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DE SIGN CULT URE(OF) MAKING

PROCESS
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TRACK CHAIRS

DESIGN CULTURE (OF) MAKING
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University of Campania "Luigi Vanvitelli", Italy
"Design culture and "project making" intercept unexpressed needs satisfiable through flexible and adaptive processes in order to configure and create customizable and evolving artefacts."

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"This track aims to explore how digital technologies such as Additive Manufacturing (3D Printing) offers designers with benefits, and why we should continue to preserve our understanding of craft making and working with materials."

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DESIGN CULTURE(S) | CUMULUS ROMA 2021
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Progetto Glume: from milling waste to resource for new materials.

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Abstract | The article discusses the results of experimental research concerning the enhancement of waste from wheat milling. It focuses on the analysis of Mulino Marino's production system, a leader cereals' milling company in the Cuneo province (Italy). The analysis of material flows identifies wheat husks and organic sand (about 30% of total wheat grains in weight) as processing residues not classified as by-products that must be discarded as waste, following current regulations. Chemical-physical characterization certifies that they present qualities that are not optimized in their current end-of-life management. Looking at the main purposes of the circular bio-economy and the SDG12, the study focuses on defining a craft protocol for testing potential uses of company's organic waste through a set of basic experimental tests to investigate performances of wheat husks as a biopolymer, similar to thermoplastics, and as a compound for a bio-based material to replace to disposable plastics (e.g. for packaging).

KEYWORDS | ORGANIC WASTE, BIO-BASED MATERIALS, MICROBIAL PROCESSING, CRAFT-MAKING, CRADLE-TO-CRADLE

1. Introduction

Nowadays, one of the most important global challenges is to undertake tangible actions toward zero-waste production processes. The SDG 12 promotes resources and energy efficiency to ensure a better quality of life and to avoid the increasing degradation of the natural environment. The improvement of natural resources management is necessary to face the trend of increasing global population that could reach 9,7 billion people in 2050 (Department of Social and Economic Affairs, 2015). K.E. Boulding (1966) suggested that humans should move towards a “spaceman economy”, considering the Earth as a single spaceship, with strict limits for extraction and pollution. An effective proposal is to move from a linear approach to the production system towards a circular or systemic one (Bonaccorso et al., 2019), increasing waste recovery and creating industrial symbiosis between complementary supply chains (Ellen McArthur Foundation, 2015).

Agriculture and food production systems present a lot of environmental issues, in terms of land use changing, soil degradation and resource depletion. It also presents critical issues in waste management like all mining processes that exploit ecosystems (Thackara, 2015). The cereals supply chain is an essential part of the food system because it is the basic diet of millions of people. In Italy, wheat cultivation is the core for the production of many basic foodstuffs. It occupies almost 1.8 million ha (Faostat, 2017) and it represents an important productive sector for the Italian economy. The Italian milling industry has more than 350 companies spread over the territory and it produces almost 7,8 million tonnes per year of wheat flour (Italmopa, 2017). On the other side, the milling industry produces also almost 3,3 million tonnes of residues not for human consumption. A part of them are used as feed in the livestock industry, but a huge amount of residues are treated as waste. In some cases, these residues present chemical-physical and mechanical properties useful for the development of bio-based materials (Genovesi & Pellizzari, 2017).

This article investigates the opportunity to enhance the milling process's residues from waste to resource for the production of new bio-based materials. The research is based on a collaboration with a company in Piedmont Region, the two residues are tested to evaluate possible applications in the design practice. The article discusses the strengths and constraints of materials obtained in terms of environmental, economic and social aspects. It also promotes the change of *mind of making* towards a systemic approach.

2. Design considering products’ origin and end of life

Considering that the most environmental issues should be addressed to decisions making during the design stage (Thackara, 2005), the design culture of making products, processes and services plays an important role in promoting sustainability. Systemic Design (Bistagnino, 2011; Peruccio, 2017) proposes to adopt a systems thinking-based approach to design practice in order to reduce the ecological footprint of production processes. The systemic approach considers products' end of life during design stages and it is inspired by nature's design principles that don't support the concept of waste (Pauli, 2015). Following the principle that “the output of a process is the resource of another one”, the concept of waste should be reconsidered. Residues obtained as results of manufacturing processes can be classified as by-products only if they respond to all requirements shown in Figure 1 (MATTM, 2017). Otherwise, they should be treated as waste. This standard is both an opportunity and a limit for alternative applications of manufacturing residues.

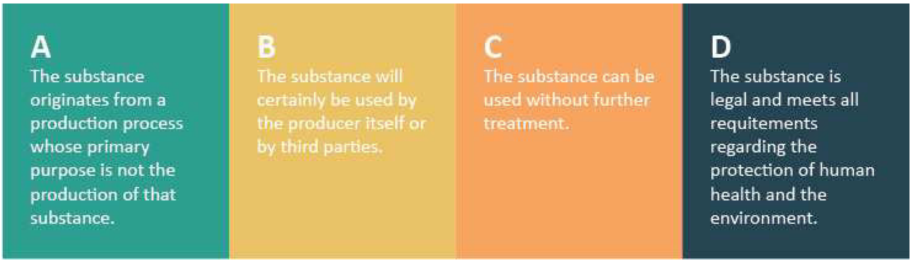

Figure 1. Conditions for classifying a residual substance as a by-product.

The opportunity to use them as by-products is essential to undertake tangible action towards circular supply chains. Materials and resources become strategically important in the design of production and consumption systems. Especially, the improvement of bio-based materials, composed of plant or bacterial resources, could produce a considerable effect on preventing environmental depletion. Bio-based materials are obtained by processes and technologies that allow their use in new fields of application (Genovesi & Pellizzari, 2017). Supply chains should respond to three main requirements to implement the circular approach:

1. improve the reuse of manufacturing residues looking at the “zero-waste” production;
2. promote the industrial symbiosis approach between manufacturing processes;
3. reinforce local supply chains.

The agri-food sector produces a huge amount of by-products and residues that could be used to create new valuable production processes and products (Bistagnino, 2011). Considering cereal processing inside mills, the most of residues are obtained during cleaning (mixture of dust, chaff, weed, seeds, broken and unprocessable grains) and milling processes (bran and wheat germ). The mixture of residues is not considered as by-product due to the complexity of characterization. While, bran, with high content of fibers and proteins, and wheat germ, rich in vitamins, proteins and oils, are classified as by-products suitable for human consumption and pharmaceutical usage (Grundas, 2003). Recent studies are evaluating the opportunity to use these by-products for other applications (Kwiatkowski, 2006; Galanakis, 2018; Dietrich et al., 2018). These studies highlight by-products' properties increasing also their economic value. Significant examples can be found also in the field of products, packaging and bio-based materials, but they could present some critical aspects linked to the land-use for cultivating plants for non-food purposes. The attention should be focused on highlighting the value of agri-food waste to overtake these environmental issues.

3. Progetto Glume: from waste to resource

Progetto Glume evaluates the opportunity to test new applications of organic residues for foodservice items and food packaging that present the urgency to replace plastics from fossil resources. The concept of “Glume” refers to the leaves of graminaceous plants that protect the caryopsis until it reaches maturity and they are separated from plants and collected during the cropping and cleaning process. The study was carried out in collaboration with the “Mulino Marino”, that since 1956 is a leading milling company located in Cuneo province (Piedmont Region, Italy). The province of Cuneo is mainly characterized by agriculture and farming economy of small and medium enterprises and in 2017 cereal cultivation reached 26% of the total agricultural area under cultivation. Annually, the company produces almost 420 tons of flours and it excels in the Italian scenario for the attention to environmental sustainability and process innovation.

In the first part of the study, the Systemic Design approach, in particular the Holistic Diagnosis (Battistoni et al., 2020), was applied to analyse the company’s materials flows (raw cereal grains, by-products, final products and waste) and to identify the main critical issues linked to organic waste. While the second part focuses on lab tests to evaluate the potentials of organic residues to create alternative food service items and food packaging, following a conceptual map of testing (Figure 2).

3.1 Material flow analysis

After the grain acceptance at the mill, it undergoes some pre-cleaning processes in order to separate the non-milling parts. Foreign matter, such as weeds, straw, stones and metallic foreign elements, are collected by compressed air machinery and sieves. *Organic sand*, composed of dust, non-regular grains and vetches, is obtained as the output of other consecutive cleaning processes that are carried out on grains. Before milling, cereal grains must be brushed and filtered by a vertical peeler, following the ATEX Directive (Atmosphere Explosive, ATEX 2014/34/UE) in order to reduce the risk of explosive dusts and ashes in the milling plant. This step is compulsory to maintain high standard levels of safety inside the plant that works at high concentration of dusts and using electrical machinery which could cause the trigger. *Wheat husk* [*WH*] is obtained as residue at the end of the peeling process and it cannot be classified as a by-product following current regulations (MATTM, 2017). Unsuitable grains for milling are separated by an optical sorting machine, while the suitable

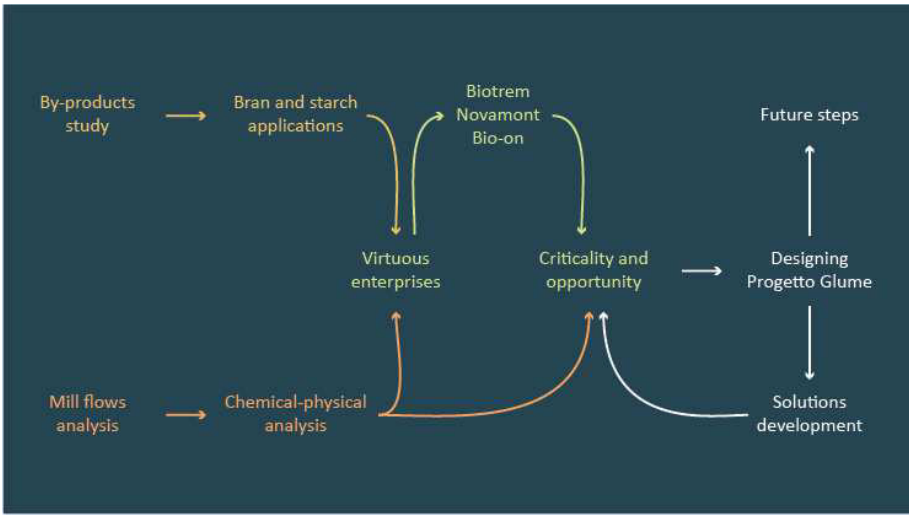

Figure 2. Design path.

part is conditioned and prepared for cylinder or stone milling. Flour, as the core product, and bran, as a by-product, are obtained at the end of the process. In 2018 the Mulino Marino has processed about 680 tons of grain obtaining 420 tons of flour. About 30% of raw cereal grain is lost as processing residues (Figure 3). Wheat flour and the first selection of bran is sold in HDPE package for human food consumption, while the other part of bran are sold as feed for the livestock industry (about 0,30 Euro/kg). On the other hand, o*rganic sand* and *WH* are not classified as by-products and they must be managed as organic waste, defining a critical issue for the mill. Considering the high quality of raw cereal grain processed by the mill, these residues could present properties that should be enhanced.

3.2 Qualitative analysis of organic residues

The characterization of these residues is the second step to evaluate the opportunity to reuse them for alternative uses. After processes wheat bran is stored following food management standards, minimizing risks of product contamination and alteration, while *WH* are collected in 25 kg bags and kept in an uncontrolled environment. Chemical analyses are carried out to assess their chemical composition, toxicological values, starches and protein values (data are available on request). Results assert that *WH* do not present any harmful toxicological value and they content noticeable values of proteins and fiber and about 20% of starch. The starch content is particularly important for the production of bioplastics as it is responsible for the phenomenon of gelatinisation (Lubis et al., 2018). However, the amount of starch should be increased to allow proper *WH* processing as a bio-based polymer, increasing cohesive property.

Figure 3. The analysis of raw cereal grain and output flows. Processes that generate residues: Roughing (a), Cleaning (b), Milling (c).

3.3.1 Vegetable polymer

This experiment is based on previous studies carried out by Jiang et al. (2016) and by the designer Pontus Törnqvist (The James Dyson Award, 2018). Looking at the Circular Economy and sustainability purposes, the starch used for tests, for increasing cohesive properties, is extracted exclusively from potato peels. The first step consists of the assessment of the percentages of amylose and amylopectin present in matrices of wheat and potato starch. Both of them present a range of 21-25% of amylose and 75-79% of amylopectin (Thakur et al., 2019).

The process to obtain the proper composition of the basic mixture is reached by gradually adding *WH* to a pure starch-based mixture for bio-polymer. This step is essential to assess if the addition of *WH*, as fiber, can cause adversities. Water is the solvent essential to dissolve starch crystals and moisturize *WH* fibers. The vinegar and lemon solution acts as an acid and it helps the ionization process in order to make the compound homogeneous. Glycerine gives more flexibility to the compound being a natural plasticizer. After gelatinisation, the samples are flexible and viscous, suitable for processing.

These proportions were indicated as Base Formula [*BF*], on which the following tests have been carried out to reach a Vegetable Polymer [*VP*] (Figure 4).

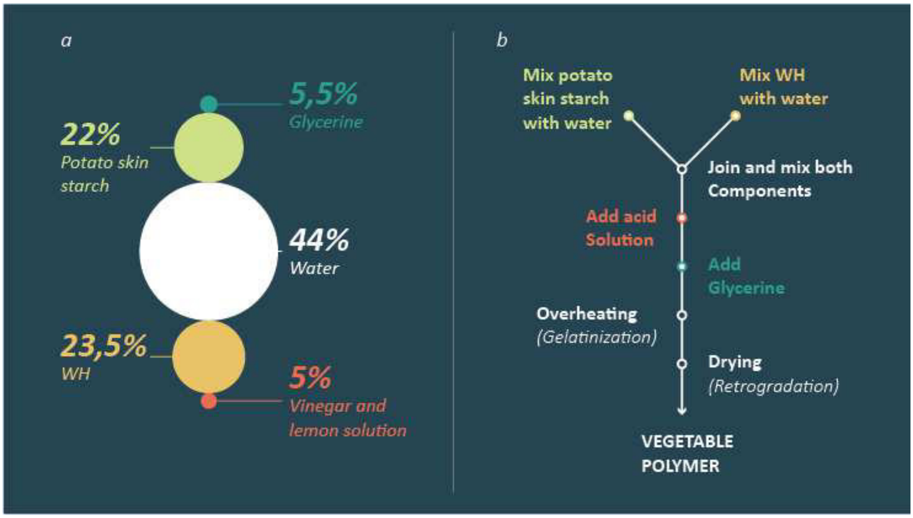

Figure 4. Optimal proportions with maximum use of WH for the basic mixture composed by WH, starch from potato skin, water, glycerine and acid solution of vinegar and lemon (a). Making processes of the Base Formula (b).

3.3.2 Manufacturing process

The BF is used to process the VP samples at room temperature, while the starch gelatinisation is done directly on the overheating phase. Preliminary tests are carried out to assess the performances of VP samples using wooden moulds under different compression times and at different drying conditions. Results of these tests are considered to improve the moulding process and the drying step.

First of all, VP samples are coated with waterproof and non-stick paper to allow a homogeneous gelatinisation process during overheating. This procedure limits the risk of dehydration of the samples surfaces exposed to contact with hot air. Furthermore, the coating avoids the adhesion of the sample surfaces to the mould surfaces during the moulding phase. The moulding process of VP sample is carried out by 3D printed moulds and counter moulds (Figure 5). Digital modelling and 3D print file generation are performed by Blender and Cura software, while printed moulds are obtained using the Anet A8 printer and Sunlu filament (PLA). Moulds shapes have sharp edges and inclined surfaces to improve the mechanical properties of VP samples.

Variables taken into account during tests concern the time of exposure to heat, the temperature reached on overheating and the drying temperatures. Drying conditions are decisive for limiting and controlling the retrogradation process of the material. *VP* samples are tested under different processing and drying conditions (Table 1).

Figure 5. Set of PLA moulds used to give shape to the vegetable polymer.

	T1(DC)	T2(DC)	T3(DC)	T4(DC)	T5(DC)	T6(DC)
Overheating						
Temperature	187°C	248°C	>250°C	175°C	235	>250°C
Timing	3’	5’	7’	3’	5’	7’
Weight						
Inbound	19 gr	19 gr	19 gr	19 gr	19 gr	19 gr
Outgoing	10,2 gr	9,7 gr	8,8 gr	10,4 gr	9,5 gr	9,2 gr
Drying						
Temperature	25°C	25°C	25°C	7°C	7°C	7°C
Timing	48 h	48 h	48 h	48 h	48 h	48 h

Table 1. Processing conditions test to find the basic formula.

The *BF* used to process the T5(DC) sample is taken as reference for subsequent tests, to assess which mechanical process is the most suitable for *VP* material. Base Formula has been exposed to lamination, compression at high contact temperatures and extrusion.

Simultaneously, experiments on the moulding of tableware were carried out in order to investigate the samples' deformation using different PLA mould and countermould. The texture of their internal surfaces is accentuated in order to fragment the surfaces and reduce tension during the drying phase. Mould's internal surface mesh allows the samples to lose humidity uniformly without temperature changes. Moreover, a dehydrating machine is used in order to limit retrogradation and to better control the drying process (Figure 6). Scraps obtained by pressure mouldings are collected and left to dry without specific constraints. After retrogradation, they are crushed and placed under pressure at high contact temperature (160°C), obtaining the melting of all fractions. This result highlights that *VP* samples present properties similar to thermoplastics. Furthermore, the hydration of the fragments improves the (re)gelatinisation process.

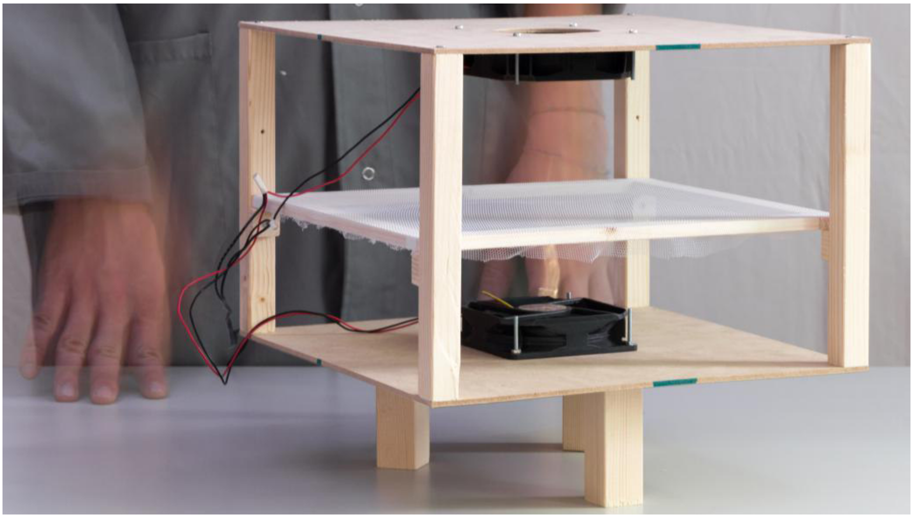

Figure 6. Self-built dehydration machine.

3.4.1 Microbial cellulose

According to From Peel to Peel project (FPTP) (Sicher, n.d.), the interaction between food-waste and microorganism can generate potential new materials. "*SCOBY*", the acronym for the Symbiotic Colony of Bacteria and Yeasts, is usually used to produce fermented foods, such as vinegar or Kombucha. This bacterial culture presents distinctive chemical-physical properties to be used as a starter to grow microbial cellulose through sugars fermentation: an extracellular polysaccharide produced by some bacterial strains such as Acetobacter, Agrobacterium, Gluconacetobacter (Rangaswamy et al., 2015). It represents an alternative to vegetable cellulose and it is already applied in medical and food sectors. Environmental conditions of microbial cellulose growth are essential to define the final result. Parameters such as carbon source, nitrogen source, temperature, pH and type of sugars influence the generation process. The key qualities that lead to testing the *WH* potential through microbiological transformation are:

- Specific surface area;
- high water retention;
- excellent mouldability;
- tensile strength.

Tests are carried out to validate whether wheat husk could feed this bacterial culture, since *WH* is composed of starches. Moreover, *WH* contains residues of graminaceous plants and its values are similar to straw, already used in unconventional fermentation to produce bacterial nano cellulose (Corujo et al., 2016).

3.4.2 Manufacturing process

According to FPTP experiments and the results obtained by the Production of Microbial Cellulose by Tea Fungus (Shehata et al., 2007), the *WH* experiment was set up using the *SCOBY* from Fermantaholics.com and 3 tempered-glass tanks for culture growing. The percentages of elements for bacterial culture growing are calculated starting from 1 l of water (Table 2). *SCOBY* is placed into emulsion after mixing all elements. Tanks are covered with fabric to allow the respiration process and to avoid dust contamination. The temperature is set between 22-25°C.

After 3 weeks, the layers of bacterial cellulose are extracted from the emulsions. Results of the tests showed that tank 3, containing *WH* as a nutrient for bacterial culture, is the best in terms of microbial cellulose growth. The Microcial Cellulose [*MC*] layer is grown over the entire area of the emulsion and it reaches the maximum of 1.8 cm of thickness. The layer is left to dehydrate upon a grid frame to promote ventilation. Once dehydrated, mechanical tests are carried out on the *MC* to evaluate its properties. The *MC* layer is rehydrated and stretched between two transpiring surfaces in order to obtain a thin film. Both two layer's sides are clamped to prevent deformation during the second drying phase. Fans are used to maintain ventilation and to avoid mould contamination. After this step, the *MC* is pulled out from frames and it looks like a thin and tough film.

	T4(DC)	T5(DC)	T6(DC)
Wheat husk	-		5%

Water	1	1	1
Vinegar	10%	10%	10%
Sugar	5%	5%	5%
Green tea	5%	5%	-

Table 2. Percentage of the elements for bacterial culture medium.

Before dehydration, the *MC* shows excellent tensile strength and high malleability. These characteristics suggest to test it as a bio-based material for packaging. A moulding test is performed to transform the film into flour packaging. The test foresees three steps of transformation: three-dimensional forming of the film and sealing of the flaps; folding and closing of one end; fill the pack with flour and close it by sealing. Firstly, the sample is slightly hydrated and wrapped on mould; two edges are joined, folded and pressed to be welded by compression. Secondly, the bottom of the sample is made by folding and compression of the lower end. Finally, after pouring the flour, the upper ends of the sample are sealed by moisturizing the surfaces that are bent and compressed. The result is a prototype pack (Figure 7).

Figure 7. Detail of the sample manufactured by artisanal process.

Scraps of *MC* layer are hydrated to reduce their stiffness due to natural moisture loss and to make them highly malleable. Two moulds (hemisphere and truncated cone) are used as a three-dimensional shape on which the *MC* residues are manually laid and compressed. The presence of water makes the residues adhere to the moulds and single fragments blend together without being more recognizable. The detachment from the moulds does not present problems of adhesion between their surfaces and *MC* samples easily take the same shape of moulds.

4. Discussions: critical issues and positive aspects

Main issues are related to material deformations during the drying processes: water loss leads to results that are difficult to control. In the case of *VP*, samples shrink by about 1 cm and the thickness decreases from 2 to 1 mm once dried. The same phenomenon is observed for the *MC* which drastically reduces the thickness from 1.4 cm to 0.007 cm. The *VP* samples with less post-drying deformation are those processed with compression at high contact temperatures (160°C): however, this process requires high energy consumption. The drying process has a significant effect on the mechanical properties of samples. Therefore, it is necessary to perform tests in a controlled environment monitoring the below parameters:

- Air circulation;
- Temperature and pressure changes;
- Influence of external light (especially for *MC* processing).

The VP experiment shows that the temperature between 60° and 70°C is the optimal condition to promote a low viscosity fluid state. Once the 90°C threshold has been exceeded, starch processing is not possible, compromising the final result.

MC tests present the processing timing as the main critical issue, especially compared to other industrial materials. 3 weeks are necessary to obtain an area of 0.28 m² with a thickness ranging from 0.8 to 1.8 cm. Another negative issue concerns the control of acetic fermentation during MC formation: only a part of the film is cohesive and compact. Temperature changes can generate spontaneous contamination by other bacteria strains that compromise the uniformity of the surface layer. The well-formed portion of MC is generated close to the bacterial culture starter (SCOBY). Therefore, the amount and placement of SCOBY used as a starter affect the final result. Nevertheless, positive aspects are related to the possibility of generating bio-based material using a low amount of energy and without fossil-fuel components. Materials obtained don’t present any physical or chemical constraints to deny their reintroduction into different production chains, nor do they contain elements harmful to the composting phases.

Positive aspects of VP processing concerns the preparation of the mixture before gelatinisation that can be carried out at room temperature (20°-25°C). VP samples reach a volumetric detail of 1 mm thanks to compression processing, while the most performing manufacturing processes are lamination (minimum thickness reached 0.5 mm) and compression at high contact temperatures, because the sample gelatinizes and takes shape simultaneously. VP can be compared with thermoplastics because VP scraps can be easily re-processed.

Microbiological processes to obtain the MC don’t require energy: the cellulose layer naturally grows on the whole surface in contact with oxygen. This process presents innovative aspects that look at the hybrid frontier of biodesign. Biodesign approach incorporates living organisms (bacteria and yeasts) into design processes as essential components (Myers, 2018). This property allows designing custom two-dimensional configurations, eliminating the production of waste from any shaping or cutting. The culture of bacteria and yeasts regenerates itself by "new" fermentation. Unlike traditional material processing, it has the ability to generate new microbial cellulose as a starter for subsequent production. MC generates two residues: solid and liquid. The solid part is composed of fermented WH that can be gelatinized following the VP procedures. While properties of the liquid fraction have not yet been characterized. These two residues are biological matrices that should be optimized.

5. Conclusion

The goal of Progetto Glume is to explore new strategies to optimize and validate the transformation of milling waste into by-products and bio-based materials through the application of an experimental approach. The study highlights many positive aspects and some constraints that should be considered as challenges for future steps. Critical issues should be taken into consideration as an opportunity for the development of *WH*’s validation tests and to define possible future scenarios. Future challenges can be organized into two main areas: the first one focuses on translating the handcraft approach to industrial one considering *VP*’s and *MC*’s mechanical performances, while the second one designing the system of local supplier (mill companies) and product processors. The research project promotes sustainable development strategies that acts locally. Indeed, future challenges include the involvement of small and medium-sized enterprises in cereals transformation sector that are able to exploit their residues reducing the environmental footprint, the exploitation of natural resources and economic costs for waste management. Project improvement should focus on design engineering, on testing *VP*’s and *MC*’s sustainability, compostability and their compliance with current regulations. The handcrafted approach adopted in the experimental research highlights that both proposals present a high potential for improvement and application in an industrial way. The abundance of locally ground cereal and the low energy requirements for waste transformation processes are the key aspects of the project. For effective development, Progetto Glume needs to create a multidisciplinary research team composed of professional figures from different fields such as biotechnology, engineering mechanics and materials science. Mill industries, feed mills and malting plants are playing a key role in the project because they provide waste/resources for the project development. Progetto Glume is inspired by many people working in the cereal sector, agriculture and design with the aim to involve and connect people of different work and research fields. This study suggests a joint-venture of design manufacturing for sustainable and strategic development in relation to the territory and its resources.

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