base di caffè, le quali verrebbero sicuramente incrementate utilizzando leganti più comuni nel settore delle costruzioni, ad esempio la bio-resina.
Pertanto, queste proprietà sono state assunte sulla base della letteratura esistente mentre i risultati ottenuti sono stati valutati sulla base del risultato estetico e della durabilità.

4.1 LITERATURE INVESTIGATION

4.1.1 Coffee as a building material

As previously mentioned in chapter 2, many studies about the valorization of spent coffee grounds have already been done. In particular, extensive research have been focused on the design field, in addition to re-using this material to produce biofuel, biochar, biofertilizer, or as a value-added material in the food industry.
These design investigations showed the possibility to mix spent coffee grounds with natural binders [90] or with other recycled materials, such as plastic, [91] in order to produce various type of objects. Moreover, they have proved the ability to produce water-proof and scratch-proof material by adopting specific treatments and manufacturing techniques.[92]
These studies represented the starting point for this thesis, indeed water-proof and strength features constitute an element of fundamental importance in building materials production. For this reason, a research of the existing literature on the possible usage of the spent coffee in architecture sector has been conducted on the online platform Science Direct[93] to develop in-depth understanding of the topic. By entering keywords linked to the issue of interest, such as "recycle coffee waste" or "building materials from spent coffee" or even "re-use coffee in building applications", it was possible to find a list of articles concerning re-use and enhancement of coffee waste in the construction sector.
Coffee application in this filed is new and still underdeveloped, consequently, the literature is sparse. Despite this, interesting studies have emerged.
After a first evaluation based on titles, the identified articles have been subjected to a second selection based on the abstracts and, finally, the full text reading allowed to determine the relevant papers.
Table 1 shows the results of the literature search. The table illustrates the following information about each article: the source, the key-word used to find it, the title, the journal in

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[90] https://www.kaffeeform.com/, accessed from 05/02/2020 to 04/05/2020.

[91] http://re-worked.co.uk/, accessed from 08/02/2020 to 04/05/2020.

[92] AA.VV., *Axion, Re-worked develop 'aromatic' furniture from waste plastic and coffee*, in "Additives for Polymers", 2010(6), 2010, p.4.

[93] https://www.sciencedirect.com/, accessed from 03/02/2020 to 27/05/2020.

which it was published, the year of publication and the volume and pages of the journal.

Then, every article is attributed to a file code to identify to what category it belongs to.
In fact, the articles have been organized into two main groups:

- Group A contains articles which consider the reuse of different types of coffee waste such as the silverskin, the husk ashes or the coffee chaff;

- In the group B all the articles most specifically about spent coffee grounds and their applications in the building sector. This group it has been split into three others subgroups have been collected:

  - B1 contains all the articles concerning mechanical and strength properties of spent coffee grounds, in most of the cases improved and pronounced by geo-polymerization treatments;

  - B2 is dedicated to articles that investigate how spent coffee grounds can influence on thermal and acoustic insulation features of the materials;

  - lastly, B3 includes those articles studying the possibility to add spent coffee grounds in bio-composites to improve their features and reduce the amount of synthetic products.

4.1.2 Group A

Source	Key-word	Title	Journal	Year of publication	Volume	Page	File code
ScienceDirect	Re-use coffee in building application	Untreated coffee husk ashes used as flux in ceramic tiles	Applied Clay Science	2013	75-76	141-147	A-01
		Environmental characterisation of coffee chaff, a new recycled material for building applications	Construction and Building Materials	2017	147	185-193	A-02
ScienceDirect	Coffee by-products	Functional properties of coffee and coffee by-products	Food Research International	2012	46	488-495	A-03
ScienceDirect	Recycle coffee waste	Recycling coffee silverskin in sustainable composites based on a poly (butylene adipate-co-terephthalate)/poly(3-hydroxybutyrate-co-3-hydroxyvalerate) matrix	Industrial Crops and Products	2018	118	311-320	A-04

4.1.3 Group B1

Source	Key-word	Title	Journal	Year of publication	Volume	Page	File code
ScienceDirect	Recycle coffee waste	Stiffness and deformation properties of spent coffee grounds based geopolymers	Construction and Building Materials	2017	138	79-87	B1-01
		Strength and microstructure properties of spent coffee grounds stabilized with rice husk ash and slag geopolymers	Construction and Building Materials	2017	146	312-320	B1-02
		Recycled glass as a supplementary filler material in spent coffee grounds geopolymers	Construction and Building Materials	2017	151	18-27	B1-03
		Compressive strength and microstructural properties of spent coffee grounds-bagasse ash based geopolymers with slag supplements	Journal of Cleaner Production	2017	162	1491-1501	B1-04
Springer	Construction materials spent coffee grounds	Engineering and environmental evaluation of spent coffee grounds stabilized with industrial by-products as a road subgrade material	Clean Technologies and Environmental Policy	2017	19	63-75	B1-05
ScienceDirect	Building materials from spent coffee	Strength assessment of spent coffee grounds-geopolymer cement utilizing slag and fly ash precursors	Construction and Building Materials	2016	115	565-575	B1-06
Taylor and Francis Online		Stiffness and strength properties of spent coffee grounds-recycled glass geopolymers	Road Materials and Pavement Design	2019	20	623-638	B1-07

4.1.4 Group B2

Source	Key-word	Title	Journal	Year of publication	Volume	Page	File code
Springer	Building materials from spent coffee	Eco-fired clay bricks made by adding spent coffee grounds: a sustainable way to improve buildings insulation	Materials and Structures/ Materiaux et Constructions	2016	49	641-650	B2-01
Taylor and Francis Online		Reusing coffee waste in manufacture of ceramics for construction	Advances in Applied Ceramics	2014	113	159-166	B2-02
ScienceDirect		Spent coffee grounds as supporting materials to produce bio-composite PCM with natural waxes	Chemosphere	2019	235	626-635	B2-03
ScienceDirect	Re-use coffee in building application	Thermal insulation improvement in construction materials by adding spent coffee grounds: an experimental and simulation study	Journal of Cleaner Production	2019	209	1411-1419	B2-04
ScienceDirect	Recycle coffee waste	Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling	Environmental Research	2020	184	109281	B2-05
		Valorization of coffee waste with Moroccan clay to produce a porous red ceramics (class BIII)	Boletin de la Sociedad Espanola de Ceramica y Vidrio	2019	58	211-220	B2-06
Taylor and Francis Online	Coffee grounds bricks	Incorporation of coffee grounds into clay brick production	Advances in Applied Ceramics	2011	110	225-232	B2-07

4.1.5 Group B3

Source	Key-word	Title	Journal	Year of publication	Volume	Page	File code
ScienceDirect	Spent Coffee Grounds Bio-Composites	Thermo-mechanical performances of polypropylene biocomposites based on untreated, treated and compatibilized spent coffee grounds	Composites Part B: Engineering	2018	149	1-11	B3-01
Research Gate		Preliminary Studies of the Effect of Coupling Agent on the Properties of Spent Coffee Grounds Polypropylene Bio- Composites	International Journal of Engineering Research and Technology	2014	7	9-16	B3-02
ScienceDirect		Green composites based on polypropylene matrix and hydrophobized spend coffee ground (SCG) powder	Composites Part B: Engineering	2015	78	256-265	B3-03

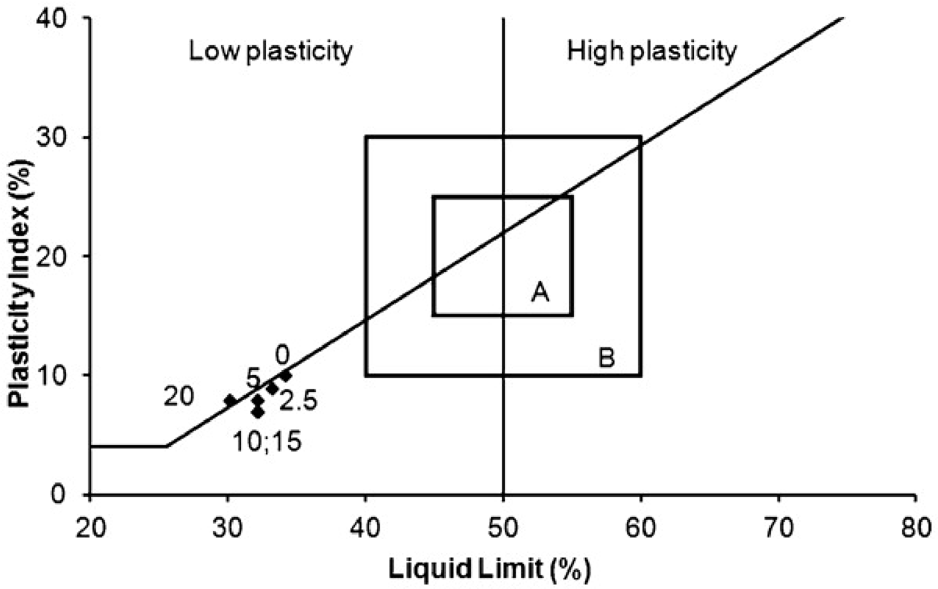

Fig. 22 - Casagrande diagram
B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 161.

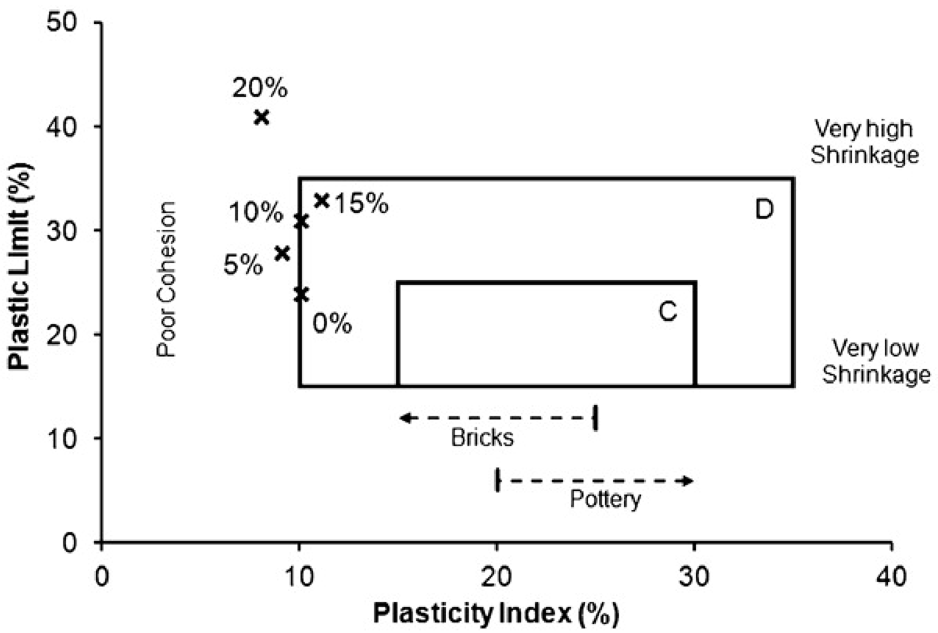

Fig. 23 - "Clay workability chart of Bain and Highley"
B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 161.

4.1.6 Relevant publications

The literature study allowed establishing better understanding on the benefits that coffee waste provides on building materials.
The selected literature foremost focuses on the re-utilization of coffee waste and the reduction of non-renewable raw materials in order to decrease greenhouse gas emissions. Moreover, they present high-value materials' experimentations. However, it is evident that there is limited information directly linked to the investigation of spent coffee grounds as an added-value element in building materials production. The discovered examples mostly attempt to increase the material's strength or insulation properties.
Three relevant studies have been selected since they investigate thermal and acoustic improvement due to spent coffee with specific tests and simulations. These articles are set out below.

Reusing coffee waste in manufacture of ceramics for construction

In 2014, the study conducted by B. Sena Da Fonseca et al. was published on "Advances in Applied Ceramics" magazine. In their research, the authors investigated the spent coffee grounds' influence in structural ceramic mixtures, considering physical and mechanical proprieties and their technological manufacturability.
For the tests, they prepared four different mixes, adding to the clay mixture 5, 10, 15 and 20% of spent coffee grounds, *"which were then fired at the temperature of 900, 1000 and 1100°C"*,[94] obtaining twelve separate samples.
In order to prepare an easily worked compound and to avoid flaws, they firstly tested the material's plastic behaviour.
Fig. 22 shows how adding coffee increases plastic and liquids limits without modify plasticity index. This means that coffee addition helps to improve composite extrudability. Moreover, it was noticed that a coffee addition of 10-15% allows having correct moulding properties of the mixture (fig. 23).
A SEM analysis was then conducted, in order to investigate bulk density, apparent porosity and water absorption. In this phase the authors observed that the material's porosity is directly related to the quantity of spent coffee and the firing

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[94] B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 159.

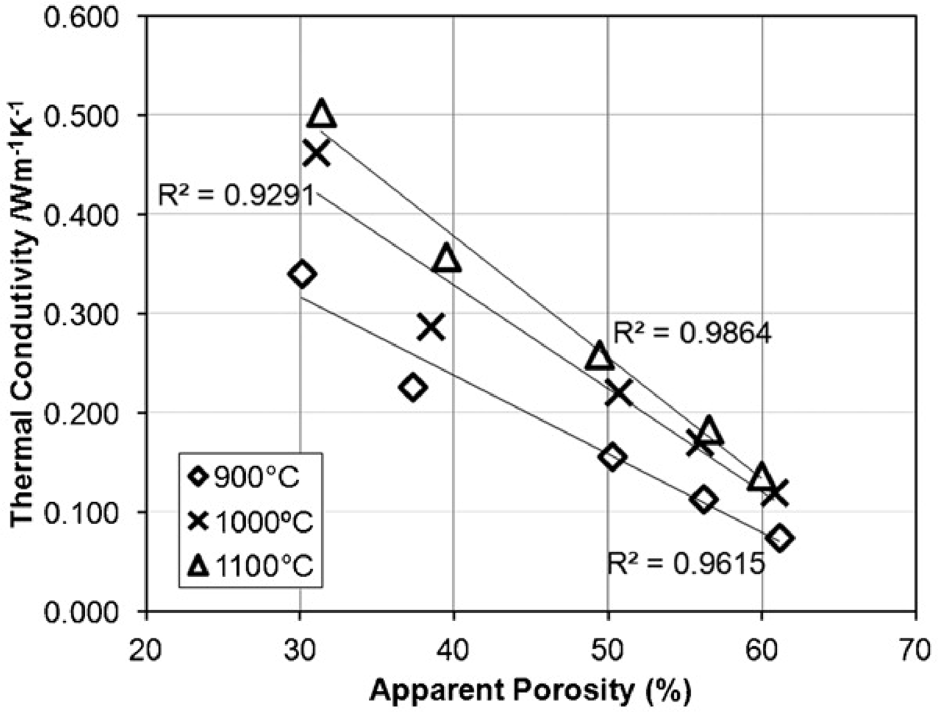


Fig. 24 - *"Relation between thermal conductivity coefficient and apparent porosity"*
B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 164.

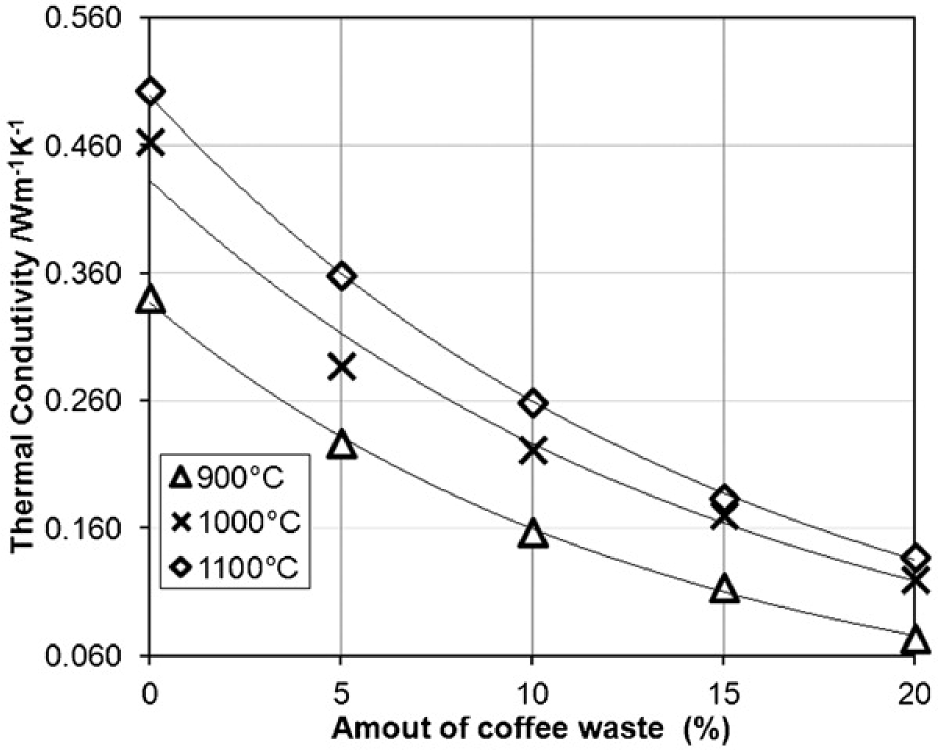


Fig. 25 - *"Thermal conductivity coefficient"*
B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 164.

temperature. In fact, the organic presence increases the apparent porosity with a consequently decrease of bulk density. On the other hand, increasing the firing temperature, the apparent porosity decreases due to the developmen of a melted material because of ceramisation process.
The porosity can affect mechanical resistance of materials, for this reason the authors made some tests *"to evaluate the suitability of mechanical behaviour in mixtures for clay brick production"*,[95] in order to respect the minimum values for *"bricks resistant to severe (20,7 MPa), moderate (17,2 MPa) and negligible weathering (10,3MPa)"*[96] outlined in the ASTM C62.
Despite high quantities of coffee waste can reduce compressive strength up to >85%, it was demonstrated that *"all the samples with 5% and the sample with 10% fired at 1100°C are resistant to severe weathering, while the samples of 10% fired at 1000°C and 15% at 1100°C are resistant to moderate weathering"*[97] according with ASTM guidelines.
Material's porosity has a direct influence on its thermal properties, this is shown in fig. 24 where it is evident that a high porosity causes a lower thermal conductivity. That depends on the firing temperature, which play a fundamental role in microstructure morphology's features and vitrification degree production.
Thermal conductivity coefficient is also related to the amount of spent coffee grounds added in the mixture. As it was demonstrated, this organic material helps to increase the porosity and, consequently, to reduce the thermal conductivity. The authors' studies reveal that *"the incorporation of only 5% coffee waste produces a significant decrease in the thermal conductivity value of >30%"*[98] while and addiction of 20% can reduce the thermal conductivity value of 75% (fig. 25). These thermal conductivity values, lower than commercial facing bricks (1.24 $Wm^{-1}K^{-1}$), commercial building bricks (1.02 $Wm^{-1}K^{-1}$) and *"closer to the thermal conductivity coefficient of cork"*[99] (0,04 $Wm^{-1}K^{-1}$), highlight the insulating properties of this new material.

NOTES

[95, 96] B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 164.

[97] B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 165.

[98, 99] B. Sena Da Fonseca, A. Vilão, C. Galhano, & J. A. R. Simão, *Reusing coffee waste in manufacture of ceramics for construction* in "Advances in Applied Ceramics", 113(3), 2014, p. 164.

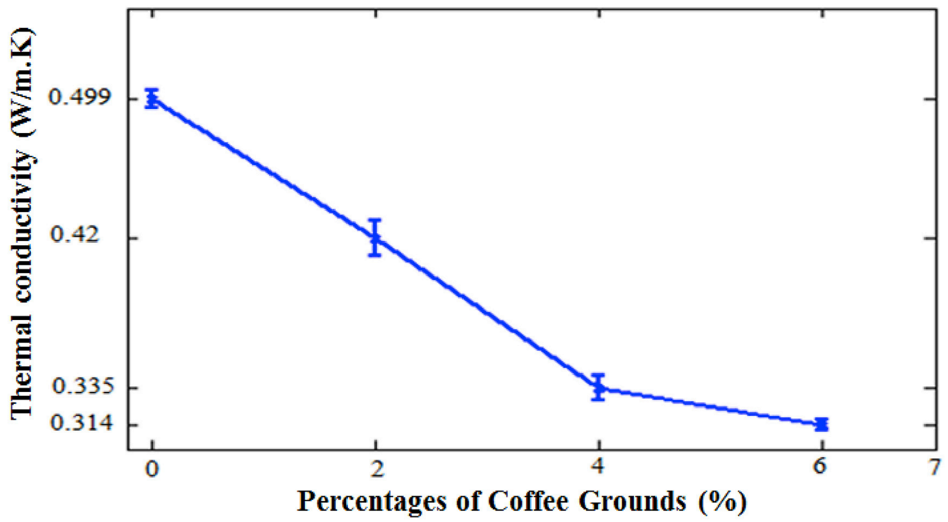


Fig. 26 - "*Evolution of thermal conductivity with different weights of coffe grounds*"
Lachheb, A., Allouhi, A., El Marhoune, M., Saadani, R., Kousksou, T., Jamil, A., Rahmoune, M., & Oussouaddi, O., *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1417.

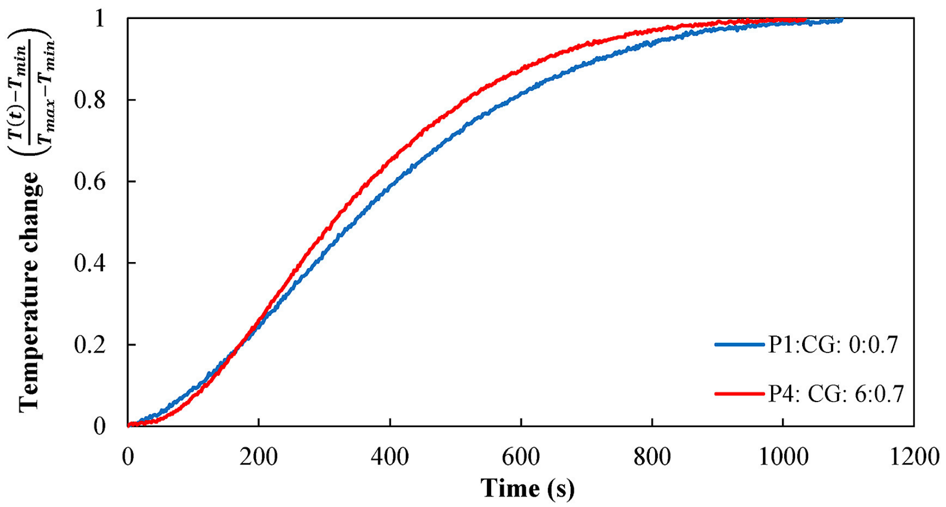


Fig. 27 - "*Temperature variation of the not irradiated face of the sample P1 and the sample P4*"
A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, O., *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1417.

Campione	Tempo			
	t 5/6	t 2/3	t 1/2	t 1/3
P1: CG: 0: 0.7	550 s	412 s	312 s	234 s
P4: CG: 6: 0.7	620 s	460 s	348 s	248 s

Fig. 28 - "*Time needed to reach 1/3, 1/2, 2/3, 5/6 of the maximum value*"
A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, O., *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1417.

Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study

Another interesting research about spent coffee grounds' thermal properties was conducted by A. Lachheb et al. in 2019 and it was published on the "Journal of Cleaner Production".
In this case, coffee waste has been added to a plaster mixture to make it more performing from a thermal point of view. Four series of samples have been created, adding a different percentage of coffee (0, 2, 4, 6%), and their properties have been tested.
The authors measured thermal conductivity using the Box method, which *"is based on steady-state heat transfer"*.[100] The results showed that the thermal conductivity was better in the samples with a higher content of coffee waste (fig. 26). In particular sample P1 with 0% weight of spent coffee had a thermal conductivity value of 0,5 W/mK while for samples P2 (2%), P3 (4%) and P4 (6%) it was 0,41 W/mK, 0,335 W/mK and 0,314 W/mK respectively.
Another measurement concerned thermal diffusivity, performed using the Flash method. This parameter *"indicates the diffusion percentage of the heat through the sample. A higher thermal diffusivity means that most of the heat is conducted and a small quantity is stored"*.[101] As shown in fig. 27, thermal diffusivity improved with the increase of spent coffee grounds moving from 38,2*10^{-8} m^2/s in sample P1 (0% in weight of coffee grounds) to 35,6*10^{-8} m^2/s in sample P4 (6% in weight of coffee grounds). This means that the non-irradiated face of the sample P1 takes more time to reach the maximum value than the non-irradiated face of the sample P4. In fig. 28 is indicated the "*time needed to reach 1/3, 1/2, 2/3, 5/6 of the maximum value for each sample*".[102]
However, the most interesting evaluation of this study is the annual simulation of the energy potential coming from the

NOTES

[100] A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1413.

[101] A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1416.

[102] A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1417.

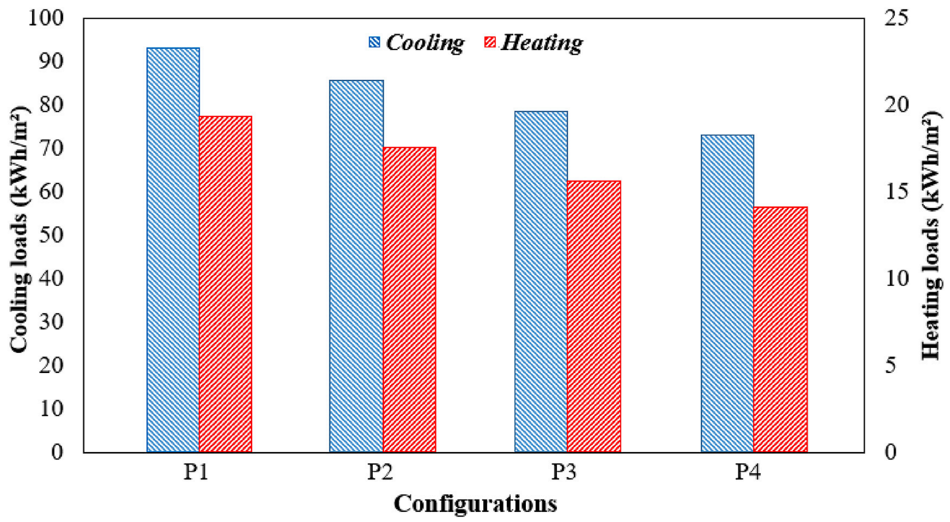


Fig. 29 - *"Cooling and heating needs of the building in Marrakech for various scenarios of composite material integration"*
A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, O., *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1418.

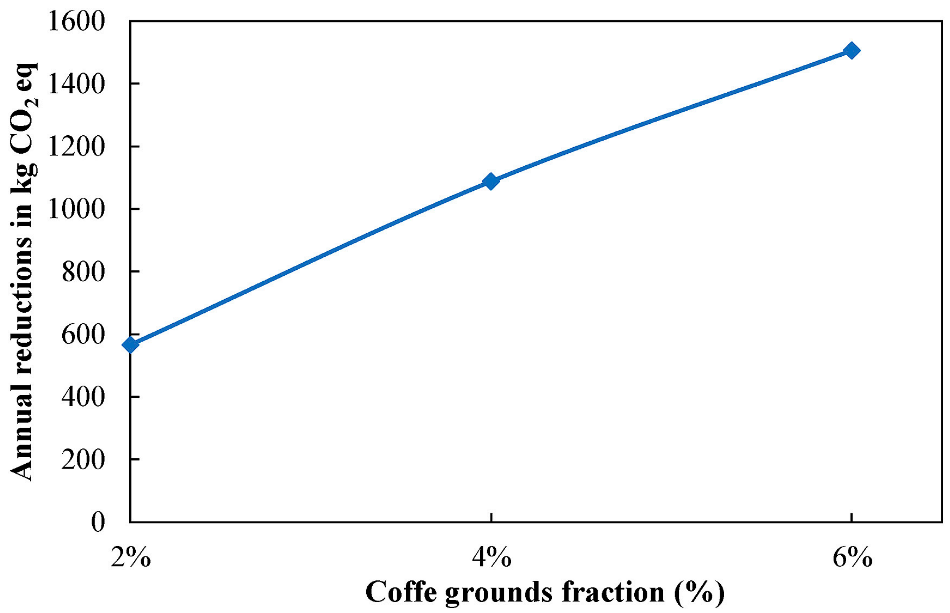


Fig. 30 - Annual reduction of CO_2 emissions in relation with coffee grounds fraction
A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, O., *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1418.

application of this plaster in a residential building. This simulation was performed under Moroccan climatic conditions using TRNSYS software. Once the geometrical characteristics of the building and the stratigraphy of the envelope have been established, the authors have outlined some assumptions adopted for the simulation:
"*- Initial temperature and humidity are set at 20°C and 50% respectively.*
- The effect of thermal bridges and shading is not taken into account.
- The heating is switched on when the internal temperature drops below 20°C.
- During the summer period, the air conditioner is switched on when the indoor temperature rises above 26°C.
- Infiltration and ventilation are set at 0.6 vol per hour.
- Internal gains were introduced to correspond to an occupancy rate of 2 seated, a microcomputer with color monitor (230 W) and artificial lighting (10W/m2)".[103]
On these bases, it was possible to simulate the annual energy demand for each of the four samples (P1, P2, P3 and P4). The application of the 6% sample caused an important decrease in both winter heating (>27,03%) and summer cooling (>21,68%) requirements compared with P1 (fig. 29). These reductions lead an energy saving, which results in lower CO_2 emission. Fig.30 shows how the adoption of plaster with 6% in weight of coffee waste saves 1505,62 kgCO_2 eq per year.
This study proved, once again, the thermal potential contained in spent coffee grounds and how they can improve building material features.

Circular reutilization of coffee waste for sound absorbing panels: a perspective on material recycling

A very interesting research was published in February 2020 on "Environmental Research" magazine. B. Yun et al. investigated the possibility to re-use spent coffee grounds to produce a new sound absorbing material.
Observing the spent coffee waste with a scanning electron microscope, it is evident that they have a convex surface, surface holes and a laminated structure. This means that it has a large specific surface area that *"allows sound energy to*

NOTES

[103] A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1417.

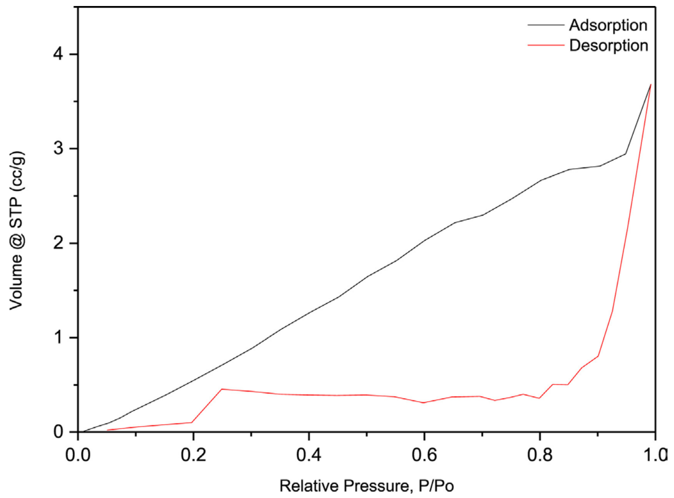


Fig. 31 - BET analysis
B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 6.

Tested sample code	Coffee waste (g)	Resin (g)
R25	25	12.5
R30	30	15
R35	35	17.5
S25	25	12.5
S30	30	15
S35	35	17.5
M25	25	12.5
M30	30	15
M35	35	17.5
L25	25	12.5
L30	30	15
L35	35	17.5

Fig. 32 - *"Samples codes and characteristics"*
B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 4.

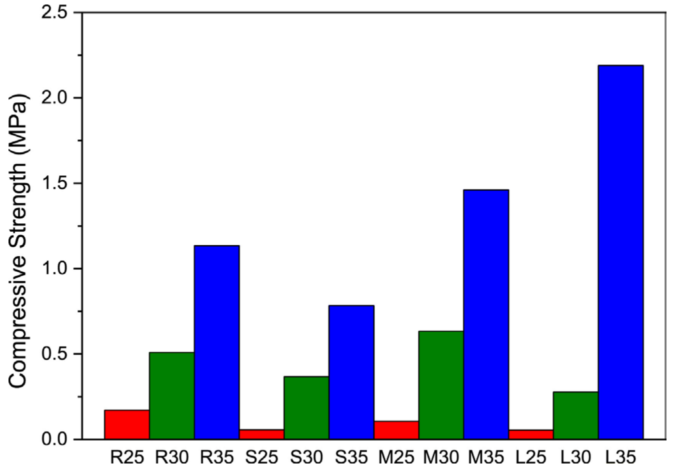


Fig. 33 - Compressive strength of samples
B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 8.

be absorbed through internal diffuse reflections".[104] Moreover, through a Brunauer-Emmett-Teller (BET) analysis the absorption and desorption lines have been outlined (fig. 31) highlighting the coffee porous structure.
On these bases, the coffee powder was split into three groups according to the dimension of the grounds: *"small size (S size) at 300 μm or less, medium size (M size) between 300 to 600 μm, and large (L size) at 600 μm or more"*[105] and, to control the density of the mix, *"the coffee volume used was 25 g, 30 g, and 35 g, respectively"*.[106] Therefore, twelve samples have been prepared mixing spent coffee with urea resin with a percentage of 50% coffee and 50% resin (fig. 32).
These samples have been subjected to several tests to define their characteristics.
To check the spent coffee usability as a construction material, the authors have tested its compressive strength assessment. In this case, it was noticed that the material's compressive strength was higher in the samples with a higher density (fig. 33). Spent coffee waste performances showed its potential as a building material.
Concerning acoustic features, sound absorption coefficients have been tested for each of the twelve samples by using 1/3 octave band analysis. The results showed, one more time, a similarity between this material and a porous sound absorbing one. Moreover, like the porous one, these samples' sound absorption coefficient increase as the material's density decrease, in fact, in this case, the highest sound absorption coefficient was noted in the 0.4 g/cm^3 density sample (fig. 34).
With the results obtained, the authors, simulated to apply this material in a hypothetical café. Figuring five different scenarios, which means cover with spent coffee panels over 0%, 25%, 50%, 75% and 100% of the available surface, they evaluated reverberation time, sound definition and sound pressure level of the room.
Concerning reverberation time they noticed that this parameter moved from 1,2s in the 0% coverage scenario to a range of 0,6-0,7s in the 100% scenario (fig. 35), respecting the optimum reverberation time (0,65s).

NOTES

[104] B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 4.

[105, 106] B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 2.

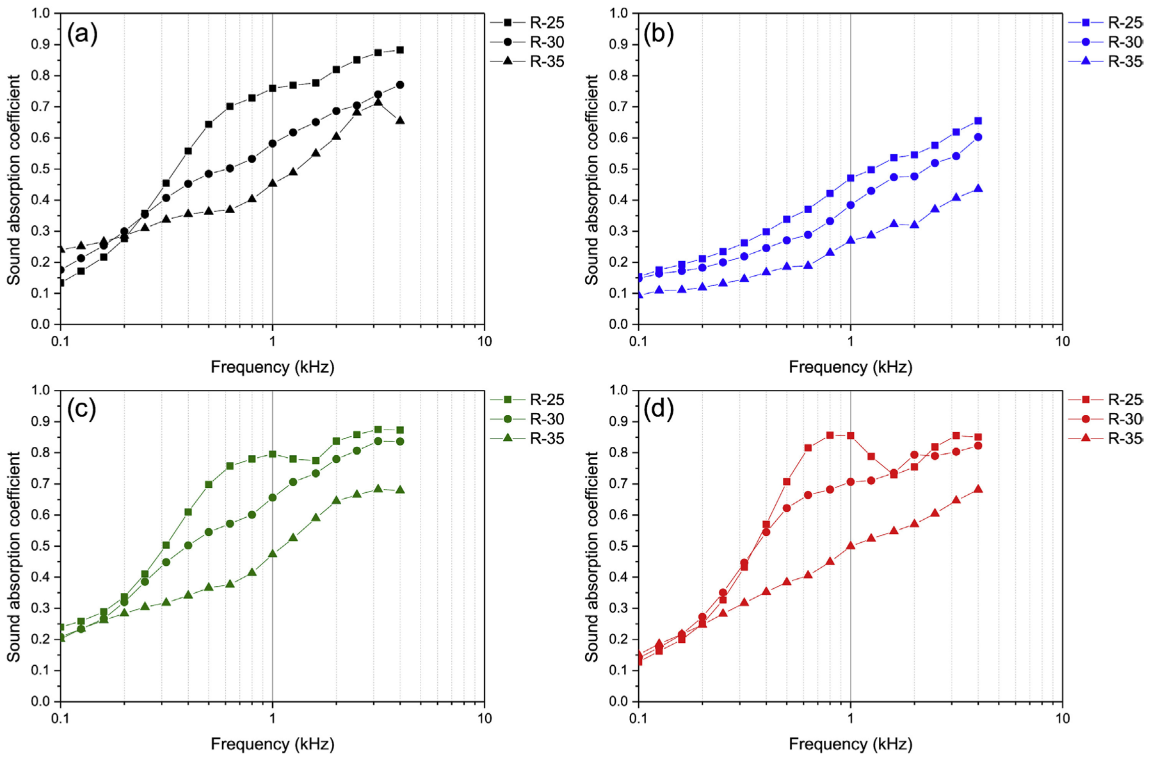


Fig. 34 - *"Sound absorption coefficient of coffee waste sound absorption samples according to particle size: (a) reference; (b) 300 μm > P_s; (c) 600 μm > P_s > 300 μm; (d) 600 μm < P_s (P_s: Particle size)"*
B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 8.

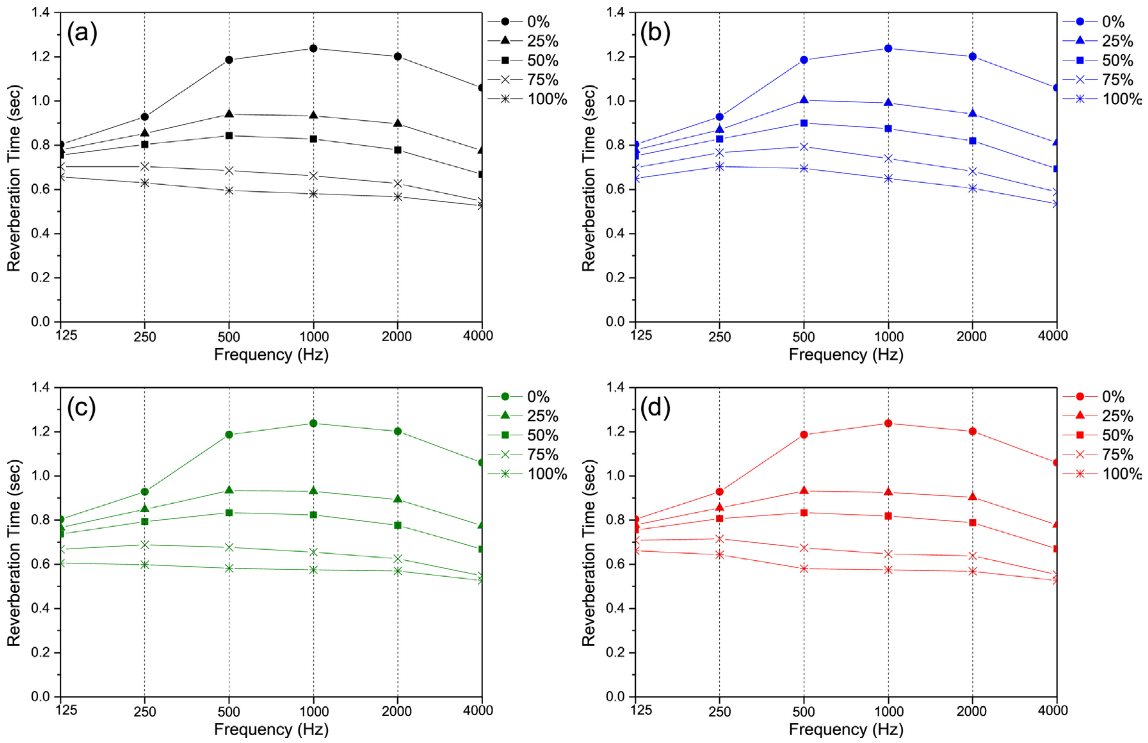


Fig. 35 - *"Reverberation time of café according to increasing coffee waste sound absorption (0.4 g/cm³) area on ceiling: (a) reference; (b) 300 μm > P_s; (c) 600 μm > P_s > 300 μm; (d) 600 μm < P_s"*
B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 9.

Increasing the spent coffee panels coverage area, also the sound definition is improved (D50). Fig. 36 shows how D50 moves from 0,4 with a 0% coverage to 0,8 in the 100% coverage scenario.
Lastly, it has been verified that the sound pressure level decrease by increasing the covered surface with spent coffee panels as shown in fig. 37.
In conclusion, this research allowed discovering important properties of spent coffee grounds which makes it suitable to play an important role in building material development according to a sustainable vision.

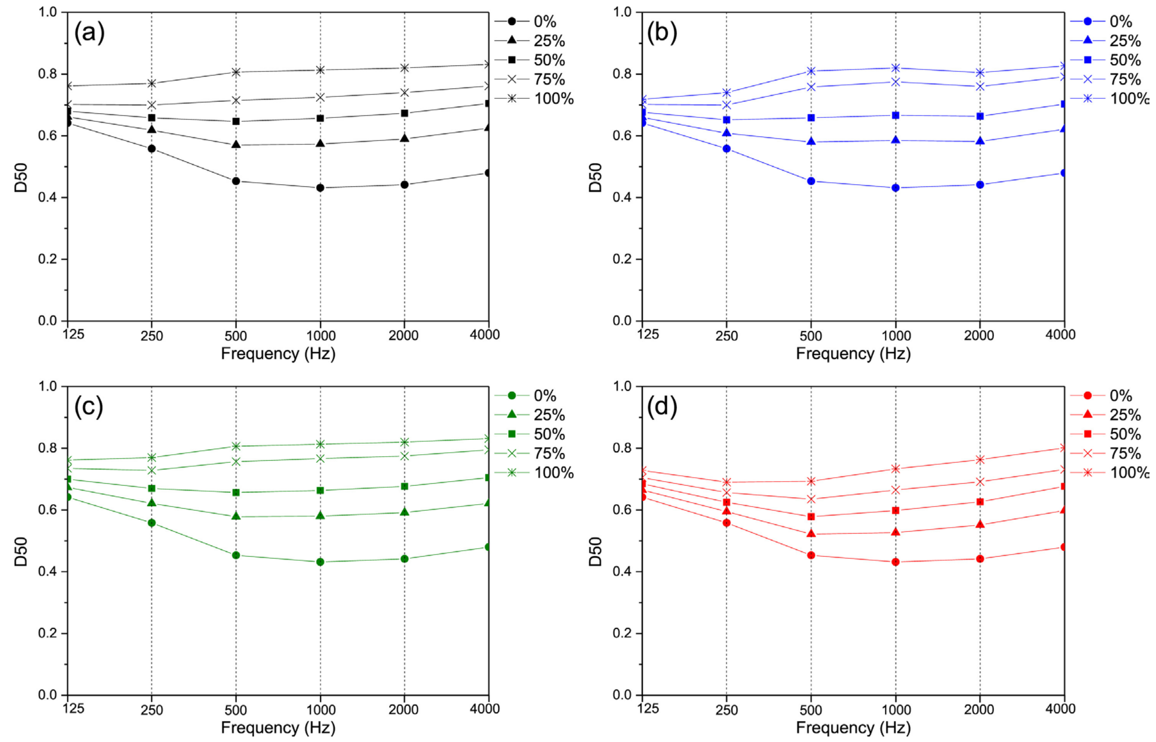


Fig. 36 - *"D50 of café according to increasing coffee waste absorption (0.4 g/cm³) area on ceiling: (a) reference; (b) 300 μm > P_s; (c) 600 μm > P_s > 300 μm; (d) 600 μm < P_s (P_s: Particle size)"*
B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 9.

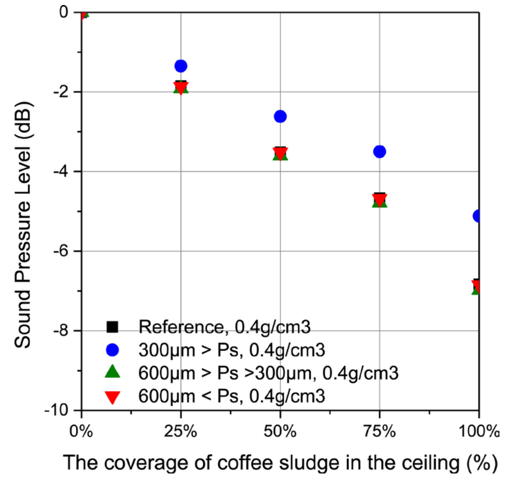
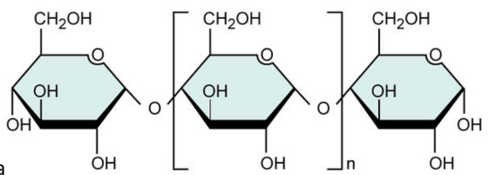


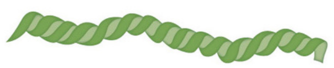
Fig. 37 - *"Sound pressure level according to increasing coffee waste sound absorption coverage"*
B. Y. Yun, H. M. Cho, Y. U. Kim, S. C. Lee, U. Berardi, & S. Kim, *Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling* in "Environmental Research", 184(February), 2020, p. 10.

4.1.7 Binders' research

The main idea of this thesis, since the very beginning, was to develop a sustainable material concerning both the composition and the disposal. Therefore, it was decided to use only natural materials, in order to ensure easier disposal, which does not pollute the environment. To achieve this goal, finding the suitable binder was of fundamental importance.
Looking at the online circular materials' database "MATREC",[107] it is evident that the most common binders are bio-resins, which means resins synthesized from natural elements. Research more accurate showed the real effectiveness of these bio-resins as a binder also for spent coffee grounds. An example is Julian Lechner's project: "Ex-presso", in which he developed his coffee cups collection bonding the spent coffee grounds with bio-resins.[108] However, bio-resins were not the only binder employed by the designer, in fact, he used also other natural binding materials such as casein and caramelized sugar.
This led to digging deeper into the world of natural binders to explore other solutions to adopt in this thesis' research.
Indeed, several types of natural binding materials were used until the middle of the last century, before the advent of synthetic bonding agents and resins,[109] and recently they are being rediscovered because of the increase of oil price and environment awareness. One of the most famous, abundant and cheap natural binders is starch, which is produced by plants, especially potatoes, corn, rice, wheat and sago, and it consists of a mix of amylose and amylopectin, two natural polymers. Amylose is a linear polymer with a helical structure made by thousands of glucose monomers link to each other in a head-to-tail arrangement (fig. 38), instead, amylopectin is characterized by a structure made by several branches linked to the coiled main-chain (fig. 39).



a



b

Fig. 38 - Amylose chemical structure (a) and diagram (b)
www.futurefoodchemist.weebly.com/amylose-or-amylopectin.html#

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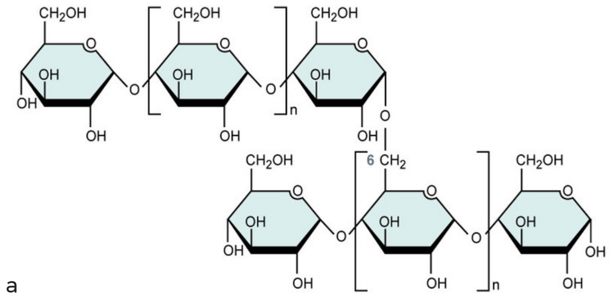
[107] https://www.matrec.com/, accessed from 24/02/2020 to 26/05/2020.

[108] S. Peters, *Materials Experience: Fundamentals of Materials and Design*, Elsevier, 2014, pp. 169-179.

[109] C. Müller, U. Kües, C. Schöpper, *Wood production, wood technology, and biotechnological impacts*, Universitätsverlag Göttingen, 2014, pp.347-381.



a

b

Fig. 39 - Amylopectin chemical structure (a) and diagram (b)
www.futurefoodchemist.weebly.com/amylose-or-amylopectin.html#

A starch derivate is dextrin, which, being obtained through a starch's acid hydrolysis, has shorter chains compared to the starch ones. Despite dextrins solve easier than starch in water, "they have a low viscosity, a higher solid content in solutions, and better bonding qualities".[110] Other two important biodegradable carbohydrate polymers are hydrocolloidal glucomannans and chitosan. The first one comes "from tubers of the Araceae"[111] while the second one is "a deacylated product of crustacean chitin".[112] Especially chitosan is a strong binder, indeed it has higher bonding properties than the synthetic urea-formaldehyde adhesives (UF resins).
Starch, dextrin, hydrocolloidal glucomannans and chitosan are used as extenders in synthetic resins to reduce the usage of petrochemical-based glues and improve their environmental performance.
Proteins can be used as adhesives for industrial applications as well, provided that they are denatured through thermal treatments or chemical reactions. They are a renewable resource from plants, animals or waste products, available all year round and cheaper than other bonding agents are.
Albumins, collagens, casein and plant proteins are the four cheaper and available proteins' groups. Their functional groups can react "with the formaldehyde and the reactive methyol groups of the UF resin"[113] to make a higher water-resistance protein/UF gel.
However, according to the recent necessity to reduce the usage of formaldehyde and synthetic binders, are developing pure bio-based binders, in order to exploit even more food industries and agricultural waste.

NOTES

[110, 111, 112] C. Müller, U. Kües, C. Schöpper, *Wood production, wood technology, and biotechnological impacts*, Universitätsverlag Göttingen, 2014, p.350.

[113] C. Müller, U. Kües, C. Schöpper, *Wood production, wood technology, and biotechnological impacts*, Universitätsverlag Göttingen, 2014, p.359.

Fig. 40 - Aesthetic performance of tadelakt technique
www.casederba.it/tadelakt/tadelakt-2/

Fig. 41 - Aesthetic performance of Venetian lusters
www.pianetadesign.it/consigli/stucco-veneziano.php

4.1.8 A material's natural protection

Considering that coffee panels are porous and not water-resistant, it has been necessary to explore a natural solution able to protect the surface without encroaching their technical properties.
In the green building sector, there are three big groups of products for surface protection: natural coatings, waxes and natural oils.[114] Natural coatings come from shellac, a specific resin secreted by some insects, mixed with solvents, binders and pigments. Solvents like water or alcohol give fluidity to the mixture, binders such as cooked flax oil help to protect the surface and, lastly, natural coloured moulds are used as pigments to create coloured coatings. The second group is the waxes one, in particular, the most common is the yellow and aromatic bee wax. An important feature of the wax is that, in contrast with synthetic coatings, it does not create a superficial film but it penetrates the material. In bio-building, bee wax is used on the lime wall surface in humid spaces, like bathrooms or kitchens, to make them waterproof and durable, examples of this technique are Tadelakt[115] (fig. 40) and Venetian lusters (fig. 41). Thirdly, natural oils, especially raw or cooked flax oil, are adopted in the green building sector to protect clay and lime coatings giving brightness and durability to the floors and the surfaces in general. Indeed, when flax oil, called "drier", comes into contact with air, starts a polymerization that transforms this oil into a protective film for the materials, the cooking process increases this property. Moreover, all these products have delicate natural fragrances that act on indoor comfort.

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[114] http://www.casederba.it/vernici-naturali/oli-cere-e-vernici-naturali/, accessed from 04/03/2020 to 10/05/2020

[115] http://www.casederba.it/tadelakt/tadelakt-2/, accessed from 04/03/2020 to 10/05/2020.

4.2 COFFEE TESTS

Fig. 42 - Spent coffee grounds humid (a) and dry (b)

Fig. 43 - Coffee drying in the oven

4.2.1 Experimental research

The research developed in this thesis aims to realize a sustainable material establishing a direct relation between product and user. This can occur exclusively, considering the word “product” in its various meanings. Indeed the main idea is to create a circle starting from a product, coffee, that gets into people’s houses as a food commodity. Once the users utilized the coffee powder, it becomes a waste. At this stage the product, spent coffee, can be considered as second raw material for the building sector. The construction industry will transform the spent coffee in a new product, which will get back in the users’ homes in the shape of building material.
Consequently, also based on the articles examined above, it was developed a new potentially performing material that, along with contributions in the coffee waste reduction, will represent an added value in the material database due to the properties of the coffee grounds, especially as regards to thermal insulation and sound absorption.

4.2.2 Components

Firstly, the components, such as the binders and the coating materials, have been selected based of the articles examined above. Although, the process has been influenced by the restrictions following the current pandemic period. At first, it was planned to test the effect of different types of binders in the coffee mixture. However, due to the unavilable testing facilities, it was necessary to adapt to easily available materials that could be used at home.

Spent coffee grounds

Spent coffee ground (fig.42a and 42b) represents the primary element of the research. According to the general idea of this thesis, initially this material was collected from people’s household waste. Later on, due to the time restraint, part of the coffee powder derived from cafeteria S.M.A.K. located on Johanneberg campus of the Chalmers University of Technology.
After being collected, spent coffee was dried in an oven at 80° C for 5 hours to completely remove the humidity (fig. 43).
It is important to underline that drying time depends on the coffee brewing technique: drip coffee, since it needs to be dipped in the water, is wetter than the coffee powder used to prepare an expresso and consequently, it takes a longer time to be completely dry.

Fig. 44 - Potato starch

Fig. 45 - Corn starch, "Maizena"

Fig. 46 - Malto-dextrin

Fig. 47 - Bee wax

Binders

All the chosen binding materials are commercial natural elements. In the first experiments material samples have been produced with two types of starch: potato starch (fig. 44) and corn starch (fig. 45), readily available in supermarkets.
At a later stage, some tests have been conducted using dextrin (fig. 46) since it has better qualities as bonding material.[116] The used dextrin, in particular, was a malto-dextrin purchased in a specific shop of products for bodybuilders in Göteborg.

Coatings

Some of the samples have been treated with bee wax to protect the material and improve its strength and water resistance. The pieces of solid bee wax (fig. 47) have been purchased in an ecologic shop in Göteborg.

4.2.3 Method

Even in this case, the restrictions have resulted in an adaptation of the techniques to the situation.

Mixture preparation

In the preparation of the mixtures the ratio between the different elements was considered in terms of volume, therefore, the quantity of components has been determined with a measuring cup (fig. 48).
Concerning quantity of water added to the mixture, it is relevant to specify that it has been always considered in relation to total powder quantity (coffee + binding material).

Fig. 48 - Measuring cup with spent coffee powder

NOTES

[116] C. Müller, U. Kües, C. Schöpper, *Wood production, wood technology, and biotechnological impacts*, Universitätsverlag Göttingen, 2014.

The steps of the preparation are shown below.

1. Measuring the required amount of spent coffee grounds and of the binder (fig. 49)

Fig. 49 - Spent coffee grounds and dextrin

2. Mixing the dry powders in order to have a homogeneous mixture (fig. 50)

Fig. 50 - Dry homogeneous mixture of spent coffee grounds and dextrin

3. Adding water and mixing one more time until you get a uniform compound (fig. 51).

Fig. 51 - Wet homogeneous mixture of spent coffee grounds and dextrin

Moulds assembly and mixture press

Different moulds have been developed to experiment with various dimentions of the end-product and to adopt the learnings from different phases of the process to create the most suitable mould for the new building material.
In these pages the technical details of the moulds and the production process are explained. The more specific learning outcomes of each experiment are presented from page 94 to 101.

Phase 1

In an initial stage small sample were produced since the aim, in this case, was to understand what the best ratio between the coffee grounds and the binder was.
The moulds (size 11 x 8 cm) used in the first experimentations (fig. 52), were made of aluminium and had a height too large for creating boards, therefore the thickness of the product was related to the amount of mixture used.

Fig. 52 - Aluminium mould, size 11x8cm

Phase 2

Subsequently, bigger moulds were adopted in order to experiment with the material's reaction to different shapes and dimensions.
In this phase a modular mould has been employed, which consisted of combinable metal elements. It was used to produce bricks of size 13 x 13 x 2,5 cm (fig. 53) and 13 x 7 x 2,5 cm (fig. 54), depending on the combination of the metal elements.

Fig. 53 - Modular mould, size 13x13x2,5cm

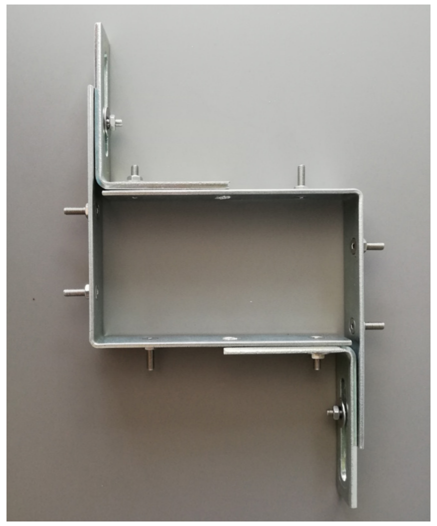


Fig. 54 - Modular mould, size 13x7x2,5cm

Fig. 55 - Mould 23x23cm, used to produce tiles

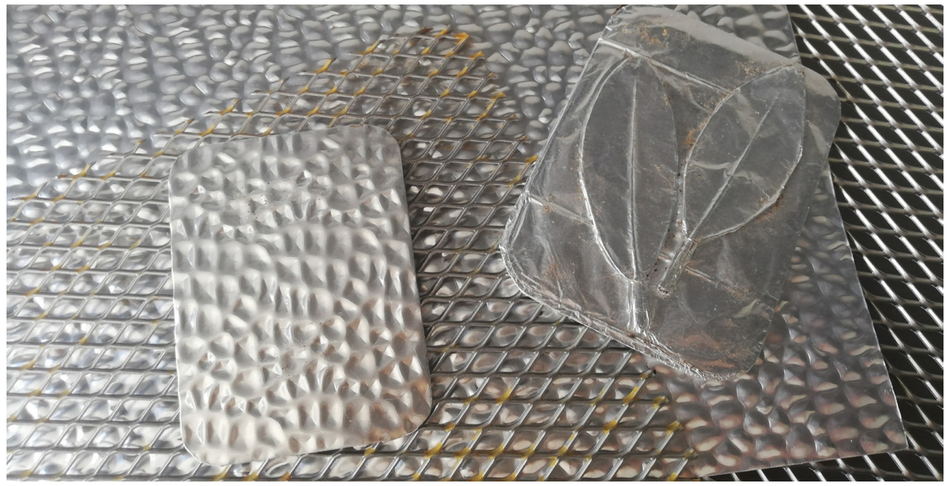


Fig. 56 - Textured bottom to printmake the material's surface

Fig. 571 - Pressing system with clamps

Phase 3
Later on, another mould dimension of 23 x 23 cm (fig. 55), was adopted to create a tile, in this case, as for the moulds utilized in the first phase, the final product height was not established but it was related to the amount of mixture used. All moulds were usedin their base form or with the addition of a textured bottom (fig. 56) to test the possibility of printmaking on the material.
A very important step in the samples production was pressing. Firstly, the material was press manually in the mould, to compact the mixture, to remove the maximum amount of air possible and to create a flat surface. In a second moment, taking inspiration from S. Moberg and J. Eliassnon's work,[117] a system of clamps was developed (fig. 57) in order to maintain the material pressed also during the firing time.

Heat treatment

The different samples have been fired in the oven at a temperature and for a time that varied from 120˚C to 200˚C and from 1 to 3 hours respectively, according to the dimension of the sample (fig. 58).
Since during the firing time, the water contained in the testing elements slowly evaporated, the samples have been controlled every 30 minutes to tighten the clamps if necessary.

Fig. 58 - Samples have been fired with clamps to maintain the material pressed

NOTES

[117] J. Eliasson and S. Moberg, *Tales of the revived, an exploration of natural leftover resources*, Master's thesis, Göteborg, 2019, J. Helmfridsson, A. Ollár, K. Pietrzyk.

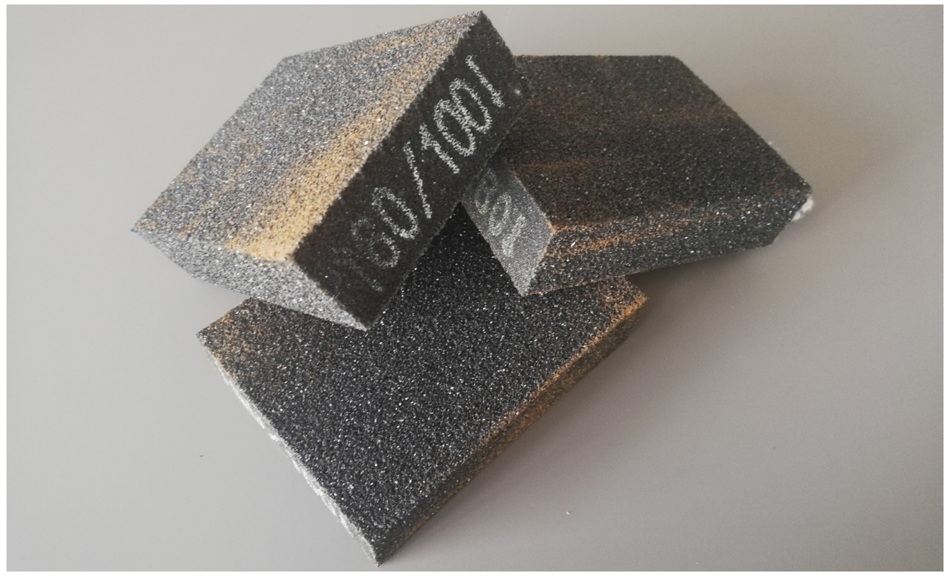


Fig. 59 - Fine-grained sandpaper

Fig. 60 - Bee wax meltining in a water bath

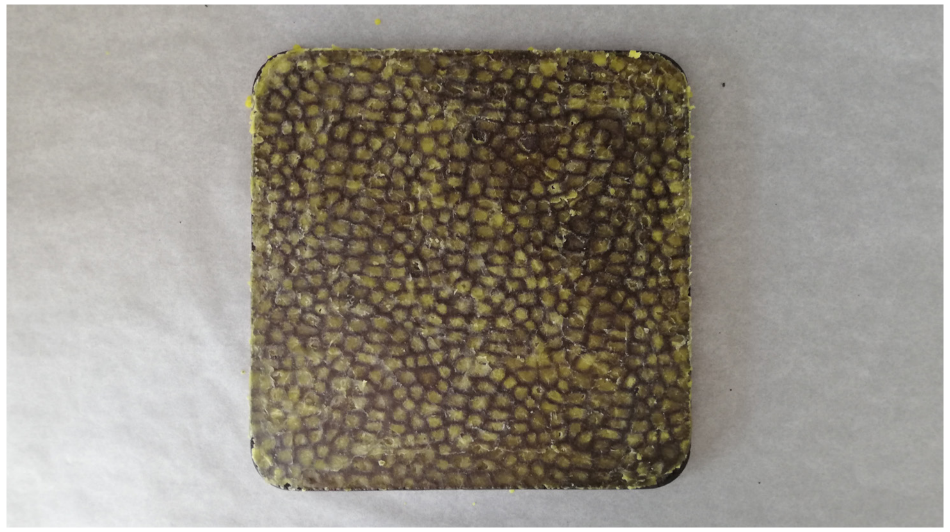


Fig. 61 - Preparation of the bee wax coating

Cooling and post-production

At the end of the firing time, the samples have been left to cool in the moulds. Cooled products have been removed from the boxes and scratched with a fine-grained sandpaper (fig. 59) to reduce the imperfection caused by a build-up of material along the edges.
The final products have been catalogued and their behaviour in the long-run has been observed as well as their aesthetic features.

Moreover, some of the samples have undergone a post-production coating treatment with bee wax to improve their features.
The finish has been prepare in three steps:
- first, the bee wax has been melted in a water bath to preserve its properties (fig. 60);
- subsequently, the liquid wax has been spread on the sample in a way that all the surface was coated (fig. 61);
- thirdly, the surface has been warmed with a hairdryer to melt again the bee wax (fig, 62) that was turned to solid, producing a yellow layer on the sample. Therefore, this operation allows the wax to penetrate the material increasing product's strength and water resistance.

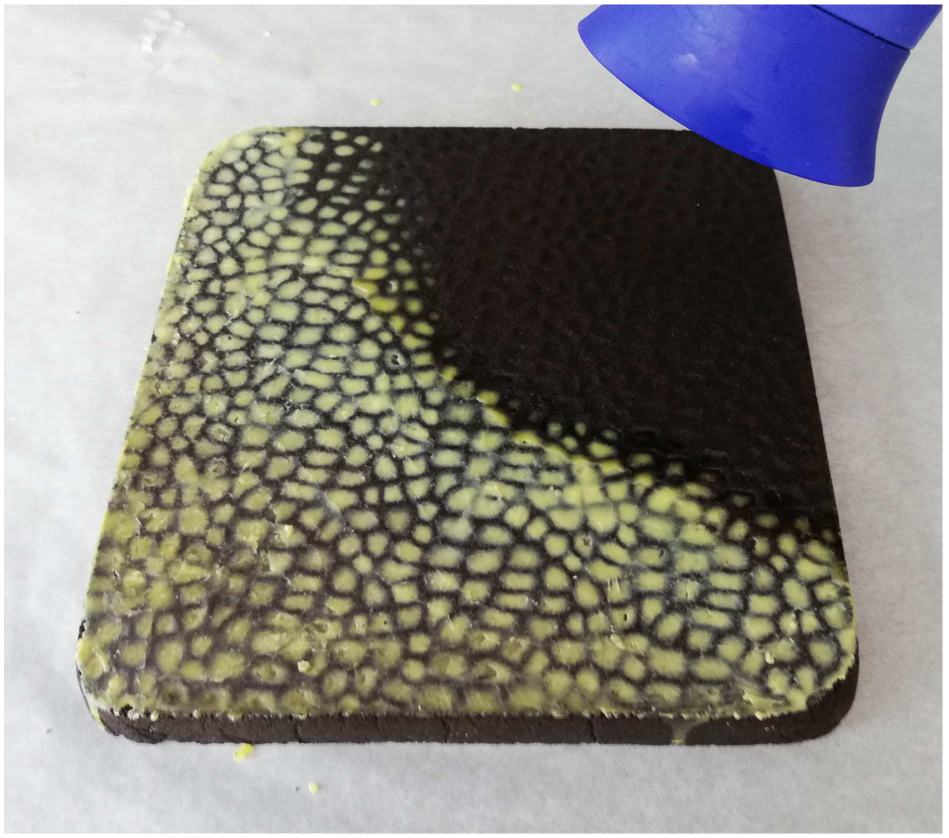


Fig. 62 - Bee wax melting and seed in the material

4.2.4 Samples

The samples production process was composed of four phases of experimentation:

- *Stage A* is the first research time;
In this phase samples of small dimensions have been produced with the purpose to establish the type of binder most appropriate and the correct ratio between coffee powder and binding material in order to reach satisfying results.

- *Stage B* relates to the texture experimentation;
as in stage A, have been used moulds of small dimensions with different textured bottoms in order to impress on the material various patterns.

- *Stage C* concerns test to a bigger scale;
during this phase samples of larger dimensions were produced in order to verify their feasibility as building materials.

- *Stage D* is related to the post-production;
part of the samples have been treated with a coating to explore how it can affect material properties.

Stage A

In this phase four mixture have been prepared. They differed in the type of bonding material, potato starch and corn starch were used, and in the percentage coffee (c) and binder (b) adopted, 70%c -30%b, 80%c - 20%b and 90%c - 10%b.
All the samples have been fired in the aluminium mould (11x8cm) using an amount of compound that allowed to obtain a product of 1 cm high.

The sample A1 (fig. 63) was prepared with 70% of coffee and 30% of potato starch.Furthermore, an amount of water equivalent to 50% of the whole volume of powders has been added.
The compound has been fired in a static oven for 2 hours at 200˚ C.
The result is a compact but light product. However, the sample's shape is not perfectly regular, probably due to the low stiffness of the mould.

Fig. 63 - Sample A1, 70% coffee grounds and 30% potatoes starch

Fig. 64 - Sample A2, 70% coffee grounds and 30% corn starch

In the sample A2 (fig. 64) the ratio of coffee and binder was maintained 70%c-30%b but corn starch was used instead of potato starch.
The amount of water and the firing time and temperature have been maintained unaltered from sample A1.
The result is a brick with a cracked surface, probably due to the chemical composition of the corn starch, which makes the material unusable.

Sample A3 (fig. 65) is a variation of sample A1 in which the amount of potato starch has been reduced to 20%.
Even in this case, the amount of water and the firing settings were the same as in sample A1.
The obtained brick has a compact but porous surface and a shape more regular compared with the sample A1.

Fig. 65 - Sample A3, 80% coffee grounds and 20% potatoes starch

Fig. 66 - Sample A4, 90% coffee grounds and 10% potatoes starch

Lastly, the sample A4 (fig. 66) has been produced to test the minimum amount of potato starch allows to produce a brick.
Maintaining unchanged the water amount and the firing settings, the quantity of starch has been reduced to 10%.
Although the material manages to maintain a definite shape, it is too friable to be adopted as a building material.

Stage B

During stage A, it was noticed that the bottom of the mould produced an engraving on the samples. This has resulted in investigating different patterns to transfer on the material in order to make it more attractive, especially in the case of possible utilization as decorative panels.
To realize the textures, various undersides with diverse patterns have been prepared to add in the mould. The mixture used for these tests is the same as sample A1 (70% spent coffee grounds and 30% potatoes starch) since it was the strongest of the three.

The first trial, sample B1 (fig. 67a) has been obtained by placing six wooden sticks on the base of the mould protected by a layer of aluminium paper (fig. 67b) to avoid them to stay embedded in the mixture.
The outcome is a compact and strong surface with thin engravings that give the idea to have a soft material.

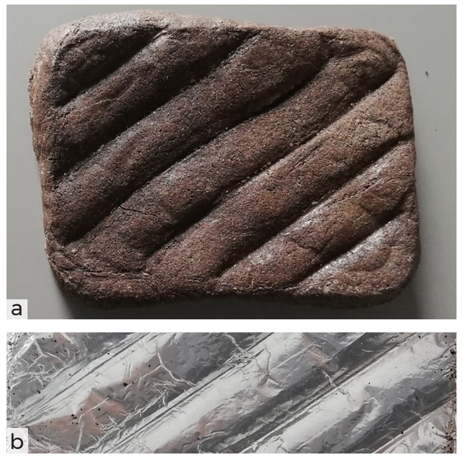


Fig. 67 - Sample B1 (a), texture's mould (b)

For sample B2 (fig. 68a) the possibility to print on the coffee brick a specific drawing has experimented. For this reason, two leaves have been covered with aluminium paper, to increase their thickness (fig. 68b), and they have been placed on the base of the mould.
The result is a surface with a clear image, this is a very interesting property since it allows to produce coffee panels able to recreate a specific drawing on the wall.

Fig. 68a - Sample B2

Fig. 68b - Leaves texture's mould

The sample B3 (fig. 69a) was produced by applying a wire mesh, with a rhomboidal texture (fig. 69b), on the mould's base.
During the pressing process, the mixture has stuffed all the halls forming on the product's surface raised prints similar to diamonds.

The result was a surface characterized by an interplay of light and shadows produced by the diamonds in relief.

Fig. 69a - Sample B3

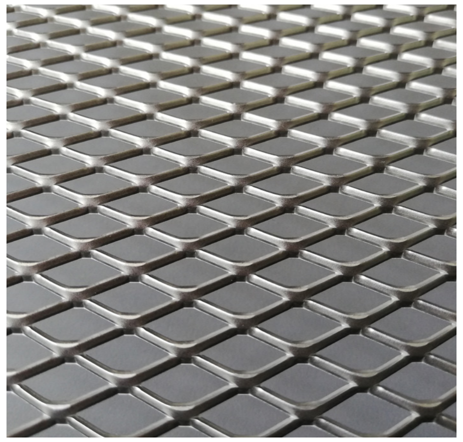


Fig. 69b - Diamonds texture's mould

Lastly, sample B4 (fig. 70a) was developed using a metal sheet with a particular texture characterized by several surface holes that can remind to the shape of an expanse of beans (fig. 70b).
Therefore, the halls present on the steel, in contact with the pressed mixture, have made an interesting pattern on the sample's surface, which can be interpreted as the mark left by the coffee beans on it.
As a result, a strong relation between the material and its texture that enhances the product's origin has been established.

Fig. 70a - Coffee beans texture's mould

Fig. 70b - Sample B4

Stage C

This part was dedicated to the experimentation of the material reactions on a larger scale to simulate the dimension of hypothetical construction elements such as small bricks and tiles.

In this phase two types of binders has been employed.
Since the sample made with potato starch started to crack after a few days, it was decided to replace the starch with maltodextrin. This binder is the result of a hydrolysis process in which the long chains of amylose and amylopectin contained in the starch are broken originating fragments of varying lengths called dextrins. The presence of shorter chains makes the material more soluble in water but, at the same time, they strengthen the binder's binding properties and reduce the retrogradation process, which was the cause of the cracks.[118]

Sample C1 (fig. 71 and 72) has been realized mixing 70% of coffee grounds with 30% of potatoes starch.
Later an amount of water equivalent to 50% of the powders quantity was added to the mixture in order to combine it. The compound has been pressed in the mould to which was applied an underside with a "coffee beans" pattern.
The sample was fired in the oven for one hour at 200˚C plus two more hours at 150˚C.
Although the result has appeared strong and compact in a first time, after one week it started to crack down the middle, proving it was not appropriate as a building element.

Fig. 71 - Sample C1, 70% coffee grounds and 30% potatoes starch, top view.

Fig. 72 - Sample C1, 70% coffee grounds and 30% potatoes starch, side view.

NOTES

[118] https://www.glutenfreetravelandliving.it/, accessed from 08/04/2020 to 15/05/2020.

In consequence of the break-up of brick C1, a sample C2 (fig. 73 and 74) has been developed replacing potatoes starch with the same quantity (30%) of maltodextrin. In addition, the amount of water has been changed by reducing it from 50% to 20% since the maltodextrin has a higher water absorption power.
The mixture was pressed in a mould in which a wire mesh was placed as underside in order to obtain a "diamonds" pattern on the surface.
Firing time and settings were maintained from sample C1.
The result was a compact and light brick with a porous surface. Moreover, in contrast with sample C1 this product is durable over time and for these reasons suitable to the building sector.

Fig. 73 - Sample C2, 70% coffee grounds and 30% maltodextrin, top view.

Fig. 74 - Sample C2, 70% coffee grounds and 30% maltodextrin, axonometry.

Starting from the results obtained with sample C2, a tile of dimensions 23x23x1cm has been developed.
To prepare the sample C3 (fig. 75) the percentage of coffee grounds and maltodextrin has been maintained unvaried from the previous test, as well as for water and firing settings.
The obtained tile was cracked and burned as a result of an exaggerated firing temperature compared with the thickness of the sample.

Fig. 75 - Sample C3, 70% coffee grounds and 30% maltodextrin

According to the consideration from sample C3, the sample C4 (fig. 76) was produced characterized by the same amount of coffee grounds (70%), maltodextrin (30%) and water (20% of the powders' total).
In this case, however, firing settings have been modified: the temperature has been lowered to 120°C and backing time has been shortened from three to two hours.
Initially, the result was a homogeneous and compact sample but, after four hours since it was removed from the mould, the tile started to crack and at last, it broke down the middle.

Fig. 76 - Sample C4, 70% coffee grounds and 30% maltodextrin

Fig. 77 - Sample C5, 70% coffee grounds and 30% maltodextrin, top view

Lastly, the sample C5 (fig. 77 and 78) has been developed. The mixture was maintained unvaried in terms of percentage but the quantity of material has been double in order to produce a thicker tile. Consequently, firing settings have been adapted to the higher height of the sample, therefore the tile has been backed two hours at 150°C plus other 30 minutes at 120°C.
The result was a tile sized 23x23x2cm, which stayed compact and strong over time, these properties, as well as its lightness, make the tile suitable as a building material. From this experiment, it can be inferred that the thickness plays a fundamental role in the product's strength and resistance, for this reason, it is important to consider adapting the height to the product's length and width.

Fig. 78 - Sample C5, 70% coffee grounds and 30% maltodextrin, front view

Stage D

The last phase consisted in experimenting with the post-production process. Samples obtained in stage C are characterized by a porous surface, which means that the material is little or no water-resistant. Consequently, in order to develop waterproof elements, a layer of bee wax was applied to the samples.

Fig. 79 - Sample D1, 70% coffee grounds and 30% maltodextrin with the bee wax coating

Sample D1 (fig. 79) consists of the replication of model C5 on which the coating has been applied. The bee wax, melted in a water bath and spread on the sample surface, has been re-warmed to enable it to seep into the material. Once the bee wax was completely absorbed, the procedure has been repeated on the other side of the tile.
At the end of the trial, the sample appeared polished and resistant against humidity, in addiction, bee wax has made the material more rigid increasing its mechanical properties.

Based on the results obtained from sample D1, bee wax coating was tested on a tile sized 23x23x1cm.
As explained for sample C4, once the product was removed from the mould it started to crack, therefore, the surface of sample D2 (fig. 80) was immediately sprinkled with wax and warmed to allow the coating seep in the material.
The liquid has filled the cracks, reducing the deformation and fracturing process of the tile. The outcome showed that it is possible to produce thinner elements by using coating able to penetrate the material strengthening its resistance and its cohesiveness.

Fig. 80 - Sample D2, 70% coffee grounds and 30% maltodextrin, 1cm thick with the bee wax coating

4.3 EVALUATIONS

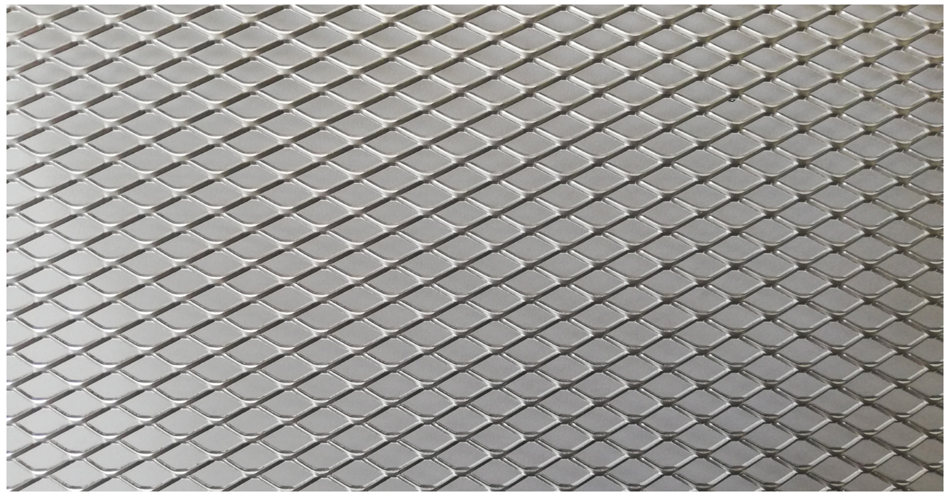


Fig. 81 - Specific underside to place on the mould base

	PERCENTAGE OF BINDER		
	30%	20%	10%
TILES	✓		
INSULATION PANELS			✓
DECORATIVE PANELS		✓	

Fig. 82 - Application of the coffee material according to the percentage of binder (maltodextrine) in the mixture

Fig. 83 - Rifts caused by the retrogradation process of the potatoes starch

The experimentation carried out on the coffee-based samples allowed to investigate and explore the several potentials of this element when it is adopted in the production of building materials.

The performed tests have shown that spent coffee is an easy to process element and that it can be modeled in various compact shape if it is mixed with binding materials.
Furthermore, since the production process requires the use of moulds and it has been demonstrated that the mixture easily adapts to different shapes, it appears that each final product's surfaces could have various textures depending on the style and the feel wished.
In addition, applying specific moulds, such as the mesh to produce "diamonds" (fig. 81), allows obtaining elements characterized by an extended surface, which enables higher exploitation of the material's sound absorption power.

The experimentations have been demonstrated how small changes in the mixture lead to different results. For example, a variation in the percentage of the binder allows obtaining different density and a consequently different grade of porosity. This influence in a significant manner the application of the material (fig. 82).
Other two variables are represented by the temperature of firing and the thickness of the material, which biases the strength and the stiffness of the sample.
Also the type of the adopted binder can influence the final result in terms of strength and long-term resistance, for example, the retrogradation process of the starch leads to the rifts of the elements over time [119] (fig. 83), making the products impossible to be used. The several tests performed have led to identifying a valid binding material: maltodextrin. Nevertheless, it was not possible to experiment other typologies of binders more common in the building sector such as natural resins, which can have a stronger positive impact on the material features.

Lastly, it is important to remark that, despite the promising results achieved, it has not been possible to conduct specific tests on the real mechanical resistance of the material. Consequently, the samples have been evaluated considering mainly their aesthetic outcome and their durability, while their physical and mechanical properties have been assumed from the pre-existing literature.

NOTES

[119] https://www.nutrimenti1.wordpress.com/2009/08/28/gelatinizzazione-e-retrogradazione-dellamido/, accessed from 08/04/2020 to 17/05/2020.

MATERIAL APPLICATIONS

"The amount of daily coffee consumption worldwide is growing, thus the potential of reusing its waste for further uses is enormous."[120]

Julian Lechner, 2015

NOTES

[120] https://www.dezeen.com/2015/05/22/kaffeeform-recycled-ground-coffee-waste-cup-julian-lechner/,

ABSTRACT CHAPTER 5

Come spiegato in precedenza, questo progetto è basato sull'idea di economia circolare domestica.
La valorizzazione del caffè di scarto prodotto nelle abitazioni rappresenta l'evidenza tangibile della circolarità del caffè che, entrato nelle case come fonte alimentare e scartato come rifiuto, può tornare all'interno delle abitazioni sottoforma di elemento costruttivo. Inoltre, come evidenziato dai test svolti, la possibilità di produrre materiali di diverse dimensioni e con varie texture permette di valorizzare il prodotto e di ampliarne le possibili applicazioni. Per questo motivo sono state sviluppate cinque proposte di utilizzo del materiale a base di caffè.

Piastrelle (rivestimento murario)

La cucina è il principale luogo di produzione di rifiuti organici all'interno dell'abitazione, nonché la stanza dove, normalmente, il caffè viene utilizzato e dismesso. Per questo motivo si è deciso di partire da questa stanza per mostrarne le possibili applicazioni.
In questo caso sono stati pensati elementi con forme e dimensioni differenti in grado di essere utilizzati come piastrelle di riverstimento murario. Dal momento che la cucina rappresenta un luogo umido è importante evidenziare che, per essere utilizzate, queste piastrelle hanno bisogno di essere sottoposte a trattamenti di impermeabilizzazione.

Pavimentazione

Le piastrelle a base di caffè posso essere utilizzate in tutti gli ambienti della casa, non solo come rivestimento murario ma anche come pavimentazione.
Come nel caso precedente, anche per questa applicazione gli elementi costruttivi necessitano di un trattamento impermeabilizzante. La cera d'api potrebbe rappresentare una soluzione in quanto, essendo un prodotto naturale, può essere facilmente utilizzata anche per la manutenzione. Inoltre, essa, non soltanto impermeabilizza le piastrelle, ma, penetrando nel materiale, lo nutre aumentando anche la sua resistenza.
A differenza delle piastrelle utilizzate come rivestimento murario però, quelle usate per la pavimentazione, essendo di dimensioni maggiori, necessitano di uno spessore maggiore.

Pannelli decorativi

La produzione di elementi di dimensioni maggiori permette di sviluppare pannelli di forme e spessori variabili che, combinati tra loro, possono essere adottati nel rivestimento di pareti creado giochi di profondità e di luci ed ombre.
Inoltre, adottando pannelli con particolari texture, come per esempio quella "a diamanti", è possibile sfruttare a pieno le caratteristiche fonoassorebenti del materiale.

Ante per arredi

Un'applicazione più attinente alla sfera del design è invece quella legata alla produzione di ante per elementi di arredo come pensili della cucina o armadi.
In questo caso è possibile trattare le ante a base di caffè con vernici colorate o alternarle ad ante classiche in legno. Inoltre la possibilità di stampare sul materiale a base di caffè texture o disegni specifici, permette di ottenere elementi di arredo particolari e personalizzati.

Pannelli isolanti

Infine, sulla base della letteratura esistente, è stata proposta un'applicazione di carattere più tecnico. Le proprietà isolanti del caffè possono essere sfruttate nella produzione di pannelli isolanti. In questo caso, poiché l'isolamento del materiale è relazionato alla porosità, è possibile adattare la miscela riducendo la percentuale di legante in modo da aumentare la porosità del prodotto.

Come dimostrato, pertanto, gli elementi a base di caffè sono dotati di una grande versatilità e, con le dovute attenzioni, rappresentano un valore aggiunto nelle diverse applicazioni all'interno delle abitazioni.

5.1 CLOSE A CIRCLE

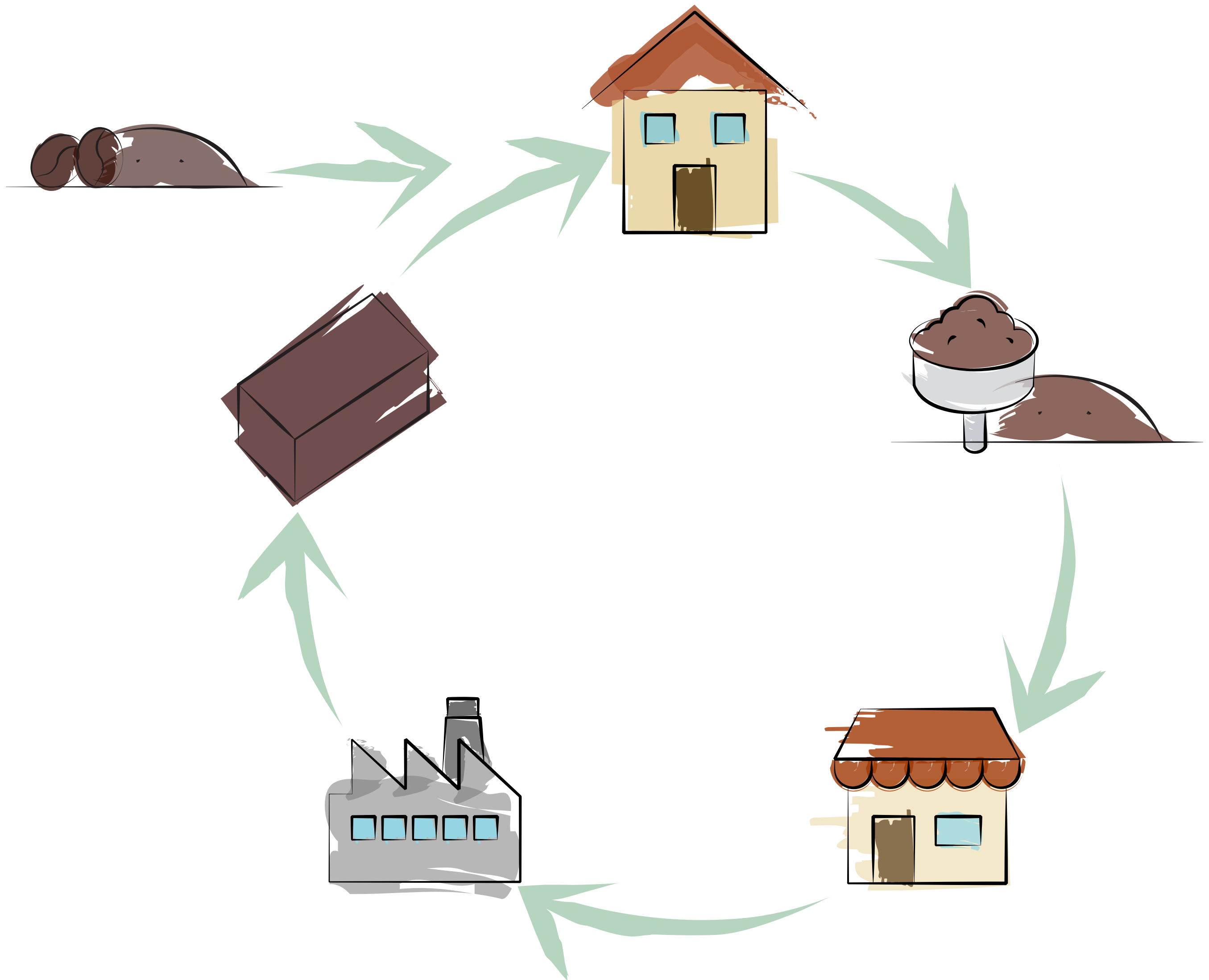


Fig. 85 - Diagram of the coffee domestic circularity: coffee enters the homes as a food commodity, once it has become waste it can be gathered in the shops, which delivered the spent coffee to the industries where it has been transformed in a building material that can return in the homes

This research is based on the idea of circularity where coffee, a natural element, after several transformations, can be disposed of in nature without causing any danger for the environment (fig. 84).
In particular, as previously mentioned, this project is focused on a domestic circularity. The proposal to collect household spent coffee grounds represents the starting point to create a circle where coffee enters in the houses as a food commodity and soon becomes waste. This coffee waste can be collected, valorized and re-used as a construction element in the houses themselves (fig. 85).
These coffee waste valorization actions represent the tangible evidence of the circular economy flow and they can encourage people to recycle waste even more carefully.
Furthermore, the various tests showed that it could be possible to produce elements with several textures, dimensions and shapes. This allows the material to be adapted from time to time to use it for different purposes. For these reasons five different scenarios of how this new coffee material can be re-used in the houses have been developed: tiles, flooring, wall panels, furniture boards and insulation panels.

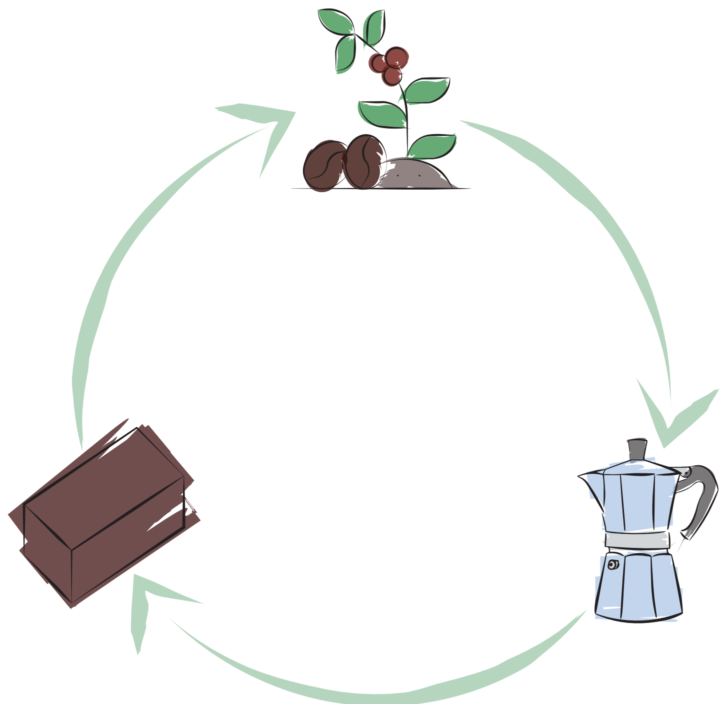


Fig. 84 - Diagram of the coffee circularity: coffee, originated by the soil, has been used as a food product, subsequently, after a transformation process, it can be re-used as a building material and at the end of its service life it can return to the soil

5.2 TILES

Fig. 86 - Kitchen's sketch where coffee tiles are used to characterize the wall behind the cooking place

Fig. 87a - Example of a wall coating with square tiles

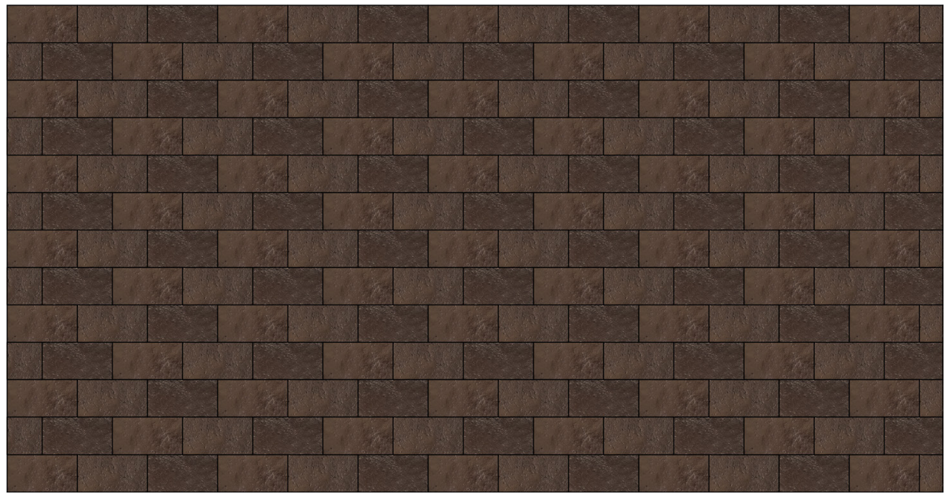


Fig. 87b - Example of a wall coating with rectangular tiles

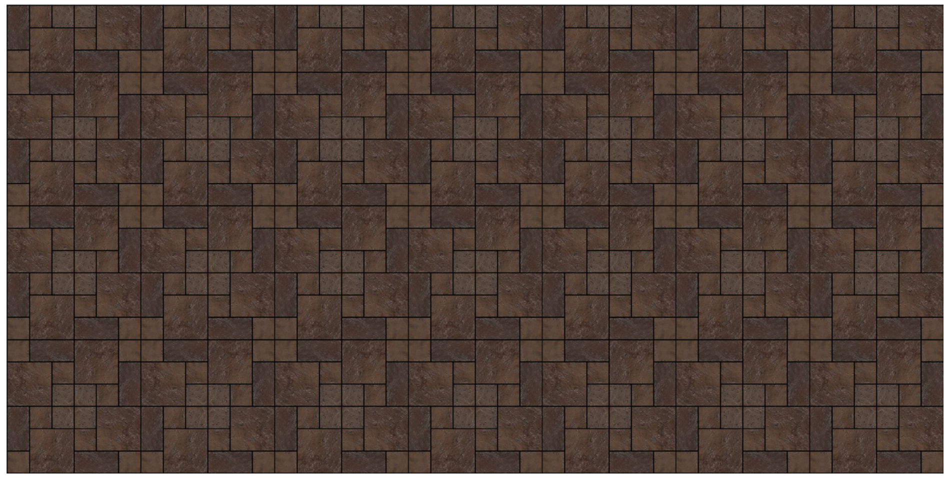


Fig. 87c - Example of a wall coating with square and rectangular tiles of different dimensions

The kitchen represents the room of the house where most of the household waste is generated,[121] in particular, it is the place in which coffee is prepared, consumed and transformed into waste. For these reasons, it is interesting to illustrate the different solutions of spent coffee's valorization as a building material, starting from its application in the kitchen (fig. 86).

Using diverse moulds it is possible to produce tiles of various shapes and dimensions such as square or rectangular with different ratios between length and height to obtain different wall textures (fig. 87a, 87b and 87c), also the thickness of the material can change according to the necessity and the function it must perform. Despite this, it is important to underline that the ability of these tiles to hold the weight of the kitchen furniture has not been tested, consequently, the proposal includes their usage as a wall coating but not as a principal element of the wall.
Furthermore, in humid areas such as the one attached to the cooking place, it is of fundamental importance to apply waterproof materials hence, coffee tiles' surface needs to be treated with a special coating able to make them polished and water resistant (fig.88).

The usage of a wall covering of this nature is not limited to the kitchen environment but it can be adopted in any room of the house.

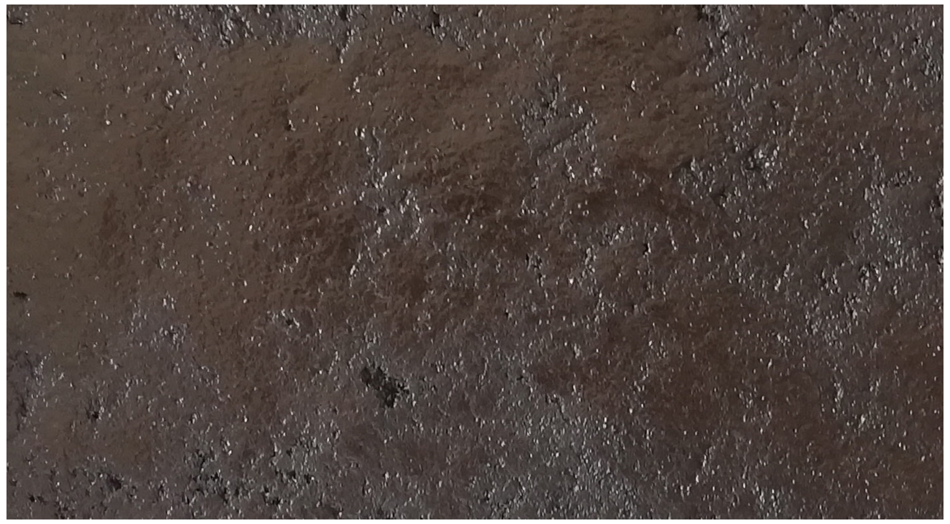


Fig. 88 - Simulation of a tile's surface with a waterproof coating

NOTES

[121] S. Boeri, & Comieco, *Atlas, Nuove pratiche per una migliore gestione dei rifiuti*, 2018, p. 38.

5.3 FLOORING

Fig. 89 - Hall's sketch where the coffee tiles are used as a flooring system

Fig. 90a - Example of flooring with square tiles

Fig. 90b - Example of flooring with rectangular tiles

Fig. 90c - Example of flooring with rectangular coffee tiles in different shades of brown

Another interesting application of the coffee material in form of tiles consists of the possibility to produce flooring systems (fig. 89).

Tiles intended for floor coverings need to be water resistant as well as the ones adopted in the solution showed above, therefore they need post-production treatments to generate a waterproof layer on their surface. This coating can be easily obtained by the application of bee wax, which is suitable also for the maintenance in order to preserve material's water resistance and to increase the mechanical resistance since this is a natural element that is absorbed by the material.

These flagstones are bigger compared to the tiles produced for wall coating. For this reason, they need to be thicker, moreover, usually they need to be flat to allow people to walk correctly. Despite this, it is possible to design various texture on the floor using square or rectangular tiles combined in different manners (fig. 90a, 90b and 90c). Furthermore, in particular situations, there is a chance to match simple coffee tiles with elements made from the same material but characterized by patterns, used as skirting boards and for small details on the floor, in order to obtain peculiar results (fig. 91).

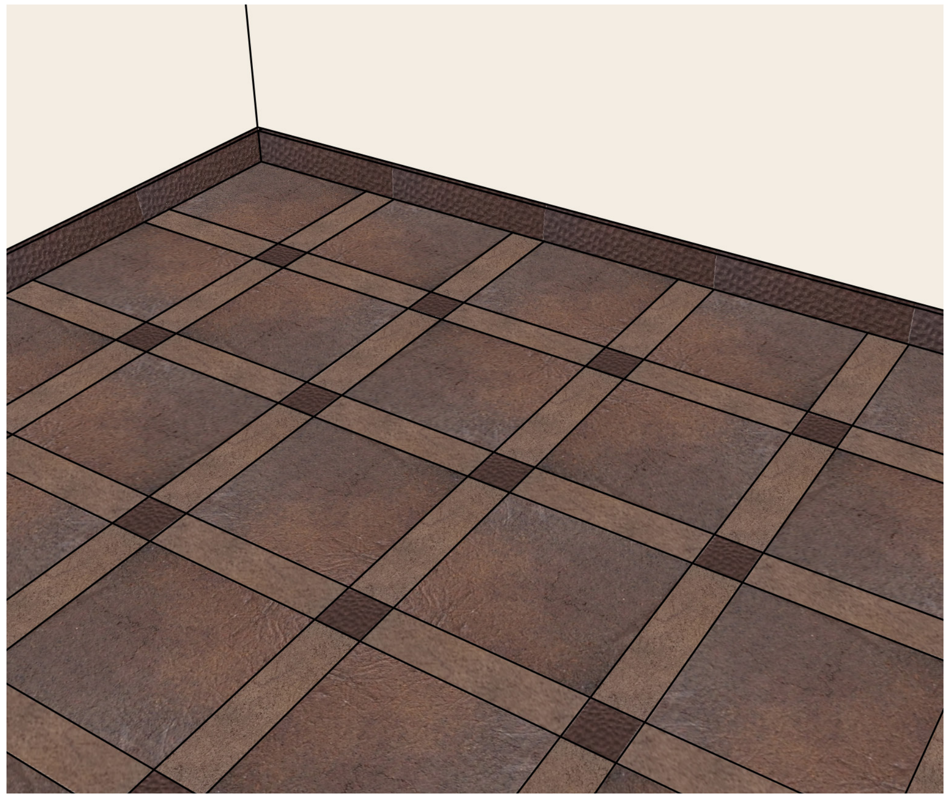


Fig. 91 - Example of flooring with a mach of simple coffee tiles and texturized coffee tiles

5.4 WALL PANELS

Fig. 92 - Livingroom's sketch where the coffee panels are used to decorate one of the room's walls

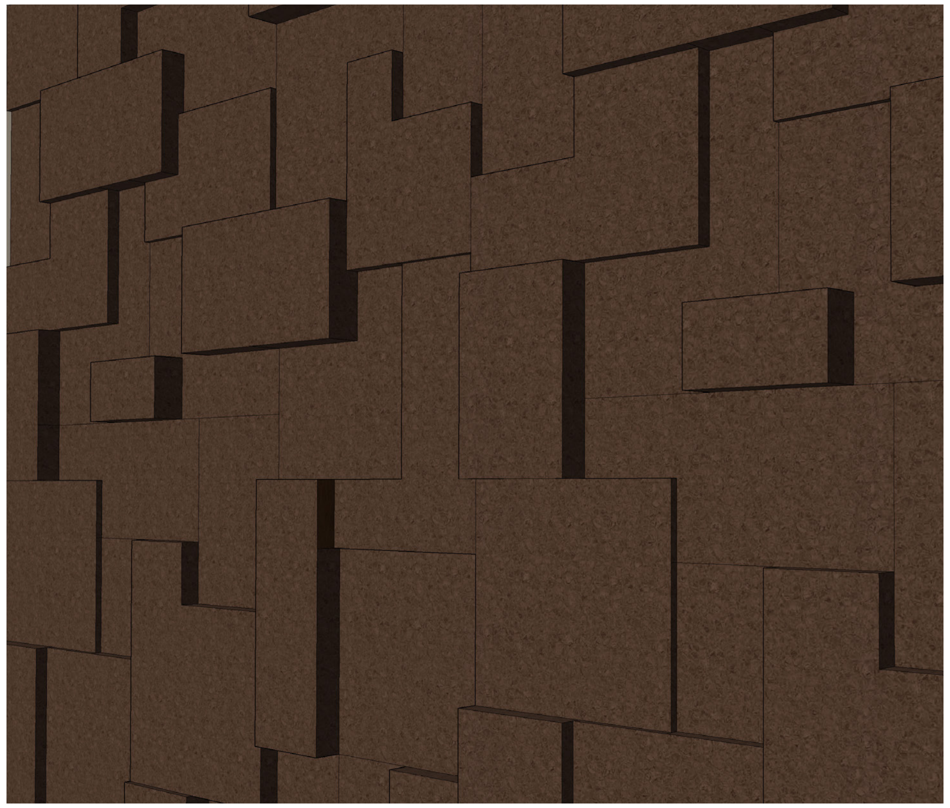


Fig. 93 - Interplaying of light and shadow on the wall produced by the coffee panels of different dimensions and thickness

Fig. 94 - Simple and flat surface of a coffee panel

Fig. 95 - Textured surface of a coffee panel

Throughout the experimentation phase, the potential of the coffee mixture has been revealed to be modelled in various shapes according to the necessity. This feature can be exploited to design particular walls composed of panels of different dimensions and thickness (fig. 92) in order to obtain an interplay of light and shadow which gives motion and depth to the entire wall (fig. 93).

Concerning the panels' surfaces, the chance to develop products with diverse texture allows designing different solutions. According to the situation and the project it is possible to employ panels with a flat and simple surface (fig. 94) on the entire area or alternate them with elements decorated with a pattern (fig. 95) to represent specific pictures or to make the wall more dynamic.
Furthermore, these panels can be applied where the control of noise and the rumbling sound is required, such as big or empty rooms, due to their sound absorption property. This feature can be implemented using elements with a diamond's texture (fig. 96) since with this motif the area subject to the sound waves rise.

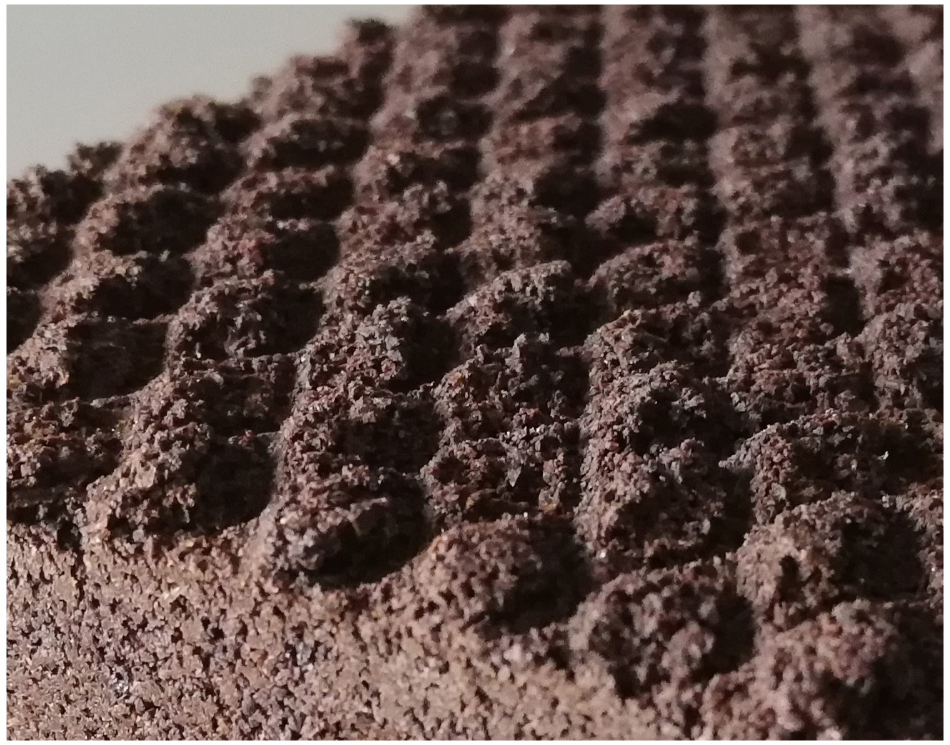


Fig. 96 - Coffee panel's surface with the diamond pattern to rise the top surface

5.5 FURNITURE BOARDS

Fig. 97 - Bedroom's sketch where the coffee panels are used as furniture's boards

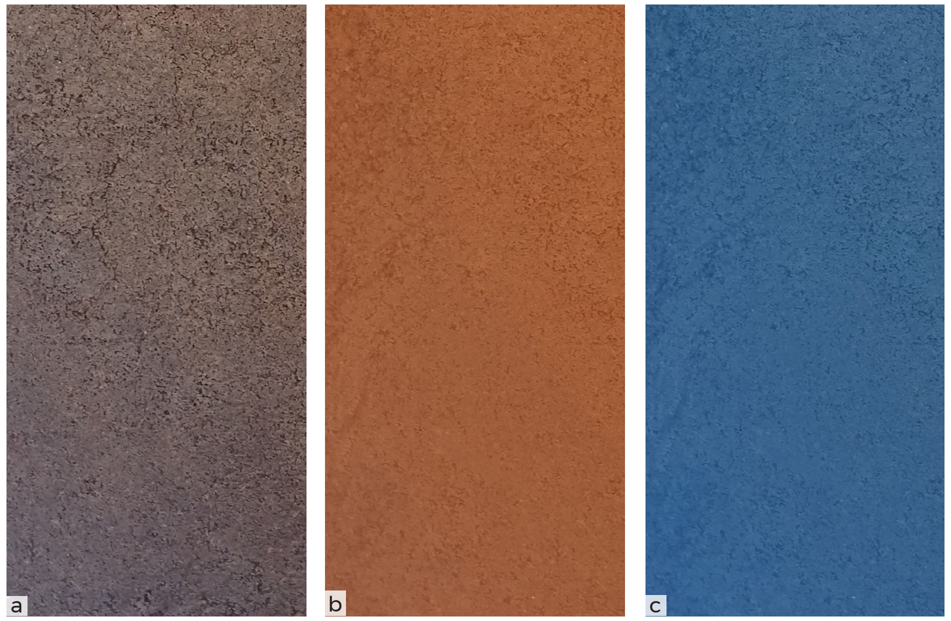


Fig. 98 - Surface of the coffee door in its natural aspect (a), painted orange (b), painted blue (c)

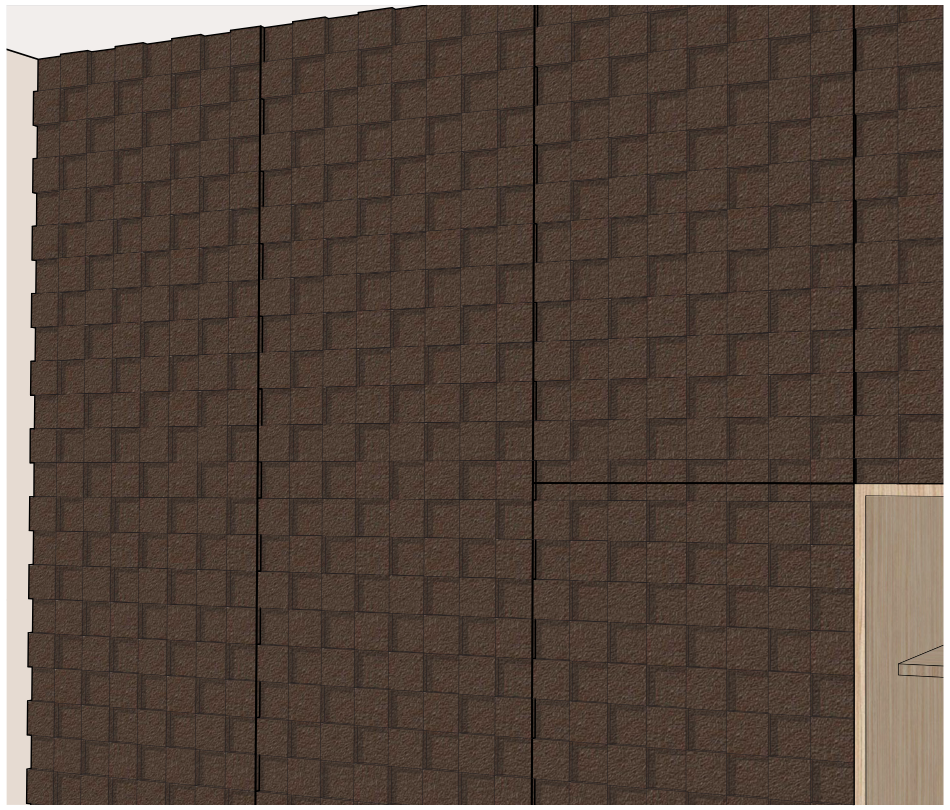


Fig. 99 - Furniture doors characterized by a chessboard texture

An alternative application for the coffee material consists of the production of boards to utilize as furniture doors (fig. 97). Despite this solution slightly deviates from the construction field to get closer to the design one, it is directly linked with the household environment, contributing to the idea of a domestic circularity of the materials.

The spent coffee boards are suitable to be applied in their simple and natural aspect (fig. 98a) but at the same time, they might be enhanced by texture and colored paints (fig. 98b and 98c). Particular patterns can be directly printed on the boards during their production phase, to characterize the furniture with basic motif (fig. 99) and specific drawings (fig. 100). Furthermore, it is possible to design the whole wardrobe surface with these coffee doors or they can be paired with boards of plywood or other materials in order to enliven the surface.

Fig. 100 - Furniture doors characterized by a drawing of hot-air balloons

5.6. INSULATION PANELS

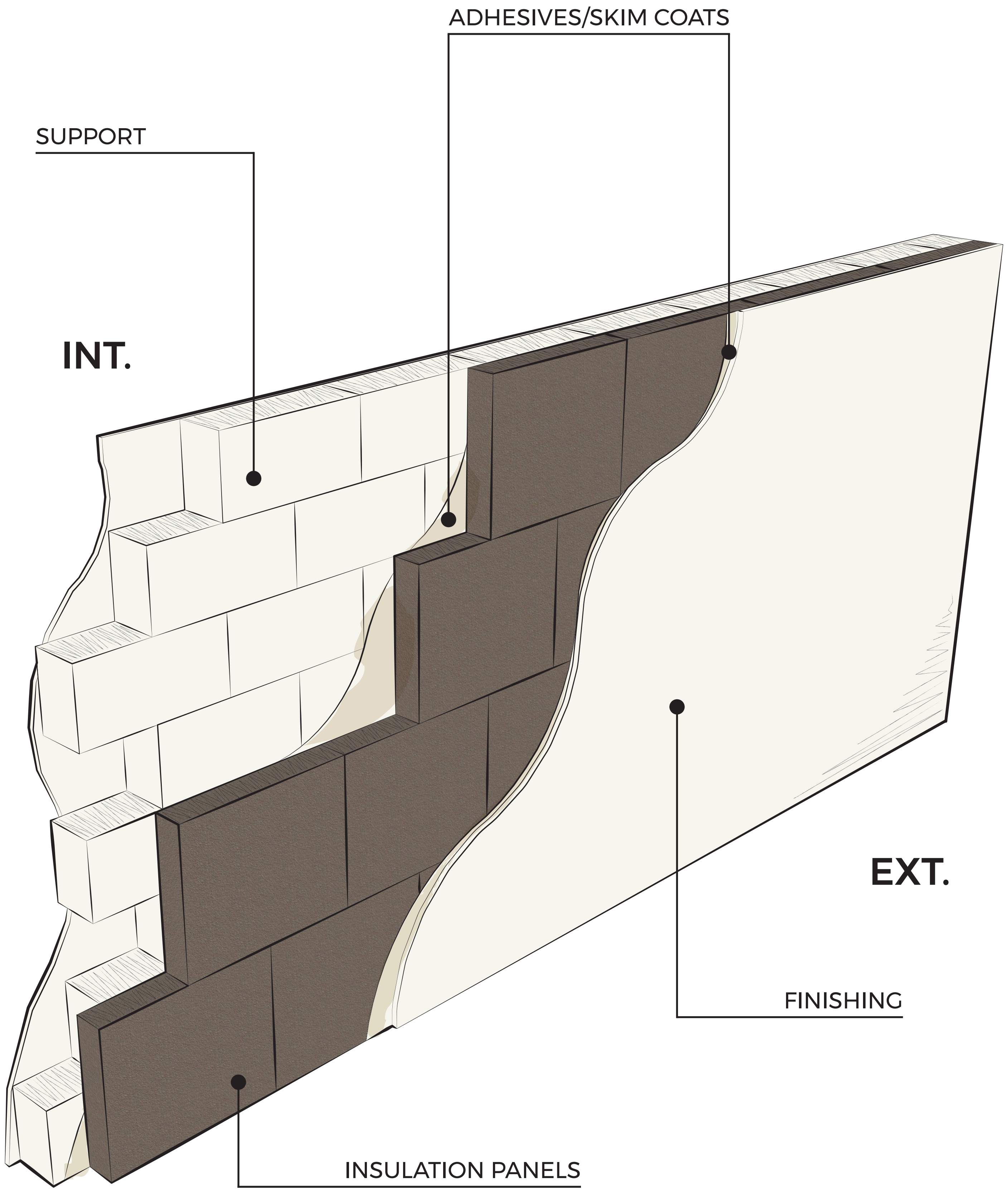


Fig. 101 - Hypotesis of a stratigraphic composizion using insulation panels made from spent coffee

Returning to the construction field, it is interesting to consider the possibility to use this coffee material in the production of insulation panels.

Insulation properties of spent coffee have been demonstrated by Lachheb et al.,[122] therefore, boards made of this material can represent an added-value in the wall layers. Since the insulation power of these elements depend upon the porosity of the material, it is possible to adapt the mixture according to necessity, reducing the amount of binder such as in sample A3 or A4 (p. 107).

In fig. 101 a hypothetical wall stratigraphy has been shown in which the insulation layer has been placed on the side of the wall closer to the colder area. However, the layer structure can be designed in various manners depending on the circumstances. Therefore, it is important to consider the possibility to realize these coffee panels in different shapes and dimensions (fig. 102) and with diverse coating on the surface in order to make them suitable for various solutions. For example, in the case of a ventilated façade or in general for outer walls, it is essential to design a panel equipped with a layer able to resist to water and humidity infiltrations, while this precaution is not strictly necessary in inner walls, which duty is to separate space with different temperatures such as the apartment and the stairwell.

As it has been shown, spent coffee elements are characterized by a great versatility that, with due measures, can serve various functions adding value to the system in which they are employed.

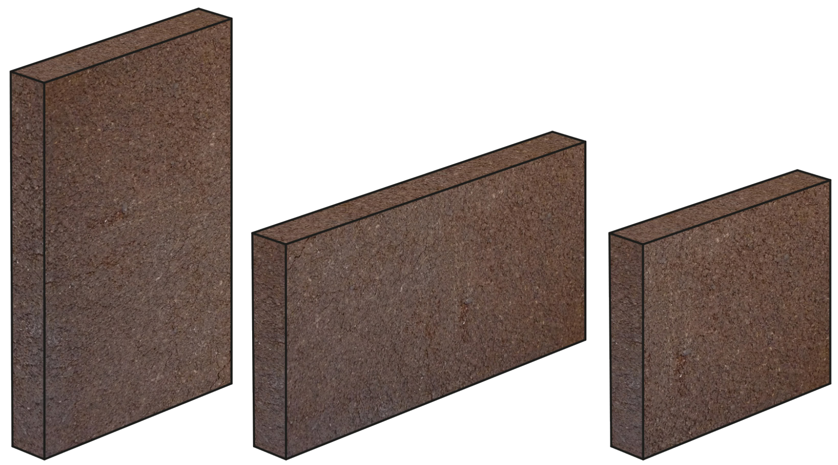


Fig. 102 - Insulation panels made from spent coffee in different size

NOTES

[122] A. Lachheb, A. Allouhi, M. El Marhoune, R. Saadani, T. Kousksou, A. Jamil, M. Rahmoune, & O. Oussouaddi, O., *Thermal insulation improvement in construction materials by adding spent coffee grounds: An experimental and simulation study* in "Journal of Cleaner Production", 209, 2019, p. 1417.

FINAL REMARKS

“ In the face of sharp volatility increases across the global economy and proliferating signs of resource depletion, the call for a new economic model is getting louder. [...] The time is right, many argue, to take this concept of a ‘circular economy’ one step further [...] and to prepare the ground for its adoption.” [123]

McKinsey Report, 2012

NOTES

[123] E. MacArthur & McKinsey, *Towards the circular economy - Economic and Business Rationale for an Accelerated transition*, Report by the Ellen MacArthur Foundation, 2012, p. 6.

DISCUSSION

As has been shown, coffee represents the second trade commodity in the world [124] with an average per capita consumption of 4,5 kg per year with a peak of 6, 8 or 12 kg in countries such as Italy, Sweden and Finland respectively.[125] This massive use of coffee produces a huge quantity of waste implementing the amount of food waste generated every year in the world. Therefore, re-using coffee becomes an act of great importance to reduce food waste production in accordance with SDGs of the Agenda 2030.[126] In particular, considering spent coffee generated in the domestic environment, it is possible to act in the household sector, since it represents the major contributor in the food waste production with the 53% of the total.[127] Moreover, re-using spent coffee, it is possible to act on environmental sustainability keeping under control the footprints caused by the food waste.[128] In particular, an action occurred on the carbon emissions that, otherwise, would be produced by the waste when they are dumped in the landfills.
The idea to develop new methods to revitalize the spent coffee is strengthened from material's belonging to the *Category II* of the hierarchy of food surplus, waste and loss,[129] which includes all inedible food waste that can be considered as a resource in the industrial sector. This is in accordance to one of the principles of the circular economy, which suggests considering waste not as garbage but as a second raw material.[130]

NOTES

[124] J. Rajesh Banu, S. Kavitha, R. Yukesh Kannah, M. Dinesh Kumar, Preethi, A. E. Atabani, & G. Kumar, *Biorefinery of spent coffee grounds waste: Viable pathway towards circular bioeconomy* in "Bioresource Technology", (302 January), 2020.

[125] https://www.quickcaffe.com/consumi-caffe-italia-e-mondo/, accessed on 14/04/2020.

[126] Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*, 2019.

[127] Å. Stenmarck, C. Jensen, T. Quested, G. Moates, M. Buksti, B. Cseh, S. Juul, A. Parry, A. Politano, B. Redlingshofer, S. Scherhaufer, K. Silvennoinen, H. Soethoudt, C. Zübert, & K. Östergren, *Estimates of European food waste levels. Reducing food waste through social innovation* in "Fusions", 2016.

[128] Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*, 2019.

[129] D. A. Teigiserova, L. Hamelin, & M. Thomsen, *Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy*, in "Science of the Total Environment", 706, 2020.

[130] https://www.ideegreen.it/economia-circolare-definizione-ed-esempi-95289.html, accessed from 17/02/2020 to 20/04/2020.

Organic nature of the spent coffee and of the binders used in this research allowed to link to the bio-circularity where the concept of improving and enhancing waste as a resource is combined with the idea of exploiting as much as possible a natural material, according with the cascade method.[131]
Lastly, building industry is the sector with the biggest impact on the natural environment because of its constant need of new feedstock,[132] consequently, act at the micro level, using spent coffee as a second raw material in the manufacturing of building elements, such as bricks or panels, can reduce the demand of primary products from nature.

NOTES

[131] M. Carus, & L. Dammer, *The Circular Bioeconomy - Concepts, Opportunities, and Limitations* in "Industrial Biotechnology", 14(2), 2018.

[132] F. Pomponi, & A. Moncaster, *Circular economy for the built environment: A research framework* in "Journal of Cleaner Production", 143, 2017.

DISCUSSIONE

Come precedentemente descritto, il caffè rappresenta la seconda merce di scambio in mendo [124] con un comsumo pro capite pari a circa 4,5kg all'anno con picchi di 6, 8 o 12kg in Stati come l'Italia, la Svezia e la Finlandia.[125] Questo grande consumo di caffè produce una grande quantità di rifiuti, incrementando il quantitativo di rifiuti organici generato ogni anno nel mondo. Pertanto, il riutilizzo del caffè diventa un atto di fondamentale importanza nella riduzione della produzione di rifiuti alimentari, in linea con gli obiettivi di sviluppo sostenibile dell'Agenda 2030.[126] In particolare, considerando i fondi di caffè prodotti nelle abitazioni, è possibile agire sul settore domestico, dal momento che esso rappresenta il maggior contribuente nella produzione di rifiuti organici con il 53% del totale.[127] Inoltre, il riutilizzo del caffè esausto, permette di agire sulla sostenibilità ambientale mantenendo sotto controllo l'impatto causato dai rifiuti alimentari.[128] In modo particolare, si può agire sulle emissioni di carbonio, che altrimenti verrebbero prodotte dai rifiutii una volta che essi vengono smaltiti nelle discariche.
L'idea di sviluppare nuovi metodi per rivalorizzare i fondi di caffè è, inoltre, rafforzata dall'appartenenza di questo materiale alla *Categoria II* della gerarchia del cibo,[129] la quale include tutti gli alimenti non commestibili che però possono essere considerati come una risorsa nel settore industriale. Questo rispetta anche uno dei principi dell'economia circolare, il quale suggerisce di considerare i rifiuti non come spazzatura ma come materia prima secondaria.[130]
La natura organica della polvere di caffè esausto e dei leganti utilizzati in questa ricerca, permettono, inoltre, di ricollegarsi al principio della bio-circolarità secondo il quale il concetto di miglioramento e valorizzazione dei rifiuti come risorsa è connesso all'idea del massimo sfruttamento delle materie naturali, sulla base del metodo a cascata.[131]
Infine, l'industria delle costruzioni è il settore che produce il maggior impatto sull'ambiente naturale a causa della costante necessità di materie prime,[132] di conseguenza, agire sul micro livello, utilizzando i fondi di caffè come materia prima secondaria nella produzione di materiali edili, può ridurre la domanda di materie prime provenienti dalla natura.

NOTES

124 J. Rajesh Banu, S. Kavitha, R. Yukesh Kannah, M. Dinesh Kumar, Preethi, A. E. Atabani, & G. Kumar, *Biorefinery of spent coffee grounds waste: Viable pathway towards circular bioeconomy* in "Bioresource Technology", (302 January), 2020.

125 https://www.quickcaffe.com/consumi-caffe-italia-e-mondo/, accessed on 14/04/2020.

126 Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*, 2019.

127 Å. Stenmarck, C. Jensen, T. Quested, G. Moates, M. Buksti, B. Cseh, S. Juul, A. Parry, A. Politano, B. Redlingshofer, S. Scherhaufer, K. Silvennoinen, H. Soethoudt, C. Zübert, & K. Östergren, *Estimates of European food waste levels. Reducing food waste through social innovation* in "Fusions", 2016.

128 Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*, 2019.

129 D. A. Teigiserova, L. Hamelin, & M. Thomsen, *Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy*, in "Science of the Total Environment", 706, 2020.

NOTES

130 https://www.ideegreen.it/economia-circolare-definizione-ed-esempi-95289.html, accessed from 17/02/2020 to 20/04/2020.

131 M. Carus, & L. Dammer, *The Circular Bioeconomy - Concepts, Opportunities, and Limitations* in "Industrial Biotechnology", 14(2), 2018.

132 F. Pomponi, & A. Moncaster, *Circular economy for the built environment: A research framework* in "Journal of Cleaner Production", 143, 2017.

CONCLUSION

***How can food waste be re-used in architecture*?**

When asked, "Can food waste be re-used in architecture?" the answer is clearly "Yes". In fact, literature is full of examples of building materials coming from food waste, such as the potato boards developed by Rowan Minkley and Robert Nicoll,[133] the panels realized with banana fibers [134] or the tiles from waste coconut,[135] however, rarely their provenience has been considered. It is important to underline that to be able to re-use food waste to develop building materials, they must be in fair condition. Furthermore, normally, it is possible to consider only one type of waste per time since the different foods are characterized by different properties. For these reasons, usually, the only waste from the industrial process are taken into account. However, the use of spent coffee as a resource has allowed examining the possibility to utilize a household waste. In fact, introducing in the kitchen specific systems able to help people doing recycling correctly, it is possible to collect spent coffee grounds easily since, after being used, they are already separate from the other types of food waste. Therefore, the pure spent coffee coming from the homes acquires value and it can be transformed in building materials to employ in the household environment itself.
The type of material developed can change according to the necessity since it is possible to produce tails for flooring or wall systems, panels for wall decoration, furniture boards as well as insulating panels to exploit fully the coffee properties.

NOTES

[133] Natashah Hitti, *Rowan Minkley and Robert Nicoll, Recycle potato peelings into MDF substitute* in "Dezeen" (online version), 2018.

[134] https://www.matrec.com/catalogo-materiali/rfru0960, accessed on 26/05/2020.

[135] https://www.matrec.com/catalogo-materiali/rncocwoo0109, accessed on 26/05/2020.

***How can coffee grounds be converted in building elements*?**

This research has shown how spent coffee can become an interesting material in the waste re-use process, since its excellent insulation and sound absorbing properties make it suitable for use as a building material.
The experiments conducted in this investigation have revealed that spent coffee grounds, when they are mixed with specific binders such as maltodextrin and with the help of proper moulds, can be shaped to produce tiles, boards and panels in different dimensions and with various textures.
It is also demonstrated that, through post-production treatments, it is possible to enforce the surface of the coffee elements with natural coating increasing some of their properties such as strength and water resistance.
The impossibility of performing mechanical tests on the coffee material did not allow verifying mechanical features of the elements. Despite this, the obtained samples showed good results concerning their aesthetic characteristics and their resistance in the long run.
Therefore, starting from these results, it is possible to conduct some more in-depth studies on the coffee material in order to explore its limits and enhance its potentialities to develop increasingly high-performance materials.

CONCLUSIONI

***Come possono essere riutilizzati i rifiuti organici in architettura*?**

Alla domanda: "I rifiuti alimentari possono essere riutilizzati in architettura?", la risposta è chiaramente: "Sì". Infatti, la letteratura è piena di esempi di materiali da costruzione che provengono da rifiuti alimentari, come le lastre di bucce di patate elaborate da Rowan Minkley and Robert Nicoll,[133] i pannelli realizzati in fibra di banana [134] o le piastrelle derivate dai rifiuti di cocco,[135] nonostante ciò, raramente viene considerata la provenienza di questi rifiuti. È importante sottolineare che, per poter riutilizzare i rifiuti alimentari nella produzione di materiali edili, questi devono essere in buone condizioni. Inoltre, normalmente, è possibile considerare solamente un tipo di rifiuto alla volta poichè i diversi alimenti sono caratterizzati da proprietà differenti. Per queste ragioni, di solito, gli unici rifiuti alimentari presi in considerazione sono quelli provenienti dai processi industriali. Tuttavia, il riutilizzo di fondi di caffè, ha permesso di esaminare la possibilità di utilizzare anche i rifiuti domestici. Infatti, introducendo nelle cucine sistemi di riciclaggio in grado di facilitare una corretta raccolta differenziata, è possibile raccogliere facilmente il caffè esausto dal momento che, dopo essere stato usato, esso è già separato dagli altri alimenti. Pertanto, i fondi di caffè provenienti dalle abitazioni acquisiscono valore e possono essere trasformati in materiali per l'architettura da riutilizzare all'interno delle abitazioni stesse.
Il tipo di materiale prodotto può cambiare a seconda delle necessità, è infatti possibile produrre piastrelle per rivestimenti murari o per pavimentazioni, pannelli decorativi, ante per elementi d'arredo o anche pannelli isolanti, per sfruttare pienamente le proprità del caffè.

NOTES

[133] Natashah Hitti, *Rowan Minkley and Robert Nicoll, Recycle potato peelings into MDF substitute* in "Dezeen" (online version), 2018.

[134] https://www.matrec.com/catalogo-materiali/rfru0960, accessed on 26/05/2020.

[135] https://www.matrec.com/catalogo-materiali/rncocwoo0109, accessed on 26/05/2020.

***Come si possono convertire i fondi di caffè in materiali edili*?**

Questa ricerca ha dimostrato come i fondi di caffè possono diventare un interessante materiale all'interno del processo di riutilizzo dei rifiuti grazie alle loro eccellenti proprietà isolanti e fonoassorbenti che li rendono adatti ad essere utilizzati come materiale da costruzione.
Gli esperimenti condotti hanno rivelato che il caffè esausto, se combinato con leganti come la maltodestrina, e modellato in appositi stampi, può essere utilizzato nella produzione di piastrelle, pannelli e lastre di diverse dimensioni e con varie texture.
È anche stato dimostrato che, attraverso processi di post-produzione, è possibile rinforzare la superficie di questi elementi con l'utilizzo di prodotti naturali, aumentando alcune delle loro proprietà come ad esempio la resistenza all'acqua.
L'impossibilità di svolgere prove meccaniche sul materiale a base di caffè non ha permesso di verificarne le reali caratteristiche fisiche e meccaniche. Tuttavia, i provini ottenuti mostrano risultati promettenti per quanto riguarda le caratteristiche estetiche e la resistenza del materiale nel tempo. Pertanto, partendo da questi risultati, in futuro sarà possibile condurre studi più approfonditi sul materiale a base di caffè per poterne esplorare i limiti e valorizzarne le potenzialità al fine di sviluppare materiali sempre più performanti.

APPENDICES

> *"We all know that we generate waste and when we stop to think about it, we feel that something could and ought to be done to reduce and recycle what we discard. However, very few of us actually know what heppens to our waste now, let alone what could be done to reduce its environmental impact."*[136]
>
> *Richard Waite, 2013*

NOTES

136 R. Waite, *Household waste recycling*, Routledge, 2019, p. 1.

APPENDIX A

Survey fac-simile

HOUSEHOLD WASTE RECYCLING

PART 1 - DEMOGRAPHICAL DATA

1) Please select your agegroup

- 18 - 25
- 26 - 35
- 36 - 45
- 46 - 55
- 56 - 65
- 66+

2) Where do you live at the moment?
(drop-down list with countries)

3) How many people live in your house including you?
(drop-down list with numbers from 1 to 20)

4) How many children live in the household?
(drop-down list with numbers from 0 to 10)

5) What kind of house do you live in?

- Own apartment in a condominium (bostadsrätt)
- Rental apartment
- Raw house / Terraced house
- Villa
- Other...

PART 2 - QUESTIONS ABOUT RECYCLING

6) How much important is recycling for you?

Not important at all	1	2	3	4	5	Very important

7) How often do you separate the household waste?

- I always separate different types of waste (paper, pla stic, glass, food waste, etc.)
- Sometimes I forget to separate the waste and I throw everything into the general trash bin
- I never separate the waste, I throw everything in the general trash bin

8) Do you think it is easy separate waste?

- Yes, it easy to identify which recycling category each (waste) item belongs to
- Sometimes it's confusing which recycling category some (waste) item belongs to
- No, it's not clear wich recycling category the different (waste) items belongs to

9) What's the most challenging thing about recycling?

- Investing the time to separate the materials within one waste item (eg.: packaging of milk - both carton and plastic)
- Understand in which bin to throw the different waste
- Take out the different trash bins every day to the common sorting/recycling station
- It'a a time consuming activity (eg.: separate in hou sehold and than time to take out to recycling station separating each trash bin in the correct container)
- Remember when and which bin to bring out (in case of a door to door collection)
- Find enough space in the flat where to put the diffe rent recycle bins
- Other ....

10) How often do you take out the trash? *(for each kind of waste there will be different options like: every day, every 2 or 3 days, once a week, every 2 weeks, other)*

- Food waste ....
- Paper ....
- Plastic ....
- Glass ....
- Metals ....
- Generic waste ....
- Other ....

11) Where do you keep your trash bins? *(for each kind of waste there will be different options like: under the sink, close to the cooking place, on the balcony, in a separate storage room, in the garage, in the hall, in the garden, other)*

- Food waste ....
- Paper ....
- Plastic ....
- Glass ....
- Metals ....
- Generic waste ....
- Other ....

12) Do you feel that you have enough space to separate your household waste?

yes no

13) Where WOULD YOU LIKE to keep your trash bins? *(for each kind of waste there will be different options like: under the sink, close to the cooking place, on the balcony, in a separate storage room, in the garage, in the hall, in the garden, other)*

- Food waste ....
- Paper ....
- Plastic ....
- Glass ....
- Metals ....
- Generic waste ....
- Other ....

14) Do you think it would be easier to separate waste if there was a waste collection system integrated into the kitchen design?

No, nothing would change 1 2 3 4 5 Very easier

15) Would you be willing to separate your old coffee grounds or used coffee capsules in a separate bin, in order to re-use them as a base for new materials?

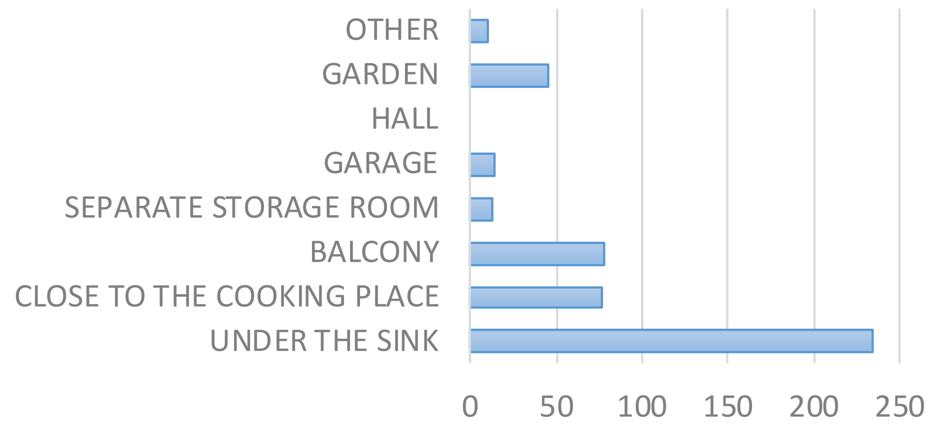
yes no

16) Where do you usually buy coffee?

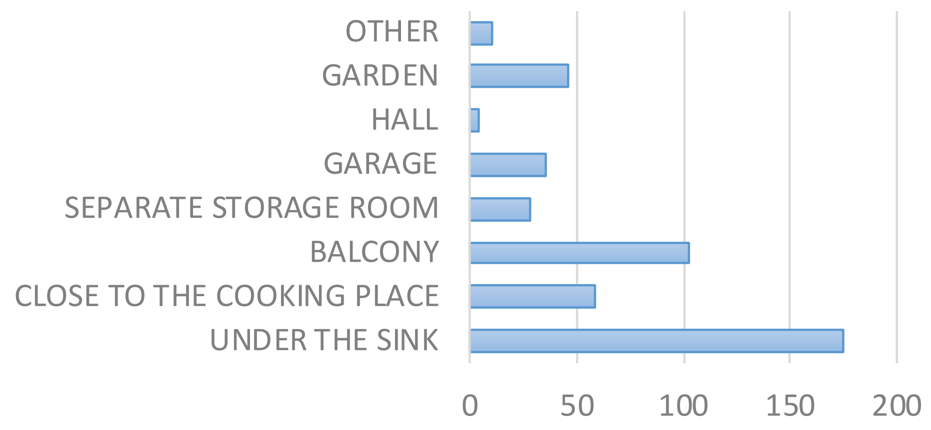
- Supermarket
- Small grocery shop
- Specific coffee shop (ex. Nespresso shop)
- Order online
- From door to door sellers
- I don't drink coffee at all
- Other ....

APPENDIX B

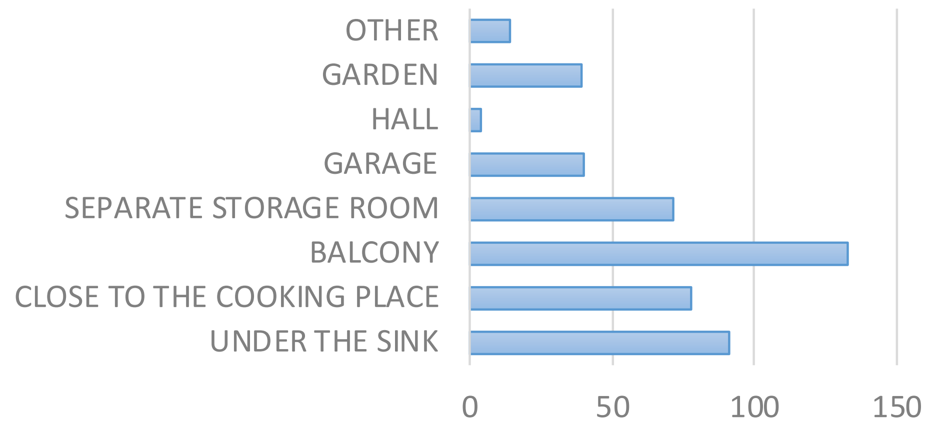
Food waste



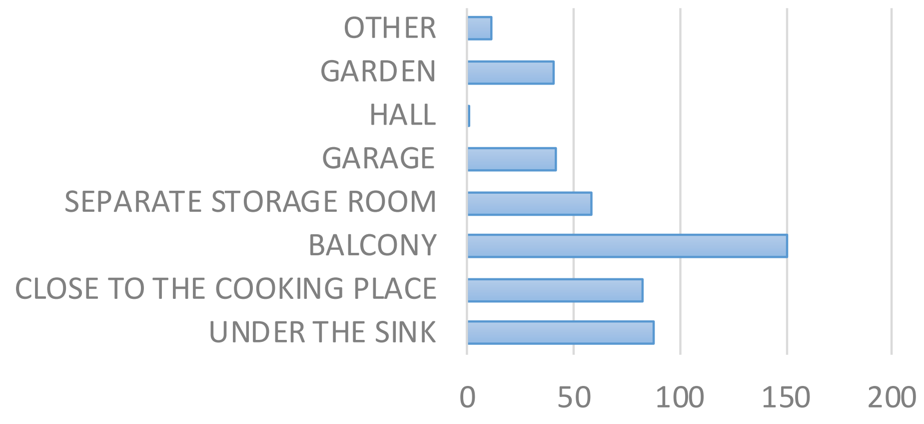
Generic waste



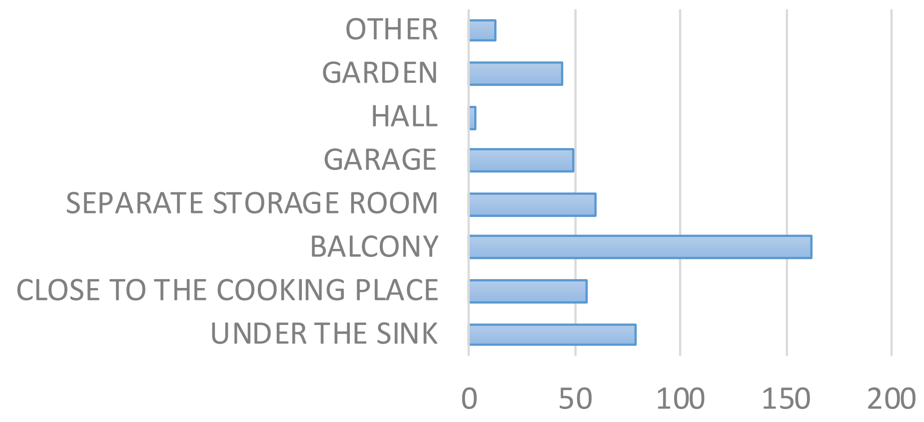
Paper



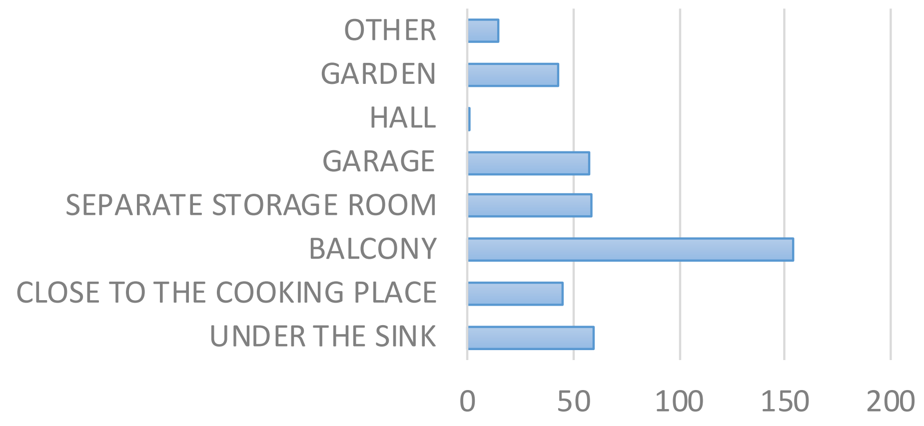
Plastic



Glass



Metals



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"A new relationship with our goods and materials would save resources and energy and create local jobs"[137]

Walter R. Stahel, 23 March 2016

NOTES

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