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DIY materials

Valentina Rognoli [a], Massimo Bianchini [a,*], Stefano Maffei [a], Elvin Karana [b]

[a] Department of Design, Politecnico di Milano, Italy
[b] Industrial Design Engineering, TUDelft, Netherlands

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ABSTRACT

The democratization of personal fabrication technologies in parallel to the rising desire of individuals for personalizing their products offers great opportunities to experiment with advanced, distributed and shared production processes as well as design new materials. In this article, we introduce the notion of Do-It-Yourself (DIY) Materials, which are created through individual or collective self-production practices, often by techniques and processes of the designer's own invention. They can be totally new materials, modified, or further developed versions of existing materials. In order to provide an operational vocabulary to discuss DIY materials, we have collected 27 DIY material cases developed in the last five years. We group the collected cases under two main categories: (1) DIY new materials: which focus on creative material ingredients (e.g. a material made of dried, blended waste citrus peel combined with natural binders); and (2) DIY new identities for conventional materials: which focus on new production techniques, giving new expressions to existing materials (i.e. they do not necessarily contain new ingredients, such as 3D printed metal). Grounded on the commonalities of collected cases, we discuss the design opportunities, including new aesthetic impressions offered through DIY material design practices.

1. Introduction

Materials in everyday artefacts are embodied in products mainly through mass production. This will not change in the near future. However, in the past decade, parallel to the advancements in mass production technologies, another approach has emerged, bringing a new dimension to the relationship amongst designers, technologies, production processes, and materials. This new approach combines *making, crafting and personal fabrication* [12,19,30]. It highlights the renaissance of craftsmanship [3–5,28], where design, self-production, and advanced and digital manufacturing technologies (e.g. 3D printing) are merged. Such evolved forms of Do It Yourself (DIY) practices are called by scholars as *Third Wave DIY*, highlighting "*DIY that draws upon the read/write functionality of the Internet, and digitally-driven design/manufacture, to enable ordinary people to invent, design, make, and/or sell goods that they think of themselves*" [11], pg. 18.

There is a growing interest for mass customization and personalization services provided by companies and industries in order to satisfy the emerging demand of unique products. A growing number of users express the need for customized artefacts, even taking into account their direct involvement in the design process and/or production. Designers are trying to find meaningful solutions that meet these needs [1,8]. The DIY approach and the revaluation of a crafts and self-production approach in product design is also supported by the *democratization of technological practices* [30] in terms of commonly used production labs, low cost and accessible fabrication tools, and open and shared knowledge about production processes.

These dynamics around DIY practices have led to the emergence of new materials for product design. In this paper, we introduce such materials created and/or shaped by DIY practices as 'DIY materials'. Belgian designer Laurence Humier explored the value of a multidisciplinary DIY approach (molecular gastronomy design and chemical engineering) to discover and produce new materials [15]; www.missdesign.it/home/Laurence_HUMIER_Cooking_Material.html. Portuguese researcher Caterina Mota has coined the term 'open material' [23]; www.openmaterials.org to describe the influence of open source philosophy and DIY experimentation focusing in particular on smart materials. In 2014, British digital fashion designer Jenny Lee introduced "Material Alchemy" (2014), presenting collections of materials and recipes to 'cook' and 'make', coupling design, materials science and craft. Common to all, the potential of autonomous and independent production of materials is emphasized as a strong means to elicit meaningful personalized *materials experiences* [16,17].

Another important point discussed in literature is on the possible effects of DIY materials on conventional material development and manufacturing technologies [30]. We argue that the emergence of DIY materials is not a threat for traditional manufacturers. Instead, the materials of self-production provide an opportunity to reconsider the features of existing manufacturing processes and industrialised material properties, in order to create new, unique experiential qualities.

* Corresponding author.
E-mail address: massimo.bianchini@polimi.it (M. Bianchini).

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Accordingly, in this article, after speculating on why designers are stimulated to become self-producers of materials, we present a number of DIY material cases and analyse them to reveal their commonalities and differences. This leads us to the vocabulary necessary to understand and discuss DIY material design practices and to inspire future design research and practice agendas. Finally, we discuss the opportunities obtained through DIY material practices for design.

2. DIY materials: emergence and diffusion

The democratization of fabrication technologies, combined with the rising desire of individuals to personalize their products [18,22] offers the opportunity to experiment with advanced, distributed and shared production processes, enabling self-production of materials and products. As Gershenfeld stated: "think globally, fabricate locally" [13]. Self-production refers to a way of controlling production processes through experimentation and tinkering: creating a material in a 'lab' and in the same lab, processing the material into a product. This approach triggers the designer to see almost everything as a possible candidate to be a matter of self-production effort.

The abundance of available information on materials and manufacturing processes, for example through materials libraries (see Akin and Pedgley [2] for an overview, blogs and websites), together with the diffusion of maker-labs for prototyping and experimenting (e.g. *Fab Lab Amsterdam* (http://fablab.waag.org/); *Design for Craft* (www.designforcraft.com), DIYBio Labs (diybio.org/) enables new forms of *citizen science* and *open source science* [9,25,29]. In this way, scientific data related to physics, chemistry, biology, and medicine are available for scientists, professionals and amateurs interested in DIY materials and self-production. Moreover, the expansion of service platforms for personal fabrication such as *Ponoko* (www.ponoko.com) provides a wide range of materials that can be directly purchased online, opening a new way for the future distribution of self-produced materials. Other platforms, such as *Instructables* (www.instructables.com) offer guidelines to create useful tools facilitating the self-production of PLA filament for 3D printing. Finally, *crowdfunding platforms*, an alternative source of financing that refers to calls open to the public (generally via the Internet), have begun to be interested in materials, as we see in the case of the project called *Polymakr* (www.polymakr.com), a free space to learn and share knowledge about 3D printing materials.

It is often possible to find in the Internet some *recipes* on how to prepare and produce natural-based materials. The creation of repositories about self-produced material is the first explicit evidence of this process. In *Open Materials* (www.openmaterials.org), over 100 materials are presented through a research group dedicated to open investigation and experimentation with DIY production methods. The Wiki platform called *Material Wiki Project* (www.materialproject.org) is also a material platform, which provides an opportunity for design professionals and students to share their material research and find collaboration opportunities.

Fab Labs or DIY Labs, along with personal labs with accompanying blogs and websites, may well be imagined as future spaces that enable new forms of open and self-created materials. In fact, the designer is enabled and feels the need to self-produce materials because she/he wants to go beyond the industrial and mass customized solutions: a mindset of tinkering with materials and experimenting through hands-on material interactions. Instead of speaking about 'industrial design', as Bianchini [7] stated in his PhD dissertation, we are in the 'industrious design' era. People – designers – can exploit their design skills by developing the necessary tools and machines, and controlling all aspects of the production as a craftsman. They can get 'inside' matter and experiment with it as an alchemist would. The result of this new approach to materials is the emerging material experience that we define as 'DIY materials'.

3. Cases of DIY materials

Do-It-Yourself Materials are created through individual or collective self-production experiences, often by techniques and processes of the designer's own invention, as a result of a process of tinkering with materials. They can be new materials with creative use of other substances as material ingredients, or they can be modified or further developed versions of existing materials. Following this preliminary definition, we collected 27 DIY material cases[1] from around the world developed in the last five years. We made a grouping under two main types that usefully distinguished the cases.

1. DIY new materials: these are designed through creative use of substances as material ingredients (e.g. a material made of dried, blended waste citrus peel combined with natural binders, and so on).
2. DIY new identities for conventional materials: these focus on new production techniques, which give rise to new identities for existing materials (i.e. they do not necessarily contain new ingredients — e.g. 3D printed metal, recycled materials, and so on).

In Table 1, introductory information for each of the case studies is summarised, highlighting the profile of the designers involved, the nature of the DIY material (e.g. its ingredients) and its related production technique(s).

Further details for the cases are now presented.

3.1. DIY new materials

We observe that DIY new materials are usually designed with creative use of organic or inorganic waste or other substances as material ingredients. Decafé by Raul Laurì is a new composite material made from waste coffee grounds. This material is the result of a long experimentation process based around use of some traditional culinary techniques. Waste coffee grounds are mixed with a natural binder and subjected to pressure and heat. The resulting material can be applied in the production of various artefacts, such as lamps and bowls.

APeel Materials by British designer Alkesh Parmar is a patent-pending process for transforming waste citrus peel into a new material with a wide range of potential uses, without having need to use additional binders. The designer created a series of objects following the Cradle-to-Cradle philosophy. Parmar focuses his work on the inedible leftovers from oranges, lemons and other hesperidia fruits. He dries, blends and mixes them with a secret combination of all natural, organic binders to create sustainably sourced and produced materials. The design process has been conceived to keep energy and water consumption to a minimum. The resulting material is firm and strong and can be transformed into a versatile flexible sheet.

Shaping Sugar by Amalia Desnoyers is a material obtained from the chemical reaction of sugar, water and glucose warmed together to 160 °C (Fig. 1). Sugar is a solid material, which can be transformed into a liquid, and back into a different shaped solid. The designer investigated these transformations in the context of enabling experimental ephemeral shapes and designs. The Shaping Sugar material has similar qualities to glass (e.g. transparency, fragility) and for this reason the designer decided to create glasses in which the sugar glass dissolves in contact with water. The result is that the liquid poured inside also becomes flavoured and the glass becomes a drink. Material, shape, colour and flavour are unified resulting in a new experience of drinking.

The Milk of Human Kindness by Masami Charlotte Lavault is a novel process for turning old milk into a mouldable, biodegradable plastic. The milk is mixed with pigment and acetic acid before being turned into a powder, pressed into a mould and put through a pressure cooker to set its form. The project draws an alternative scenario and explores a

[1] Some of these cases are presented in detail in the PhD thesis by Bianchini [7], and other researches conducted together with Maffei [6] focusing on self-production and micro production in the field of industrial design.

Table 1
Collection of 27 international DIY material case studies ordered by type.

DIY new materials			
Materials	Designers	Basic ingredients	Production techniques
Decafé http://www.rlauri.com	Raul Lauri	Coffee ground waste mixed with a natural binder	Coffee ground waste is mixed with a natural binder and subjected to a transformation process involving pressure and temperature.
APeel http://www.apeelmaterials.com	Alkesh Parmar	Dried, blended waste citrus peel combined with natural binders	Drying, blending and mixing leftovers from oranges, lemons and other hesperidia fruits with a secret combination of all natural, organic binders.
Shaping Sugar http://www.ameliadesnoyers.com/Shaping-Sugar-1	Amalia Desnoyers	Sugar, water and glucose	The process is based on the chemical reaction of sugar, water and glucose warmed together to 160 °C.
Milk of Human Kindness http://www.themilkofhumankindness.com	Masami Charlotte Lavault's	Spoiled milk mixed with pigment and acetic acid	The mix is turned into a powder, pressed into a mould and put through a pressure cooker to set its form.
Autarchy Vessels http://www.formafantasma.com/autarchy	Forma Fantasma	Flour, agricultural waste and limestone, dyeing with vegetable-based dyes	After mixing the ingredients and shaping the dough, the material can be hardened by baking at low temperatures or drying naturally.
Impasto http://steenfatt.dk/work/impasto	Nikolaj Steenfatt	Fibre composite (sawdust, used coffee grinds, animal glues and coloured pigments) and oak wood	The raw materials are mixed with pigment into a dough, pressed, rolled and folded into flat sheets. Afterwards the sheet can be shaped using vacuum forming.
Terra http://www.terradesign.org	Terradesign	Earth and agricultural residue	After mixing the components and shaping the dough, the material is dried.
StoneCycling http://www.stonecycling.com	Tom van Soest	Industrial waste	The project mechanizes the process of pulverizing, pressurizing, and adding heat, using a tub grinder and a kiln. The raw material comes from demolition and construction waste or manufacturing refuse with no binders required.
Biocouture http://www.biocouture.co.uk	Suzanne Lee	Bacterial culture in a sugary green tea	The process uses microbial cellulose (composed of millions of tiny bacteria grown in bathtubs of sweet green tea) to produce clothing.
Xylinum Cones http://www.jannishuelsen.com/?/work/Xylinumcones	Jannis Huelsen	Bacteria cellulose	The process is based on organically grown microorganisms.
Micro'be http://bioalloy.org/micro-be	Gary Cass & Donna Franklin	Wine or beer and acetobacter bacteria	Process of fermentation that transforms wine to vinegar.
Grow It Yourself Mushroom® Material http://giy.ecovativedesign.com	Ecovative	Renewable biomaterial grown from fungal mycelium and low-value non-food agricultural materials	The process uses an agricultural waste product such as cotton hulls, cleaning the material, heating it up, inoculating it to create growth of the fungal mycelium, growing the material for a period of approximately five days, and finally heating it to make the fungus inert.
Thousand Years http://www.studiolibertiny.com/work/#/thousand-years	Tomas Libertiny	Beeswax from 60,000 bees and metal scaffold as a framework	The process is based on the construction of a metal scaffold that serves as the framework for a beehive, before letting nature take over.
Propolis http://www.marlene-huissoud.com/samples/	Marlène Huissoud	*Propolis*, a biodegradable resin collected by bees from rubber trees	The beekeeper once a year has to remove a portion of the propolis in order to extract the honey from the frames of the beehive. Propolis seems to have similar properties to glass and it is possible to experiment with traditional blowing and engraving techniques.
Wooden leather http://www.marlene-huissoud.com/from-insects-silkworms	Marlène Huissoud	Silkworm cocoons	After dissecting the cocoons, the natural glue that holds the structures together – called sericin – can be reactivated by wetting and heating the fibres to create a strong paper-like material.
Coleoptera Bioplastic http://www.aagjehoekstra.nl/coleoptera.php	AAgje Hoekstra	Insect shells that include chitin	It is necessary to carry out a chemical process to transform the chitin into chitosan, which bonds better due to a variation in the molecular composition. The material is then heat-pressed to create a plastic, with the oval-shaped shells still being visible.

DIY new identities for conventional materials			
Materials/Artefacts	Designer	Basic ingredients	Production techniques
FIDU Technology (patented) https://zieta.pl/home/291	Oskar Zieta	Metal sheet	Involves a sustainable production process that welds thin metal plates together at their edges and then inflating them to create any number of shapes and objects. Thanks to the programmed process and a combination of sheet-metal and 'air', designers can only control key joining points of the geometry, whilst surfaces and negative space are the result of free deformation.
MX3D Material	Joris Laarman	Metal	An additive manufacturing project based on hacking an

Table 1 (*continued*)

DIY new identities for conventional materials			
Materials/Artefacts	Designer	Basic ingredients	Production techniques
http://www.jorislaarman.com/home.html#/winter_alpha/gp04jhm_press			industrial robot with an advanced welding machine able to print with metals, such as steel, stainless steel, aluminium, bronze or copper without the need for support-structures
Can City http://www.studioswine.com/can-city	Studio Swine	100% recycled aluminium from cans	A project of a mobile foundry, used to cast aluminium stools from drinks cans collected on the streets of São Paulo, Brazil. The designers wanted to create a system that would help the Catadores to recycle the rubbish they collect and transform it into products they can sell.
Open source Sea Chair Project http://www.studioswine.com/sea-chair	Studio Swine and Kieren Jones	100% recycled plastic debris from oceans	Created from a small factory on board a vessel that collects and processes marine debris into a series of stools. Plastic caught in fishing nets or found on the shoreline is sorted according to colour, chopped into nuggets, and then melted at 130 °C in a DIY furnace.
Creative Line 02 http://www.vailly.com/projects/line02--movie/	Thomas Vailly	Latex sheets	A versatile and low tech way to produce fluid and organic plastic shapes, using rotational moulding to make objects inside stretched latex
U.R.E. process http://cohda.com/projects/rd-process/	Cohda Design	100% recycled plastic (bottle, food trays)	U.R.E. allows plastic to be heated to a molten state, manipulated, and then be fused together. People can be part of the process.
Polyfloss http://www.thepolyflossfactory.com	Polyfloss Factory	100% recycled plastic (bottle, food trays)	A simple technology allows the transformation of waste plastic into a new raw material that looks like 'plastic wool'. This project is about an innovative plastic recycling process inspired by the principle of candy-floss machines.
Original Stool http://www.breadedescalope.com/index.php/original-stool	breadedEscalope	Polyurethane, dyed synthetic resin, varnish	The material is manufactured with a solid hollow orb, which houses a flexible silicone mould of the Stool. Resin is filled into the silicone form in the orb. Then, the orb is set in motion, simply by rolling it through the streets, down a slope, into white water etc. Since the orb is rolling in all directions, the resin coats the entire inner surface of the form whilst hardening. The flexible form "records" all influences from outside.
Endless process http://www.dirkvanderkooij.com	Dirk Vander Kooji	Recycled plastics (from refrigerator)	The process is based on the conversion of an old industrial CNC (*computer numerical control*) extruder into an interfaced mechanical arm that prints, level after level, continuous layers of low-resolution plastic. The designer was able to modify and hack to transform an old industrial machine in to a real and new 3D printing robot
Precious Plastic http://davehakkens.nl/work/precious-plastic	Dave Hakkens	100% recycled plastic	The designer has created a micro-factory based on an open source DIY plastic recycling machine. The micro-factory is composed of a set of plastic machines, used to set up a small-scale plastic workshop.
Perpetual plastic project http://www.perpetualplasticproject.com	Better Future Factory	100% recycled plastic transformed into filaments for 3D printers	The designer has created a micro-factory able to recycle plastic materials, creating new ready-to-use PLA filaments that can be used to 3D print small objects.

novel moulding technique to turn a wasted dairy product into milk-protein based plastic artefacts.

Autarchy Vessels designed by Studio Formafantasma are containers made of flour, agricultural waste and limestone (Fig. 2). After mixing the ingredients and shaping the dough, the material can be hardened by baking at low temperatures or drying naturally, and dyed with vegetable extracts from spices and roots. The project was developed in cooperation with a chemist's studio and also draws upon traditional techniques that were used during the Renaissance period. "Autarchy" suggests an alternative ('low technology') way of producing goods where inherited knowledge is used to find sustainable and uncomplicated solutions.

Impasto by Nikolaj Steenfatt is a self-invented biodegradable natural fibre composite made of wood and coffee production leftovers (Fig. 3). The Impasto project was driven by a personal interest in materials, surface structures and alternative production processes, finding inspiration in intuitive experiments. The raw materials are mixed with pigment into dough — then pressed, rolled and folded into flat sheets. Afterwards, the sheet can be shaped using vacuum forming. This project is based on sustainable materials research, with the aim of creating a new biodegradable material, easy to work with and simple to use.

Terra is the material developed by Adital Ela, comprising earth and natural fibres, shaped through a unique compression process that combines indigenous and traditional knowledge and contemporary production methods. Objects made from Terra are 100% organic, can be produced everywhere with local earth and agricultural residue, require zero energy, create no pollution and are fully renewable and compostable.

StoneCycling by the Dutch designer Tom van Soest (Fig. 4) found a way to use demolition and industrial waste as raw materials for creating products with higher value. It focuses on three categories of products: bricks, tiles and furniture. The designer mechanizes the process of

Fig. 1. Shaping Sugar by Amalia Desnoyers, © Amalia Desnoyers.

Fig. 2. Autarchy Vessels designed by Studio Formafantasma, © Studio Formafantasma.

pulverizing, pressurizing, and adding heat, using a tub grinder and a kiln. The raw material comes from demolition and construction waste or manufacturing refuse with no binders required. This opens the possibility for a continuous, waste-free production cycle.

A particular group of DIY materials is created by using microorganisms and demonstrates that bio-materials can grow on their own. Biocouture by English designer Suzanne Lee has a focus on fashion design, seeking to grow textiles from a vat of liquid. The process uses a sugary green tea recipe with the addition of a bacterial culture. It takes between two and four weeks to grow a sheet sufficiently thick to use. Sheets are then dried down; either shaped over a wooden dress form – like the ghost dress and ruff jacket – or sewn together conventionally. Depending on the recipe, the material can either feel like paper or vegetable leather. A percentage of the fermentation liquid is finally recyclable.

Xylinum Cones by Jannis Huelsen presents a production line, using living organisms to grow geometrical objects. The project uses bacteria cellulose characterised by high purity, strength, mouldability and increased water-holding ability (Fig. 5). After a growth period of three weeks, the cellulose cones are dried and added to a sculptural assembly. The main motivation of the Xylinum Cones is on the one side to prove

Fig. 3. Impasto by Nikolaj Steenfatt, photos by Nikolaj Steenfatt.

Fig. 4. StoneCycling by the Dutch designer Tom van Soest, © StoneCycling.

the reproducibility of organically grown objects, but on the other side to find a balanced level of geometric precision and organic diversity. The aim of the project is to create a transparent production cycle and tangible objects, which allow the building of a relationship with a new and culturally unloaded material.

Scientist Gary Cass and artist Donna Franklin, combining their knowledge, have found a way to self-produce a new fabric through a fermentation process. Micro'be led to the first dress made with wine or beer. It is thus an organic fabric that comes from fermentation using acetobacter bacteria that usually turns wine into vinegar.

Grow It Yourself Mushroom® Material by Ecovactive is a high-performing biocomposite created from humble raw materials. The mushroom material is an example of how to produce materials grown from agricultural bi-products and mycelium. Mycelium is a natural self-assembling glue that can digest crop waste to produce cost-competitive and environmentally responsible high-performance materials. From the project website it is possible to buy a Grow It Yourself kit that includes bags of living Mushroom® Material and other products. Growers can use this material to make their own new creations.

In some cases insects are used as raw materials. Thousand Years by Tomas Libertiny resulted in a series of Honeycomb Vases made of beeswax (Fig. 6). Libertiny's 'collaboration' with honey bees pushes the boundaries of so-called conventional design by defying mass production and enabling nature to create what would typically be considered a man-made product. The material comes from flowers as a by-product of bees, and in the form of a vase ends up serving flowers on their last journey. He constructed a metal scaffold in the form of a vase that served as the framework for a beehive, before letting nature take over. It took more then 40,000 bees and one week to make a single vase.

From Insects by Marlène Huissoud shows the potential of insects as an innovative future material ingredient. The designer has experimented largely with *propolis*, a biodegradable resin that honey bees collect from trees and use as a sealant for their hive (Fig. 7). In particular she worked with a glossy black variant that is extracted from rubber plants and has a comparable look and feel to glass. The designer also creates a material she calls *wooden leather* using silkworm cocoons, which are made from hundreds of metres of silk threads. After dissecting the cocoons, the natural glue that holds the structures together – called sericin – can be reactivated by wetting and heating the fibres to create a strong paper-like material. The wooden aspect of the material comes from the tens of thousands of fibres combined together in the silkworm's paper. She is interested in using insects as co-partners in the design process.

Coleoptera bioplastic by AAgje Hoekstra developed a plastic made of pressed insect (beetle) shells. After laying its eggs, a beetle dies — with

Fig. 5. Xylinum Cones by Jannis Huelsen — Photos by Schwabe/Huelsen.

Fig. 6. Thousand Years by Tomas Libertiny — Photos by Rene van der Hulst.

the result that insect farms in the Netherlands throw away 30 kg of dead beetles every week. Before the beetles are disposed of, Hoekstra peels them so she is left with just the shells, which are made of a natural polymer called chitin that is also found in crab and lobster shells. She uses a chemical process to transform the chitin into chitosan, which bonds better due to a variation in the molecular composition. The material is then heat-pressed to create a plastic, with the oval-shaped shells still visible. The plastic is waterproof and heat resistant up to 200 °C.

3.2. DIY new identities for conventional materials

This section describes a series of case studies that exemplify how new DIY and craftsmanship approaches are evident in the production processes of conventional materials, through which those materials gain new identities. As we saw in the previous examples, also in these case studies the most important aspect is the DIY approach; that is, the way in which the designer builds his/her own machines to transform material. We witness great experimentation approaches, tinkering with materials and processes to obtain new experiences. After such initial efforts, it is possible for other people to build the same machine and achieve the same results simply by following instructions.

FiDU Technology (Free inner Pressure Deformation) is by the Poland designer and materials researcher Oskar Zieta, who developed his own production technology based on an innovative method of changing bits to atoms. The designer uses precise robots and organised tools to create a sustainable production process that involves welding thin metal plates together at their edges and then inflating them to create any number of shapes and objects. Thanks to the programmed process and a combination of sheet-metal and 'air', designers can only control key joining points of the geometry, whilst surfaces and negative space are the result of free internal deformation - 'controlled loss of control'. MX3D — Metal Printing by Joris Larmaan Lab is an additive manufacturing project based on hacking an industrial robot with an advanced welding machine able to print with metals, such as steel, stainless steel, aluminium, bronze or copper without the need for support-structures. It aims to create an affordable multiple axis 3D printing tool available for consumers and professional workshops around the world. This example is useful to demonstrate that the designers want to, and are able to, hack existing machines to use them in creating new design ideas.

Can City by British Design Studio Swine is a project of a mobile foundry used to cast aluminium stools from drinks cans collected on the streets of São Paulo, Brazil. Over 80% of the cans are collected informally by Catadores (independent waste collectors who pull their

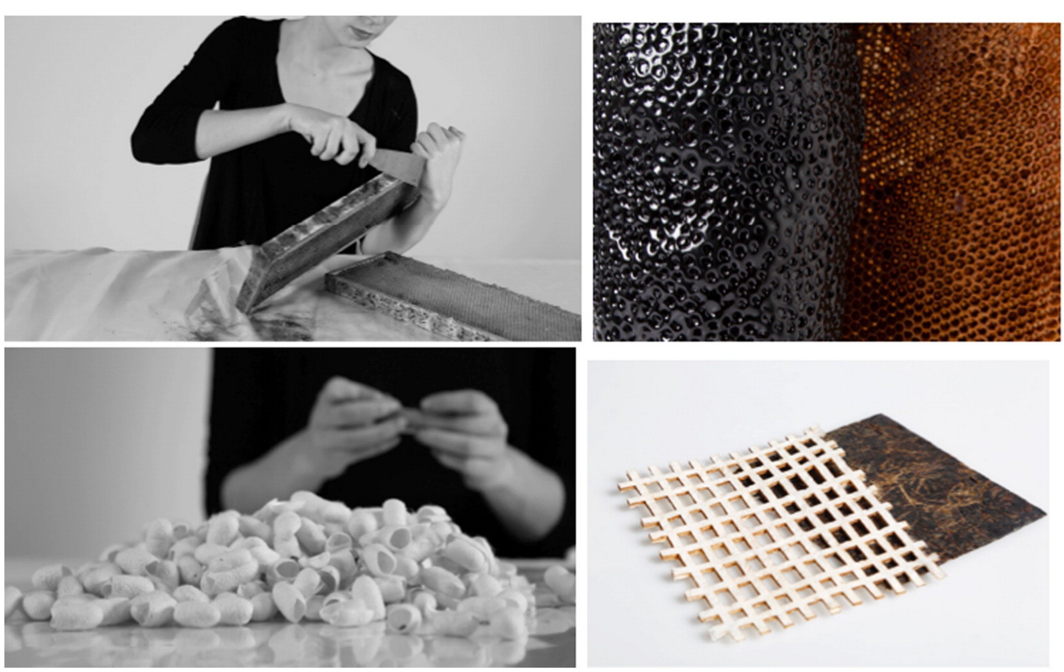

Fig. 7. *From Insects* by Marlene Huissoud: propolis and wooden leather, © Studio Marlene Huissoud.

handmade carts around the streets). Studio Swine wanted to create a system that would help them recycle the rubbish they collect into products they can sell. 'Can City' creates a system where livelihoods can extend beyond rubbish collection and in this way explores the possibility of industry returning to our cities, using free metal and free fuel to produce an endless range of individually crafted aluminium items adaptable to customisations and able to be 'cast on demand'. They explore how design can be the result of local materials, craft heritage and vernacular design colliding with innovation and new connections. The designer in this case is the facilitator of the creative process, teaching locals how to create new identities for conventional materials.

Open source Sea Chair is another project by Studio Swine. In collaboration with Kieren Jones at the Royal College of Art, Studio Swine has created a small factory on board a vessel to collect and process marine debris into a series of stools (Fig. 8). Plastic caught in fishing nets or found on the shoreline is sorted according to colour, chopped into nuggets, and then melted at 130 °C in a DIY furnace. The open source design uses readily available materials and basic DIY skills to enable the creation of a sea chair. The designers have released a manual so that others can also build the chairs.

Line 02 by Thomas Vailly is a versatile and low-tech way to produce fluid and organic plastic shapes, using rotational moulding to form objects inside stretched latex. Latex sheets can be considered as numeric surfaces, capable of being stretched, scaled and blown to create a great variety of fluid volumes. The latex mould doubles as packaging and is hacked away by the customer once they get the product safely home. Line 02 is a dialog between 3D-modelling, rapid prototyping, craftsmanship and design. The project is part of "the creative factory" — a collective of designers reclaiming control over their creations. Within an empty factory in Eindhoven they create their individual production line and their machines, tools and products, whilst establishing relationships with the community around them. The creative factory suggests an alternative to industrialization, production and consumption.

In the field of plastic materials, many DIY projects are based on low-tech (or no-tech) machine tools enabling self-production. U.R.E. Process by Cohda is an example focusing on how the designer can develop a new process that allows plastic to be heated to softened state, then manipulated by hand and fused together seamlessly to form rigid plastic structures. The RD chair made by this process is assembled without glues, internal support frames, or additional fixings in its production and is therefore 100% recycled plastic. Additionally, several U.R.E. recycling factories have been presented live during various design festivals. These live events allow the public to be part of a process of feeding the events with their plastic waste (bottles, food trays) are reclaiming that material as new designs able to convey new materials experiences.

Polyfloss by the Polyfloss Factory, a designers group from the Royal College of Art, is a technology that enables the transformation of waste plastic into a new raw material. It is an innovative plastic recycling process inspired by the principle of candyfloss machines (Fig. 9). Polyfloss is described also as 'plastic wool'. After the waste material (polypropylene) is shredded, it is inserted into the rotating oven, where the molten plastic is projected through the small holes onto a drum via centrifugal force. The space between the oven and the drum lining allows the polypropylene to cool down and harden, creating fibres. Once cooled, Polyfloss can be easily re-melted to create new objects without expensive or complicated manufacturing techniques. This new process allows the setting up of contextual recycling and small-scale circles of reemployment, which is rare for polymers, usually and historically dependent on big scale manufacturing and production engineering knowledge. Polyfloss has various textures and creates a wide range of applications and products with unique material properties, from textile, architecture, packaging and products, to art installations.

Original Stool by breadedEscalope is produced via a unique process (Fig. 10). The material is manufactured with a solid hollow orb which houses a flexible silicone mould of the Stool. Resin is filled into the silicone form in the orb. Then, the orb is required to be set in motion by simply rolling it through the streets, down a slope, into white water etc. Since the orb is rolling in all directions, the resin coats the entire inner surface of the form whilst hardening, just as with industrial rotational moulding. The flexible form "records" all influences from outside. Therefore, the shape of the outcome varies depending on the sort of landscape covered, the way it is handled, etc. After a couple of minutes, the resin turns from a liquid to a solid state and a unique shaped object is born. An "Original Stool" is always an unpredictable character that describes the capturing story of its evolution. Every single object is

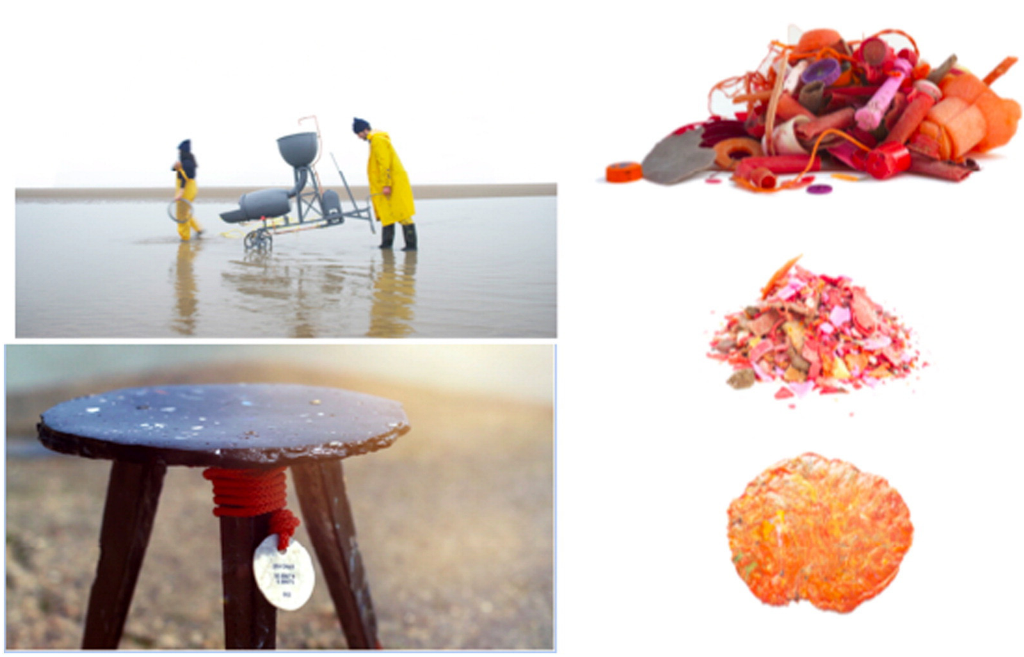

Fig. 8. Project by Studio Swine and Kieren Jones.

Fig. 9. Polyfloss by the Polyfloss Factory, © Polyfloss Factory.

individual. Each has its own story and a place to be called 'home'. The carefully conceived, free-range kinetic process captures a specific time and place, by permitting the environment to impart distinguishing characteristics. The aim of the designers' conjoint work is to find new approaches and strategies for generating socially sustainable objects. The Viennese team is thereby addressing issues of socioeconomic and cultural relevance concerning spaces and artefacts.

Endless Process by the Dutch designer Dirk van der Kooij is an automatic and flexible manufacturing process, through which he can evaluate, finish off and build furniture in recycled plastic from refrigerators without the use of casts. He converted an old industrial CNC (*computer numerically controlled*) extruder into an interfaced mechanical arm that prints, level after level, continuous layers of low-resolution plastic. The robot was made from equipment taken from an old automotive assembly line that the designer was able to modify and hack into a 3D printing robot.

There are two other good examples concerning the recycling of plastics using a DIY approach to the production of materials.

Precious Plastic by Dave Hakkens is a project developing open-source and DIY plastic recycling machines (Fig. 11). The designer stated that plastic is one of the most precious materials on earth. It is lightweight, strong, easy to shape, and suitable for recycling using relatively low reprocessing temperatures and pressures. Nevertheless, effort is often not made into sorting plastics and hence providing a supply of reclaimed materials with which to create new products. The Precious Plastic project developed a set of plastic machines, useful to set up a small-scale plastic workshop. An interesting point is that the machines are based on general industrial techniques, but designed to be easy to build and operate by oneself. Whilst this entire project is still in development, the machines are shared online as an open source and hence improved by the community.

Taking a similar approach, the Perpetual Plastic Project by Better Future Factory is a micro-factory designed as an interactive recycling installation, which lets people make 3D prints from their plastic waste. This project focuses on the idea that old plastic products can be used as filament for 3D printing processes, instead of virgin material stocks. These recycled filaments could be processed to obtain new products. The aim is to change users' perception of plastics and encourage the recycling of plastic items.

4. Opportunities for design

> *The industrial revolution was a revolution of engineers. Now, it is designers who are ushering in a new revolution. Designers work in networks that enable them to develop new materials, their own machines and systems. They are seeking out ways of producing and distributing their work themselves. These developments offer an alternative to mass production, but also point to different ways of organising our economy and society*.(The Machine, www.the-machine.be)

In creating DIY materials, design capability is influenced and shaped interchangeably through 'learning by doing' and 'learning by interacting'. Designers express themselves in making: creating unique materials and products that can reveal their personal touch. Common to all design cases presented in this article is the designers' ability to create unique, personal, and non-repeatable (material) applications. These manifest through imperfect surface qualities, attributable to the uniqueness of the performance that defines self-production processes. As Lee [20] argues, in DIY material design practices, the designer becomes an alchemist willing to self-produce materials following the magic conversion of a substance into another. "*Material perfection was sought through the action of a preparation* (Philosopher's Stone for metals; Elixir of Life for humans), *while spiritual ennoblement resulted from some form of inner revelation or other enlightenment* (Gnosis, for example, in Hellenistic and western practices)" [21]. In DIY material design practices, the designer becomes a craftsperson, able to build and to modify the tools for his/her production aims. A result of the DIY material design process is new aesthetic expressions grounded on 'imperfect aesthetic qualities' that show the existence of an alchemist's (i.e. designer's) manual labour and craftsmanship, and hence traces of humanity. On an emotional level, DIY materials can facilitate 'attachment' due to their

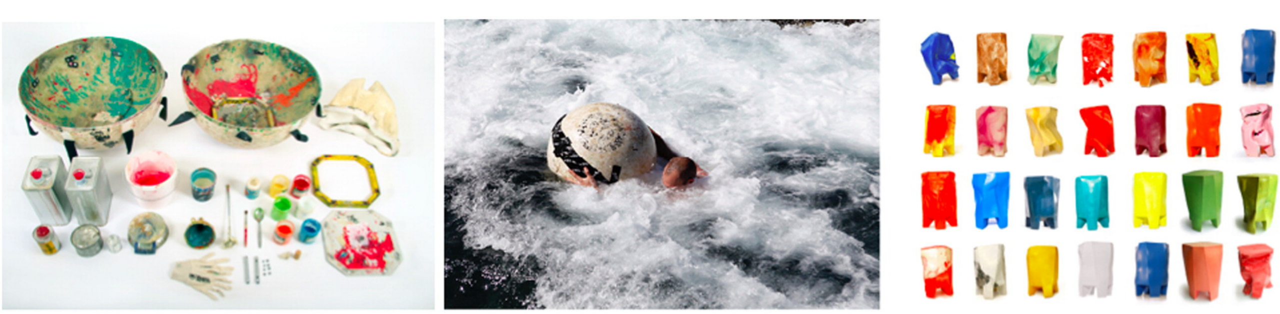

Fig. 10. Original Stool by breadedEscalope, © breadedEscalope.

Fig. 11. Precious Plastic by Dave Hakkens, © Precious Plastic.

self-produced nature (i.e. being proud of what one creates). Or, they can generate 'surprise' amongst those who come into contact with the results: finding out, for example, that a given material comes from recycled coffee grounds or from plastics collected from the ocean.

The predominance of automation processes and quality controls have led to the almost total elimination of errors and imperfections in production artefacts. Thus what we have witnessed across the last century is the dominance of an aesthetic model tied to perfection in every sphere of human life: the body, the life style, artefacts and their materials [27]. Craftsmen shaped clay for centuries with their hands, leaving signs of their expertise through the creation of unique artefacts. Industrial production demanded a shift in approach – not only from making to designing – but also in mind set, to create the 'standard' instead of the 'unique'; to be able to produce in large quantities with reproducible perfect forms and surface finishes. Valorising imperfection is a way of expressing workaday reality and creating innovation. By bending imperfections to our will, intensifying them, and imbuing them with aesthetic value, a new image can emerge [26]. This novel approach to material aesthetics also explains designers' interest in creating unique materials, where imperfection becomes synonymous with added value, originality and personalisation. Hella Jongerius and Gaetano Pesce are two of the first names amongst great contemporary designers who explore ways to add value through defects and imperfect variations arising from a mix of craft and industrial production.

The design and production approach observed in DIY materials is often *naïve* and free from preconceptions related to structured industrial production approaches. DIY materials self-producers have an enormous potential for failure, but at the same time there is a space for the development of innovative materials based on 'undisciplined' innovation processes [10]. In other cases, limited financial and technological resources stimulate self-producers to develop forms of *reverse innovation* [14]. Moreover, the opening of design and production processes can create infinite variations and small improvements of the same materials. This approach, in particular, becomes interesting if the number of self-producers and researchers investigating DIY materials increases: traditional producers may be interested in opening their own knowledge and multiplying the chances of developing democratized technologies. This scenario suggests a fruitfulness to explore the relation between DIY materials and social innovation [24].

DIY materials production, as observed through the case studies reviewed in this article, is characterised primarily by reduced economical investments in R&D and technology (which often are low cost) and secondly for the on-demand and on-site production of small quantities of material. This feature reduces both the economic risks for self-producers and environmental impact of self-production. In many cases design and production of DIY materials is a *trial and error* process. There are no particular negative effects (in terms of economic and environmental impact) if the production process does not work. Any investment in technology can in fact be absorbed: low-cost and multipurpose fabrication technologies (e.g. 3D printers) could be easily convertible. Moreover, other personal fabrication devices are often created modifying (hacking) existing technologies in logic of extreme miniaturization and simplification of industrial processes.

The rise of personal fabrication (digital- or craft-assisted) creates a potential space for the development of customized fabrication technologies that could match a demand for tailor-made materials. Around the concept of DIY materials could be developed entrepreneurial and business models that could reshape the relationship between materials and products: thanks to the growth of digital manufacturing this relationship seems to be reversed. For example, in additive manufacturing the centrality of material and process become apparent: what products can be made starting from these technology and materials? A second point concerns the evolution of DIY materials and how they are produced. In particular, it is important to understand the convenience to scale-up these emerging forms of self-production creating a new kind of industry or new forms of *open and distributed microproduction* [6]. The collection of DIY materials presented in this article reveals a population of self-producers who seem to favour this second option.

DIY materials emphasize the importance to configure the means of production and the creation of the (micro) places where production experiences are realized. Many self-producers are interested in showcasing their production performances as a key aspect in the creation of unique material experiences. In other cases, the self-production is conceived to be itinerant and applicable in different contexts. An emerging global network of community-based fabrication spaces (for experimenting–prototyping–manufacturing) could redefine the concept of materials libraries.

Mass customization and more recently *user innovation* [31] are two growing trends in the world of industrial goods, but do not seem to exist in the industrial production of materials. The large producers do not seem interested in the personalization of materials, but are more interested to offer a wide range of materials covering diverse customer needs. Imagining new services to produce materials on-demand and on-site, taking into account the dynamics triggered by materials self-producers, could bridge this gap. And yet, this gap can be bridged also by developing physical and virtual platforms that allow self-producers access to industrial technology whilst at the same time enabling industry to support design and production processes developed by informal and independent innovators.

Furthermore, DIY materials allow designers to develop a tinkering practice with raw materials (and ingredients) and hone their practical skills with machines and tools for production. They experiment, test, re-test and adjust products and production processes, along the way deriving pleasure and inspiration from the 'learning by doing' inherent to hands-on experimentation. Self-producers act as new artisans, but importantly do not deny all the recent and important technological developments that have affected the world of materials.

5. Conclusion

This paper has introduced and defined the new concept of DIY materials. Through the analysis and structuring of almost 30 case studies, we aimed to illustrate the breadth and depth of the DIY materials phenomenon, highlighting its current and projected importance and abilities to create emerging material experiences.

DIY materials are created through individual or collective self-production practices, often by techniques and processes of the designer's own invention. They can either be totally new materials or modified or further developed versions of existing materials. The development of this new trend in the sphere of materials and design has in part been enabled by the democratization of personal fabrication technologies, in parallel to a rising desire amongst individuals to have personalized products. DIY materials offer great opportunities to positively contribute to product design through material experimentation as well as distributed and shared production processes.

We have created an initially simple two-way classification to consider different types of DIY materials: the first type describes DIY new materials focused on creative material ingredients, whilst the second type describes DIY new identities for conventional materials focused on new production techniques.

Of course as DIY material development increases pace, it will be necessary to add and review cases to check that the existing classification still holds true. Furthermore, we expect a need for follow-up work that seeks to establish sub-categories based on material types of material applications, as well as articulating the phenomenon of DIY materials from other points of view. DIY materials are an in-progress trend that is not currently possible to crystallize or describe operationally within a definitive framework. Certainly, their presence (and their creation by designers) expands designers' vocabulary of material and production dimensions of design, allowing designers to control the whole material creation process and to change the quality of the material or hack the machines or tools performing simple production operations. At this point it is important to take an observational and critical stance: to observe whether DIY materials will develop as a trend and envelope an ever growing number of designers, or whether it will be seen as a fad with an accompanying quick passage having little impact and few consequences in world of design.

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