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Material tinkering for design education on waste upcycling

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Abstract
Materials are primary elements in the process of design and are gaining more and more attention in design education. The present work illustrates the practice of material tinkering, concentrating on its effects on design education, as regards the upcycling of waste into material demonstrators, deemed to assess their possibility to evolve into sustainable artefacts. After a general illustration of the scope and objectives of material tinkering, the exposition describes the recent experiences of this practice into design schools, highlighting its pedagogical significance worldwide, and in the particular case of the Italian situation. Finally, the exposition concentrates on the specific case of work carried out in two prestigious Italian Universities (Università di Camerino and Politecnico di Milano) from 2015. The paper tries to clarify its position and significance concerning previous literature, for what appears relevant to the education of designers and for their formation in the local context to be applicable worldwide. The research method evolves from trial-and-error, typical of experimentation on materials, to the conception of material demonstrators and suitability to be applied into products, having as boundaries the choice to use some kinds of waste in an upcycling philosophy.

Keywords
DIY-Materials, Materials from waste, tinkering, materials education, teaching the experimental method

Introduction
Materials are crucial elements in the design process. As a consequence of this fact, materials education is becoming more and more significant in the field of Design, because it assists future designers in becoming more sensitive towards the expressive and functional qualities of the material. Traditionally, learning about materials has been an intellectual and book-based activity. And it is still the case in most of the Design schools worldwide, and also in Italy. On the other side, though, the recent diffusion of different approaches toward materials and the rise of specific educational and experimental tools, such as materials libraries, followed then by Fab Labs, would add tangible and practical opportunities to enhance materials knowledge in the field of Design. In more general terms, designers need continuous education about materials, because new ones are developed every day, and also since we are rapidly evolving from industrialized materials towards customized ones. This change of perspective also involves self-production of new materials in a laboratory or workshop context, due to the effect of stringent necessities, such as re-integration of waste into the production process. This process is also virtuous in the way towards educating for sustainability and suggesting ways in which products and services are matching all essential criteria of the circular model (Andrews, 2015). Materials knowledge implies internalization of facts, information, and skills, the combination of which

would be able to produce designs using material possibilities to achieve the desired user experiences (Haug, 2019).

Concerning design education, for some years, there have been studies, research and projects aimed at teaching materials to design students with an approach as close as possible to their way of thinking and designing. The concept of 'designerly ways of knowing' has been coined by Nigel Cross (Cross, 1982) as the result of reflections, which started to emerge in the late 1970s in association with the development of new approaches in design education. It is possibly expressed by saying that 'designerly ways of knowing materials' are now required and start to become available. It was introduced by research on the expressive-sensorial dimension of materials (Rognoli & Levi, 2005; Rognoli, 2010), to other works focused on materials meaning (Karana, Hekkert & Kandachar 2009: 2010). The concepts of Materials Experience (Karana, Pedgley & Rognoli, 2014; Karana, Pedgley & Rognoli, 2015) and Materials Driven Design (Karana, et al., 2015) were then proposed to give a theoretical structure to these approaches and create useful tools that could guide young designers step by step in the project with and for materials.

In parallel, various materials libraries have been developed, each characterized by different peculiarities of service and or collected materials and offering valuable support for multidisciplinary work (Dhen, 2013; Akin & Pedgley, 2015). However, they still appear very project-specific and not always suitable to enable corrections for unpredicted issues arising during the design process (Wilkes et al., 2018).

In recent years, we have witnessed the wide spreading of the maker culture and the Fab Lab[1] and that has allowed, in a fully democratic way, direct activity on artefacts and materials, above all in the field of design education (Blikstein, 2018). As consideration for the development of the concept of DIY-Materials introduced by Rognoli, Bianchini, Maffei and Karana (2015), the maker culture has spread both the idea of being able to get their hands-on materials and the place, the skills, and the tools to do it. DIY-Materials were defined as

> *"materials created through individual or collective self-production experiences, often by techniques and processes of the designer's invention, as a result of a process of tinkering with materials. They can be new materials with the creative use of other substances as material ingredients, or they can be modified, or further developed versions of existing materials"* (Rognoli et al., 2015).

The DIY-Materials are, therefore, materials designed and self-produced as material demonstrators by the designer her/himself. Often, they use rudimentary technologies obtained, through the experimentation process, with little investments and alternative raw materials, usually own waste from other production processes or materials and components at the end of their life cycle. Having recognized this emerging phenomenon in the context of international design and having studied it (Ayala-Garcia, 2019), it has undoubtedly helped its formalization as an approach and accordingly, its inclusion in the training paths of designers.

[1] There are almost 1600 Fab Labs around the world. More updated information at https://www.fablabconnect.com/1600-fab-labs-worldwide/

To make the two ends meet, namely materials education and maker culture, is not obvious. Though, therefore it is suggested that a preliminary “hands-on” familiarity on the material, to assist the transformation of material didactics into participatory activities, which have a natural development into experimental materials labs and would be finally aimed to inspire the design process. The experimental process with materials was referred to as “material tinkering” (Parisi, Rognoli, & Sonneveld. 2017) Material tinkering is linked to the Experiential Learning concept, which involves the creative exploration of the connections between experience, learning, and personal development (Kolb, Boyatzis & Mainemelis, 2000). Going more into depth, this implies developing a learning method for enabling the students to acquire new knowledge through the direct experience with phenomena observed: this can be applied to the development of materials.

In particular, it is widely recognized that designers need to be educated not only in the use and function but also in the relevant technical, expressive and sensorial possibilities and potentialities of materials. Acquiring this knowledge implies a continuous dialogue and feedback between materials scientists and designers, which means that the latter would intervene into the creation of the material, but also that reciprocal exchange of suggestions would take place over time (Wilkes et al., 2016). This process can be achieved using several approaches: a general perception, recognized from the times of Bauhaus experience, is that a theoretical and book-based material education is not sufficient to provide instruments for the use of materials in design (Rognoli & Levi 2004). In contrast, the designer needs the first-hand experience of materials to apply them in a meaningful way to the design project. In other words, the theoretical study of materials science does not usually include any participatory activity (e.g., tactile experiences on materials). It can be deemed to be sufficient for well-known industrial materials, such as conventional oil-based plastics. Here, the interaction of the senses with the material is definitely limited, when not weak, being confined to sight and possibly taste, in both cases with the use of uniform colours and surface finish, and very simple and repetitive textures. The return of interest for materials, such as wood and natural textiles, which is linked to obtaining a more sustainable end-of-life scenario for products, has brought back, in turn, the possibility of a broader and more productive interaction with materials, to be translated in a “materials experience” (Karana, Pedgley, & Rognoli, 2014). The consequence is that materials selection takes place first based on their expressive and sensorial qualities. Still, on the other side, when a material has only started to be developed, it may be not obvious to evaluate what these qualities would be when having only preliminary materials samples.

The research trends mentioned above have influenced the previously described tools for material research in design. The Fablabs or incubators[2], for example, which are gradually being transformed into places where not only potential materials are developed but also the evolution of suitable models, geometries and bio-inspired solutions are considered. It has the advantage of discussing the relation between the material, and the geometry obtained, also in terms of complexity, suggesting that in some cases the link between the two can be powerful and direct. In contrast, in other situations, the same effect can be obtained almost

2 such as in the example of the Rhein-Waal Hochschule (https://fablab.hochschule-rhein-waal.de/fab-materials-en), the Materials incubator (https://www.materialincubator.com/about) and the FabLab Barcelona (https://fablabbcn.org/)

irrespectively of the material used. The latter is true for example for auxetics, where, provided the material is sufficiently deformable, it can bend in the three directions, when stretched, depending only on the internal cellular structure. New potential geometries can be reached by material-independent experimentation on single aspects, such as, e.g., kirigami cutting (Tang & Yin, 2017).

The concept of material tinkering

Design has been recognized in theory by Donald Alan Schön as a reflective practice, not different from education. The notion of “reflective practitioners” is based on the understanding that our knowing is in action, often in a tacit form, implicated in the way we act. Reflection-in-action may indicate a process through which practitioners encounter an unusual situation and have to take a different course of action from the usual or the initially planned one (Schön, 1983). On the other hand, reflection-on-action may include an analytical process, asking practitioners to reflect on their thinking, actions and feelings in connection to particular events in their professional practice (Schön, 1991). The context that encloses this reflection is that creativity can be learnt to a point provided the right instruments and processes are disposed of for the purpose (Akoury, 2019): this applies of course also to materials development and uses in design.

In particular, in recent years, it has been widely recognized as “learning by doing”, therefore tinkering around problems by “trial and error” until a solution is found, can represent a possible or even irreplaceable approach in several fields, for example in computational education (Koehler & Mishra, 2005). As suggested by Resnick and Rosenbaum (2013) “*The tinkering approach is characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities*.” This applies not only to engineering and design but also to science and engineering education. Therefore, tinkering may be particularly beneficial for multidisciplinary research (Mader & Dertien, 2016). Tinkering has the advantage to cover all kind of intuition and implicit knowledge and also recognizes that new results may embed a seed of randomness.

It can also be expressed in other terms, for example, as a Practice-led Research Process (Nimkurat, 2012). In this way of proceeding, practice is able at the same time to elucidate the research problem, offering then a context for inquiry, allowing gaining new knowledge and finally giving evidence to support research outcomes (Niedderer & Roworth-Stokes, 2007). Reflecting upon material tinkering, this implies understanding what we are looking for in a material, to which sectors of application it appears more suitable, therefore knowing better its “personality” and finally proving the point we made at the start of experimentation. In most cases, though, some modifications will need to be done to the initial assumptions. Therefore, the testing will need to be repeated by changing some parameters (recipes, temperature, time, mould, etc.). It has been recently suggested that this process may gradually lead to a sort of “Darwinian evolution”, leading to the selection of the most suitable materials for the purpose (Rognoli, Pollini, & Santulli, 2017).

The experimental approach has been revealed as an effective means of meta-learning, hence allowing the student to be aware and in control of his/her learning process. As far as design is concerned, this has been linked to the possibility to transfer the student’s expectations, by making them explicit, to the artefact produced (Winters, 2011). This method involves the opportunity to start working without a pre-conceived plan, but rather reasoning about one issue and gathering information about it, subsequently filtered through the student's own experience. This way to proceed has often been defined as "tinkering", and in some contexts, such as, e.g., museums, it has been identified as a practice useful also from the teacher's side, is an effective tool to refine frameworks for learning and facilitation (Gutwill, Hido, & Sindorf, 2015). In the case of materials, tinkering allows naturally experiencing complexity, by making connections or analogues with prior experiences, everyday life, and scientific practices, including the heuristic method of "trial and error".

Experiences dedicated to children proved successful, also for the first introduction of concepts challenging to grasp otherwise, such as sustainability, by the functional and expressive possibility to re-use waste in materials (Santulli & Lucibello, 2018). This can have an interest also beyond educational purposes, leading to a kind of "revived beauty" of the waste materials through design: of course, initial education based on tinkering can help to elucidate their potential (Bramston & Maycroft 2014; Sauerwein, Karana & Rognoli, 2017). It has been applied to several materials, resulting in the end-of-life in waste particularly tricky to recycle, such as fibreglass (Aversa, Rognoli & Langella, 2019).

As a matter of fact, "material tinkering" has been developed as a methodology in some labs around the world, with different substrates, for example with mycelium, which concentrates on growing the material with the idea to produce it in a customized way (Parisi & Rognoli, 2017; Karana, Blauwhoff, Hultnik & Camere, 2018). A definition is proposed, recognizing that "Material Tinkering is a design practice characterized by specific features, procedures, supportive activities, and goals. It aims to extract data, understand material properties, understand constraints, and recognize its potentialities. It helps to gain knowledge about materials and to develop procedural knowledge through experiential learning" (Parisi, Rognoli & Sonneveld 2017). Other experiments have different characteristics, closer to a pedagogical method to enhance the sensitivity and the education of students to the expressive-sensorial attributes of material so to facilitate its application in the design phase. In this case, therefore, the fundamental aspect is experimentation: as a consequence, the error is not perceived negatively, but rather as a possibility for the student to improve problem-solving skills.

More structured definitions of material tinkering have come out over time, which suggest other characteristics of this practice. In particular, this appears to be, as discussed above, a tool for experiential learning on the material through the application of self-production of the so-called DIY-Materials (Rognoli et al., 2015). The obtained materials have been studied to try to elucidate their aesthetics, which appears based on different principles than those of industrial materials (Ayala-Garcia & Rognoli, 2017). More specifically, the latter appear based on homogeneity and uniformity, precision and repeatability, whereas in contrast DIY-Materials. Therefore, material demonstrators originating from these, present imperfections and especially may change aspect overtime, presenting ageing and degradation, not differently from what happens to natural creatures. This has some significant connections to some material culture; for example, the ancient Japanese tradition of Wabi-Sabi exalts the beauty of the imperfect things (Ostuzzi, Salvia & Rognoli 2011). These on the other side result in enhanced expressivity and similarity to natural materials, such as it is the case, e.g., for solid wood in terms both of presence of fibres and contrast of colours, as well as the presence of aromatic scents. On the other side, the presence of flaws and imperfections contributes to the valorisation of materials, since it can be presented as a sign for personalization of DIY-Materials. It allows rebuilding the bond with objects, which does break at the moment when this starts to be perceived as “waste” for the most various reasons, which include, but are not necessarily linked, to their functionality.

In more general terms, the onset of DIY-Materials can be defined as a change of paradigm, therefore a way of thinking, which proceeds from the previous paradigm of fabricated materials, modifying some concepts. Plastics represented materials being light and easily mouldable, with no visible alterations overtime, only slightly photodegradable with prolonged exposure to sunlight. The presentation of polypropylene at its first appearance in the form of home products between the 50s and 60s does reflect this attitude of the material since the advertisements are centred on the lightweight and unbreakable character of the products (Colonetti, Brigi, & Croci, 2014). Conversely, DIY-Materials and the process of self-production would also enable the concept of sustainability entering into the picture. Since the recent indications (EU directive 98/2008 on waste) require that the first option to be explored is whether the production of waste can be avoided, it is essential to know the character of waste to integrate it effectively in new materials. This would also facilitate the production, which needs ideally to take place with the most limited consumption of energy and raw materials, with the objective to create new materials and prospective products of some success. This would contribute, by defining some more proper use, to a possible end-of-waste (EoW) strategy for the waste in an object.

If performed in this way, material tinkering can contribute to the success of the upcycling process, therefore generate more value. The use of materials derived from waste can contribute to the sustainability of product design. More difficulty has been encountered once trying to delineate a concept of aesthetics for these materials, which have been defined as *revived materials* (Sauerwein et al., 2017). It can be solved or explained by reasoning on the imperfection, as a natural characteristic of materials, especially in terms of differentiating them from plastics, seen as the paradigmatic synthetic material, and also to preserve as much as possible the visibility of waste introduced, in terms of fragments, texture or colour nuances. On the other side, there is an undeniable significance in terms of educational content, to be communicated through an appropriate educational route. In particular, using waste obliges one to reflect on the reasons for the success of a product, accordingly on its perception by the customer. Also, self-production implies that the customer and the manufacturer would possibly converge, so that a material can be produced on-demand, according to definite requirements.

The case study considered

The target of the material experience course is design students, who already have some basic knowledge of materials and production processes, in particular of what is required for an effective and compliant moulding of material, even in the absence of industrial systems. The typical duration of the experience for each student or group of students (normally no more than three are involved in the same project) is a course that lasts one semester and starts with some class lectures to start reasoning on the context of DIY-Materials, followed by workshop activities. This inevitably involves some practical home activity for the students, because many attempts and refinements are required during the process of tinkering, and also to the circumstance that often cooking or curing of the material may take some time. The leading idea was that the development of the material demonstrator through the tinkering process would have a didactical value through the learning and practice of the experimental method. A well-known link exists nevertheless between cooking and the experimental approach, in terms of stepwise development and optimization of recipes and procedures (Munari 1992).

In the experience described in the article, the concept of material tinkering is illustrated using the culinary metaphor, because it fits well with the idea of ingredients, recipes and preparation through mixing and cooking. Experimenting with materials is similar to food preparation since a recipe/method is followed and gradually improved, tinkering on it by "trial and error". It is necessary to experiment before finding the right quantities of ingredients, including how the waste is prepared to be introduced into the host "matrix", usually formed from a polysaccharide (e.g. starch) or protein (ad example whey milk). In practical terms, waste does not always turn into dust as it is sometimes convenient to use a reference to the original production system from which the "secondary raw material" derives.

Of course, adopting a "fuzzy" geometry for waste can create limitations to its integration of excess in the structure, to achieve what in engineering terms is indicated as an effective and strong "interface," i.e., with perfect bonding to the hosting matrix. It is recognized though that adapting the whole material to include waste not necessarily powdered to its finest mesh is also a part of the formative path during experimentation, since design can assist in solving this issue. Another purpose of the "trial and error" method is the optimization of the production process, which includes the cooking method, if necessary, the temperature and time for it, and the hardening phase, which led to the possible use of the material after removing excess moisture, thus avoiding the degradation process as much as possible and necessary, with consequent formation of fungi or mold.

Another problem which encompasses the whole method is the selection of a mould and attention to the two main drawbacks of inappropriate moulding. These, in particular, are the incomplete filling of the mould, and the problematic extraction from the mould. In the first case, we have the manufacture of an unfinished piece and, in the second case, the result is a damaged piece.

The result of the application of a tinkering process is not to have a finished product. However, in the literature, there are examples of experimentation experiences that come to the production of personalized DIY-Materials for different purposes (Cecchini, 2017; Ordoñez & Rexfelt, 2017). What we want to underline here is that the hands-on use of waste during projects and workshops can be important for students and design professionals to foresee interdisciplinary collaborations, aimed at promoting the industrial re-development of discarded materials.

However, here the issue is not directly linked to spreading practices for "designing from the bin", but to the creation of a "material demonstrator", which can reveal the possibilities of the individual waste in its introduction into the matrix. For this reason, some possible solutions have been frequently explored, such as aromatization with different herbs, or natural substances (e.g., sage, curcumin, thyme, etc.) or colouring with natural dyes, such as beetroot water or anthocyanin from orange peels. All these strategies are consistent with the idea of designing the perception of the material using the expressive-sensorial dimension (Rognoli, Ayala-Garcia, & Parisi, 2016).

The role of waste upcycling and the development of the projects

The starting point of the entire research considers that to obtain valid material demonstrators is necessary to use the maximum amount of waste. In the experiments conducted in the design courses of the two universities involved in the study, the use of waste from the food sector and therefore readily available and "zero km" has been promoted. It was considered appropriate to highlight two critical aspects of the possible production of materials: the first concerns the use of food waste not suitable for human consumption. The second concerns the matrix in which the waste is introduced, which must be composed with expired products. Therefore, nothing fundamental, necessary and useful is subtracted from other cycles.

In practical terms, two types of matrices were employed in this kind of experimentation, which are respectively based on polysaccharides (e.g., corn or potato starch) or protein (e.g., milk whey) matrix. In this sense, attention was taken to the use of past "best before" date products. Over four years considered (2015-2018), around 200 projects were developed, over 80% of which involved the development of a plasticized starch matrix, while less than 20% used protein-based matrix, and the main difficulty of the latter appeared the "cure" process, therefore their progressive hardening while drying.

Having said that, the only products further necessary to the recipe, which cannot be considered as waste, are the plasticizer, which are a viscous additive, such as glycerol or honey, in the case of polysaccharides matrix, or an acid solution, such as vinegar or lemon, in the case of protein matrix, to contribute to their denaturation, therefore to reduce water absorption. The two matrices used to refer to the so-called plasticized starch (Garcia, Martino & Zaritzky, 2000), often expressed in a simplified way as bioplastics, and to Galalith, a casein-based material, which is currently defined today, as some other coeval material, such as cellulose acetate, as an "early synthetic plastics" (Lokensgard, 2016). In Galalith originally denaturation was achieved using formaldehyde but can also be obtained introducing nontoxic substances, as can be the case for vegetables and seeds that have a substantial amount of protein in them, for example, lupine. As a matter of fact, the so-called "vegetable casein" was of extensive use during the last century (Chang & Chao, 1935).

The students were left free to develop their material demonstrator with the only limitation that a type of waste had to be used and enclosed in a self-produced biopolymer matrix. Following this, some criteria are given for which the waste material can be valorised in an “upcycling” philosophy, as opposed to its technical use in a generic powder form, therefore losing most characteristics that make it recognizable. These criteria can be described as follows:

- The material is not reduced to very fine powder if not necessary and is not encapsulated into a newly produced material (e.g., synthetic polymer resin, such as acrylic or epoxy).

- In the case it has particular characteristics (e.g., birefringence, surface roughness, colour, etc.) these are preserved as much as possible.

- In natural materials, the differences of shape or colour and other characteristics, for example, porosity, can be considered typical and therefore contribute to value.

- Imperfections and defects are not being considered as defects; instead, they have a part in the aesthetics of the material, as emphasized by the microscopy observation.

Results and discussion

The tinkering approach is aimed at obtaining significant experiences in the development of materials, and then at selecting the more promising materials for investigations and further developments. In these circumstances, the use of waste or scraps further complicates the matter, because it could be challenging to communicate the value of a material obtained from the recycling of scraps. Using the classification of DIY-Materials (Ayala-Garcia & Rognoli, 2017), we examine the materials considered waste because they are regarded as resources belonging to five "kingdoms": *vegetabile, animalae, lapideum, recuperavit and mutantis*.

However, in sporadic cases, students have also used sand, which belongs to the realm of the lapideum, and is a widely available waste. Furthermore, the use of sand can modify the moulding of the material. Besides, some have used cotton gauze, as waste from the textile industry, or spruce sawdust, as waste from the wood industry, both of which belong to the kingdom recuperavit, as well as the ash of spent cigarettes.

As a consequence of the above, we have developed a different but complementary classification based on the chemical rather than the biological origin of the various types of waste. In this way, the resources can be divided into cellulosic, wooden, ceramic and various.

In general terms, most of the waste used can be classified as of food origin, however making a further distinction between food waste that is inevitably produced (therefore what is not needed for human consumption, for example, eggshells, walnut shells, mussel valves, etc.) and possible food waste, the production of which cannot be avoided.

In other cases, the cellulose content is higher, and the hardness of the material is reduced. Some of these elements are used, at least partially, in some food preparations, such as in the case of orange peels, which can also be the source of particularly marketable additives (Pfaltzgraff, De Bruyn, Cooper, Budarin, & Clark, 2013).

Other types of food waste can present a particular utility, in the sense of providing a specific aroma or perfume, which can facilitate the acceptance of the DIY-Material, such as the case of banana peel waste, with the addition of anise (Galentsios, Santulli, & Palpacelli, 2018).

All the material demonstrators originate from the tinkering process of the experimental experiences narrated in the paper are represented in Figure 1. From the first considerations downstream of the experience, we have extrapolated numerous factors. In particular, we can say that the choice of wastes introduced into the matrix is influenced by:

- Easy availability. Some types of waste are available, especially in the Italian context, all year round and are usually zero km because many people, including students, often consume them. Examples of these are coffee grounds, banana fibre and citrus peel, potato peel, carrot peel, and eggshells. It can be noted that also the seasonality of food waste is significant and, some of the DIY-Materials presented here are the result of a course that has always been held in the winter semester, thus allowing also the use of shells of walnuts, hazelnuts and pistachios. Other types of shells, such as that of mussels, are not related to seasonality if not to the place (available in seaside resorts or fish restaurants). Another important factor for easy availability is also the cost, and in general, these foods are on the average cheap.

- Easy processability for introducing the scrap into the matrix. The advantages of some scraps, such as coffee grounds, are that they can be reduced to powder or in any case, as in the case of orange or banana peels, they can be easily cut. It contributes to the regularity of the waste form introduced into the matrix. In other cases, as for the wooden shells (from the seeds) or ceramic (from the mussels), the fragments are less regular. It, on the one hand, offers more expressive possibilities, also in terms of colour shades and disorganized textures. Still, on the other hand, it makes it more challenging to integrate the waste into the matrix, creating inhomogeneity. This, in materials science, is defined as the creation of an "interface" filling matrix.

- Limited formation of mold or fungi. Some scraps require previous processing, such as drying in a fan oven. It is the most widespread preparation process for food waste and is applied, for example, to coffee grounds and orange peels. Another possibility is the use of herbs in the mixture, as suggested by the culinary tradition, such as thyme, cinnamon, curcumin, etc. The tinkering process has led to the exclusion of some experimentation path due to the persistence, for example, of mold, as happened with crab exoskeletons (in chitin) in a starch-glycerol-lemon matrix.

- Recognizable colour or ability to change colour. Some types of food waste, among those mentioned above, have a colour that identifies its origin. On the other side, especially in materials developed in film formats, hence with a thickness lower than 500 microns, the use of coloured water for production proved useful. This was the case for example of the already mentioned beetroot water or water from fennel or chicory boiling. Starch-loaded water from pasta or rice boiling, a typical kitchen waste, could also be proposed for use in the future, possibly after being naturally cooled down. In addition, milk whey-loaded water from mozzarella cheese preparation was attempted, as suggested by Caliendo, Langella, Santulli, and Bove (2018), which is supposedly leading to an improved hardness of the obtained material.

Figure 1. A collection of materials demonstrators self-produced by the students over a few years of materials courses. (Camerino, 2015-2018)

When tinkering with materials, evidence should always be considered. There are some basic shapes and artefacts that are more effective than the initial demonstrator for evaluating specific properties and characteristics of the DIY material. In particular, a characteristic that must be observed is the possibility of obtaining curved shapes without the gradual development of cracks in the material. Besides, checking the thickness uniformity can also be important. Both these purposes can be achieved by producing small bowls, as shown in Figure 2. It should also be considered that the moulds useful for this purpose are easily available, for example, those for cupcakes.

Other problems can also be easily experienced, such as the application of a counter-model ensuring its perfect closure on the mould with simple means, for example, a small mechanical clamp. The demoulding process depends on the material of the mould and also on the possible application of procedures to facilitate it, such as the use of silicone-coated baking paper.

Figure 3 focuses on the prevalent types of colours and shades that can be obtained. The experimental results obtained must not be described as such, since they represent only attempts to design the "personality" of the material generated by combining it with the functional or expressive properties that may be suitable for some applications. The question of gradual/loose colouring cannot, for example, be resolved with objective considerations, since there are colours easily to obtain with simple experiments, in particular those based on anthocyanins or carotenoids (reds and oranges), tannins (brownish), or natural colours of some products, such as starch or wax. During tinkering, other colours were experimented to be used rarely, as not very available. We mostly refer to shades of blue. As far as colour is concerned, it must also be taken into account that some types of waste can hardly undergo colour changes, as in the case of coffee grounds or even some fibrous or wooden waste, such as that of hemp. This difficulty has led students to focus more on obtaining different textures or nuances, which can lead to giving the material demonstrator a personalized character. In other words, their imperfection allows highlighting their naturalness and uniqueness.

Microscopic images can be of great use to better differentiate the material demonstrators and often also to present them. In most cases, we have used magnifications from 10x to 40x (Figure 4). From a pedagogical point of view, it is possible to have interesting results when the material demonstrators explain the potential of processability of the DIY-Materials itself. For example, for the creation of holes, preparing the application of low-cost devices, such as toothpicks, small pipes, etc., in the mould. The use of screws or nails instead demonstrates a specific resistance to penetration. After completing the part of the experience on the material demonstrators, it would be interesting to illustrate the relationship of the DIY-Materials between them, in terms of similarities and differences, without limiting them to colours and textures. It transcends the limits of a material library, as it is based on the subliminal perception of different DIY-Materials and helps us investigate their "personality".

To start with, tentative collective presentations of materials demonstrators’ families (those in Figure 5 are all based upon starch with the participation of different natural colours and waste types).

Figure 2 Small bowls made of "Frangile", a DIY-Materials developed by Patrizia Calcagno, Martina Carraro, and Francesca Pucciarini.

As a material demonstrator, the small bowls are suitable for the first investigation on the properties and qualities. Frangile is a DIY-Materials created using basic ingredients, like starch and sugar, enriched with flavours obtained by adding spices or food. The aim was to design a packaging made of edible materials. Because of its inherent brittleness, it can be used as a temporary object in the food industry.
Designing Materials Experience course 2014/2015, School of Design, Polimi. (photo by Calcagno, Carraro, Pucciarini))

Figure 3 Variety in the use of natural colours with tentative geometries (Camerino 2015-2018)

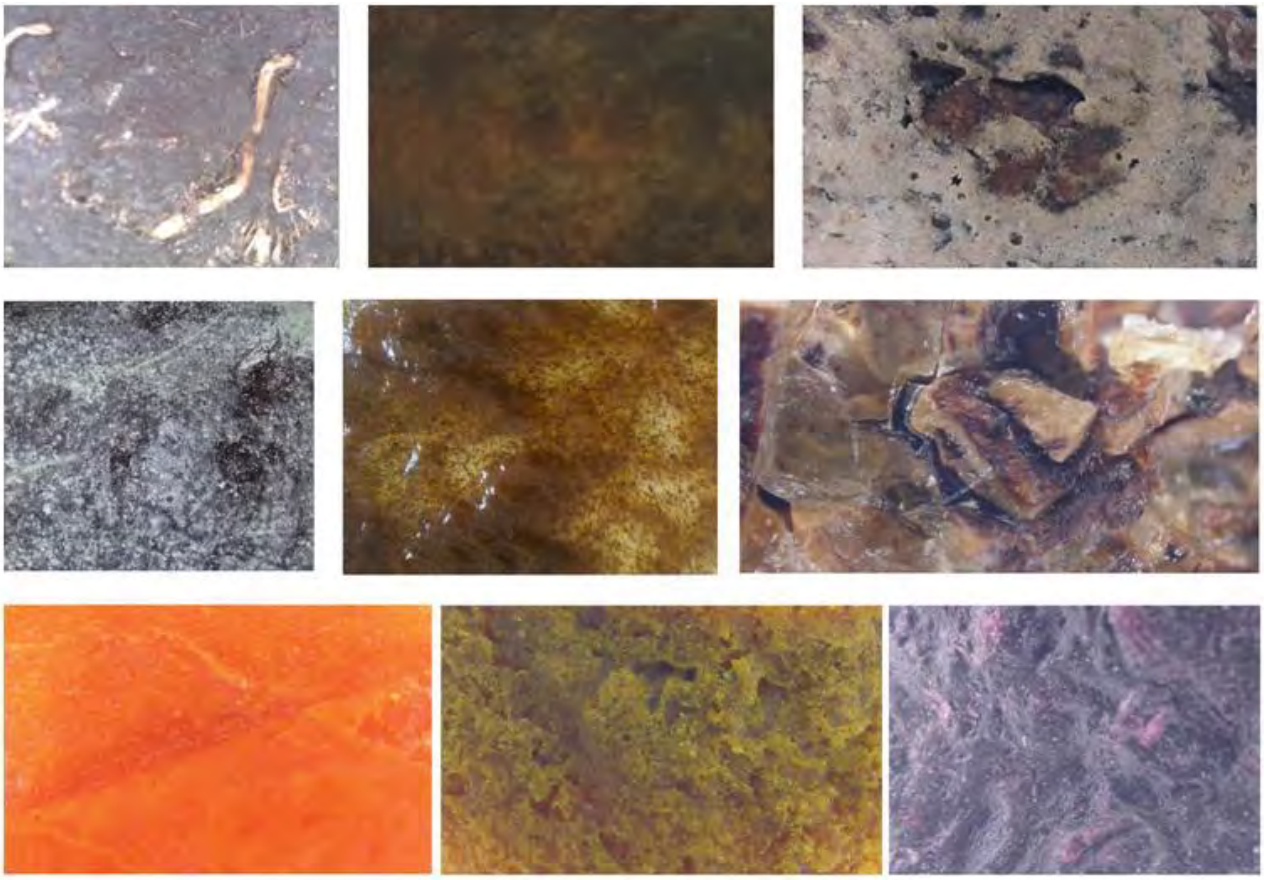

Figure 4 Examples of microscope images of materials demonstrators (Camerino 2015-2018)

Figure 5 Initial attempts for the presentation of different DIY-Materials shortly and expressively using a material mood board (CREDIT: Federica Voltattorni, Unicam)

From these initial considerations, obtained during tinkering with materials, a more precise and concrete classification of the "personality" of the single DIY-Material seems to emerge, as shown in the following figures (Figures 6-9) dedicated to materials belonging to different "kingdoms". The DIY-Materials kingdoms are useful work-tools, capable of starting the reflection on the potential of DIY-Materials, rather than closed and limited categories. The interest of this development is particularly given by the fact that in this way the possible further developments of the material are naturally proposed by the material itself, which is observed at the same time technically, functionally and expressively. This is consistent with the philosophy of do-it-yourself materials and can guide their further improvement.

Considering what has been said so far, it would seem that tinkering on DIY-Materials is to be carried out exclusively in the Fab-lab because, with these, we share the knowledge of experimentation and makers culture. However, these are not the only places to experience material. Instead, we want to suggest conducting material experiments on different scales and with different purposes (e.g. geometry, moulding, textures/colours, mechanical performance, joining, etc.). In this context, we recognise the concept of "Materials Club", a platform of skills and tools that can support students and design professionals who want to make experimentation on materials their strong point. The Materials Clubs are born from the systematisation of resources and structures for the experimentation of already existing but not exploited materials in their possibility to work in a coordinated way (Ziyu, Rognoli & Ayala-Garcia, 2018).

Besides, DIY-Materials are gradually acquiring a status comparable to the designed materials in terms of the learning experience incorporated into them. Samples of materials developed over the years by the students of the Politecnico di Milano formed the "Made @ Polimi" collection[3] (Figure 10), and they are also included in the material libraries."

In academia and material design research contest, many people work on developing personal approaches to material tinkering. In general, all this ferment seems to lead to complementary results that confirm the authenticity and consistency of the concept of tinkering and DIY-Material and their value in the world of material education.

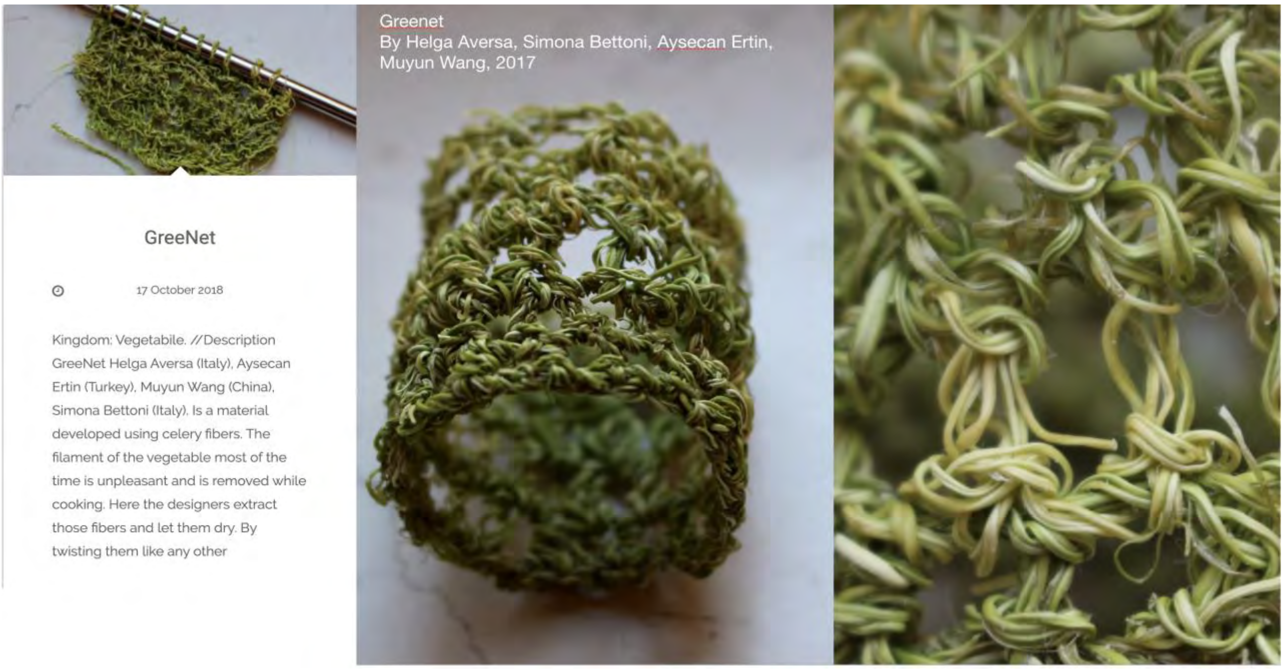

Figure 6 Greenet, DIY-Material developed by Helga Aversa, Simona Bettoni, Aysecan Ertin, Muyun Wang.

It is a material demonstrator produced using celery fibres. Designing Materials Experience course 2017/2018, School of Design, Polimi. (photo by Aversa, Bettoni, Ertin,Wang - http://www.diymaterials.it/category/made/made-polimi/)

3 http://www.diymaterials.it/category/made/made-polimi/

Figure 7 It's never too lat(t)e DIY-Material developed by Aslan Dicle, Ibrahim Dinullah, Shao Yizhuo, Unal Betul.

It is a material demonstrator produced using expired milk. Designing Materials Experience course 2017/2018, School of Design, Polimi. (photo by Dicle, Dinullah, Yizhuo, Betul - http://www.diymaterials.it/category/made/made-polimi/)

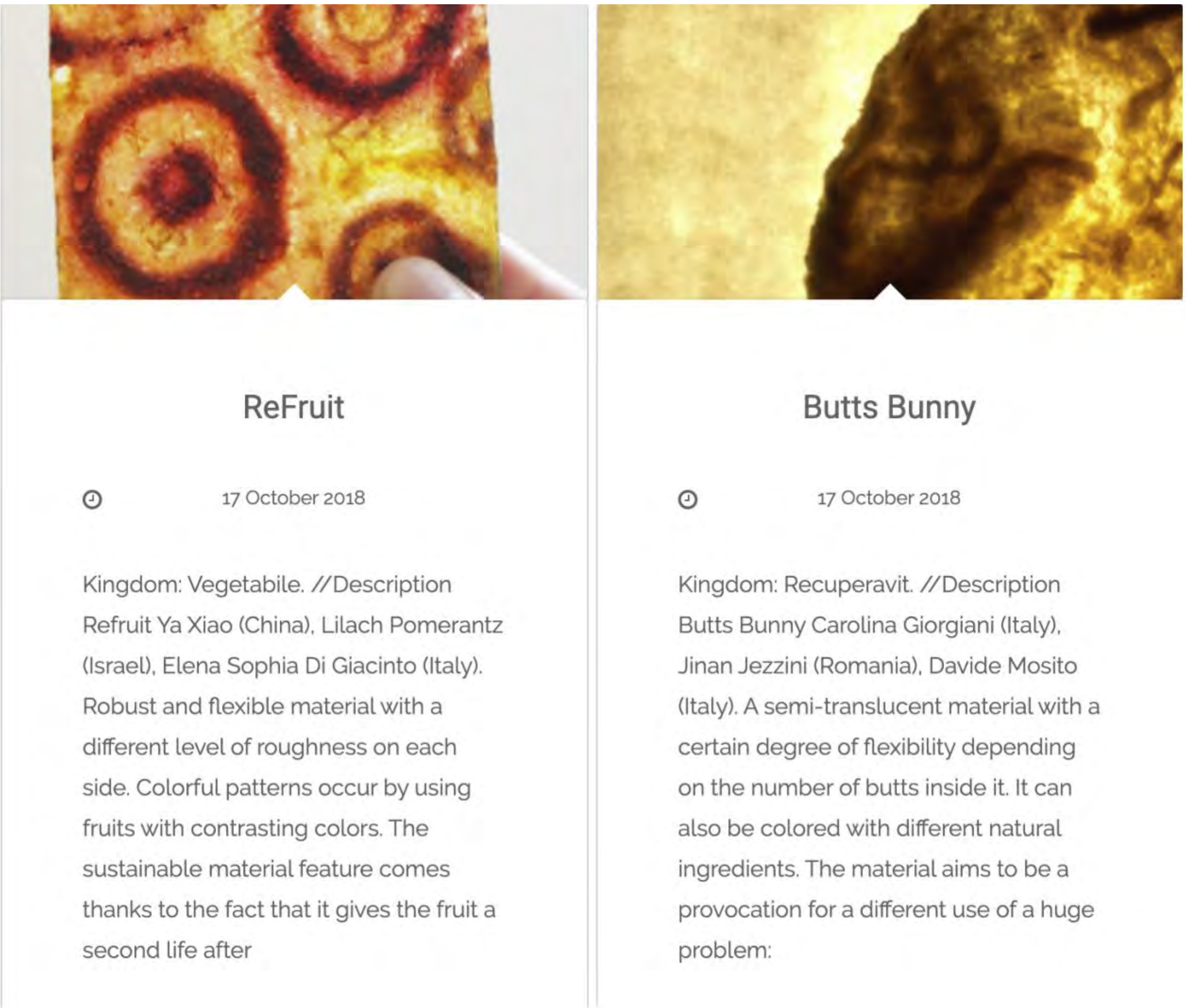

Figure 8 Two descriptions of DIY-Materials.

ReFruit is a material demonstrator developed by Ya Xiao, Lilach Pomerantz, Elena Sophia Di Giacinto using fruit waste. Butts Bunny developed by Carolina Giorgiani, Jinan Jezzini, Davide Mosito, using cigarette butts. Designing Materials Experience course 2017/2018, School of Design, Polimi. (photos by Xiao, Pomerantz, Di Giacinto and by Giorgiani, Jezzini, Mosito - http://www.diymaterials.it/category/made/made-polimi/)

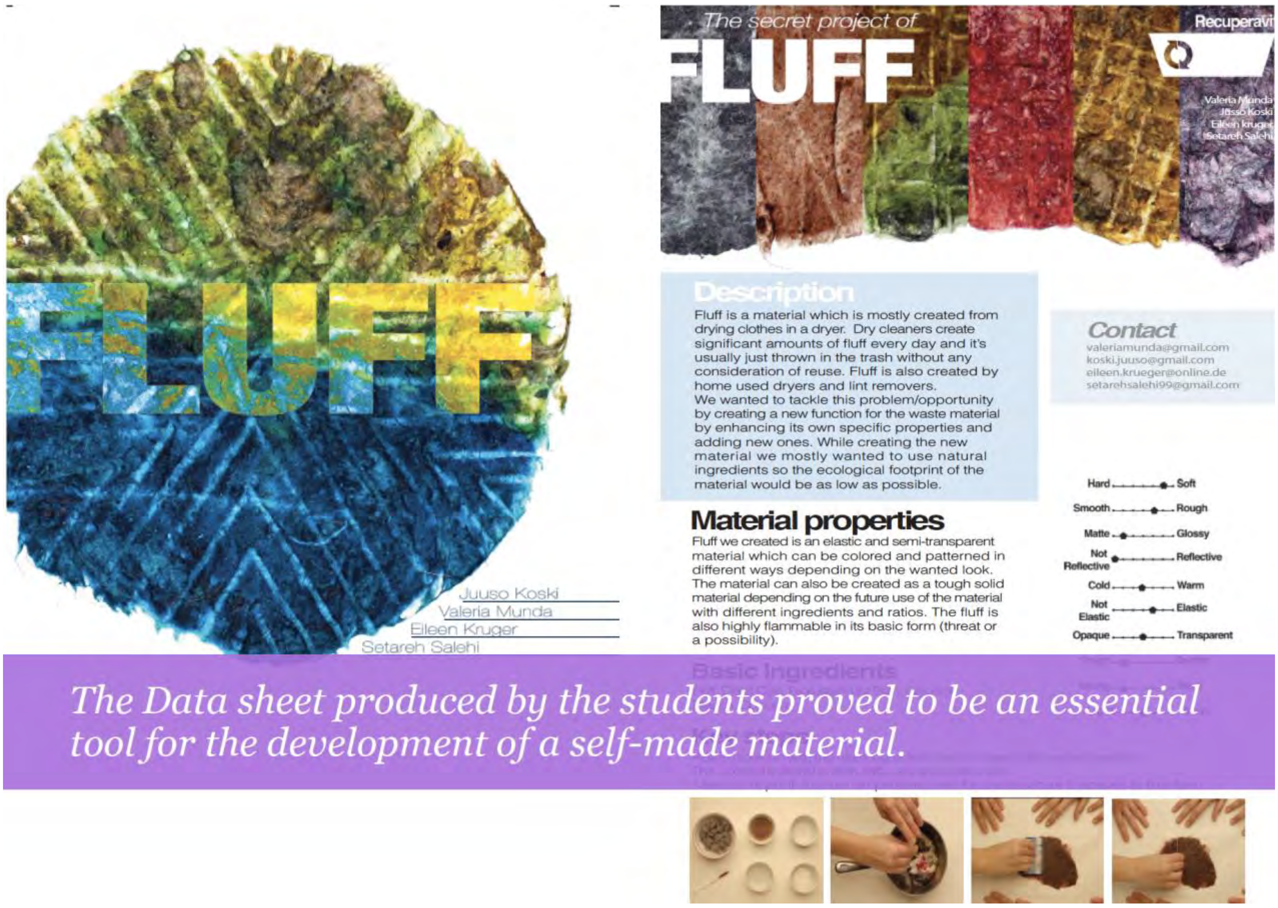

Figure 9 Fluff is a DIY-Material developed using the lint in the dryer machine (in Laundry services).

It was designed by Juuso Koski, Valeria Munda, Elleen Kruger, Setareh Salehi. Designing Materials Experience course 2016/2017, School of Design, Polimi. (photos by Koski, Munda, Kruger, Salehi)

Figure 10 Made@Polimi display of DIY-Materials at the materials library of Politecnico di Milano[4], 2018
(photo by Camilo Ayala Garcia - http://www.diymaterials.it/the-diy-materials-club/)

Conclusions

This paper exposes the practice of self-produced materials as demonstrators of infinite possibilities and potential. We have shown the process which, starting from the waste, thanks to the method of tinkering the materials, allows us to propose some demonstrators of materials useful for regulating on possible material experiences. In other words, the idea was to invite design students to work and design around this topic and improve the role of understanding the meaning of materials in design education, using the recycling of waste as a trigger to start the process of their transformation on material demonstrators.

After a general illustration of the scope and objectives of material tinkering, the exhibition describes the recent experiences of this practice in design schools, underlining its pedagogical significance worldwide. The work presented here, therefore, focuses on the particular cases carried out in Camerino and Milan since 2015, trying to clarify its meaning compared to the previous literature, for what appears to be relevant for the education of designers and their

4 http://www.materioteca.polimi.it/en/sample-page/

training in the appropriate local context and transposing it worldwide. The research method evolves from trial and error, typical of experimentation on materials, to the conception of material and suitability demonstrators to be applied to products, having as limit the fact of using certain types of waste in an upcycling philosophy. The materials produced can be described in engineering terms as biopolymer matrix composites and are developed in demonstrators, which can help designers know several aspects that lead to acceptance of the materials. These include colour, consistency, shape and visibility of waste, but also thickness control, effective moulding and processability. Future developments would lead to the study of the properties of the materials, the engineering characterization and the evaluation of the technological potential. These are phases in which the designer can be actively involved and not act only as a user of the technical data measured by the materials engineers, as has also been often so far. The synergy between engineers and materials designers, obtained through shared participation in the process of tinkering materials, can offer the complete perspective of the feasibility of materials, both expressive-sensorial and technical-technological.

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