‘Grow-Made’ Textiles

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Abstract

This paper explores the emergent notion of the ‘grow-made’ by evaluating current work produced for *Mycelium Textiles*, a design research project that investigates the potential for co-making and co-designing with mycelium. Mycelium is the root of fungi, it is composed of a fine network of thread-like branches and is found underground. By cultivating mycelium on a range of substrates, it is possible to grow materials by harnessing its ability to digest and transform cellulosic food into natural composites. This paper will specifically discuss work in progress into mycelium colonisation techniques applied to textiles and their potential to propose innovative patterning processes and slow-grown embellishments for fashion applications. By revisiting traditional textiles and surface embellishment techniques, the project also examines the potential to cultivate the self-assembly properties of living organisms to evolve ‘self-patterning’ textile protocols. Inscribed within an exploration of alternative sustainable fabrication models, the project explores expanded design toolkits and methods for co-making with living systems. Augmented by husbandry techniques, traditional and contemporary textile craft can inform the cultivation of living mycelium for patterning and surface embellishments. Whilst textiles are profoundly anchored in the history of humanity as material and cultural artifacts, they have so far allowed us to navigate both the hand-made and the man-made paradigms. With emergent practices in biodesign, the notion of the ‘grow-made’ is now also possible. What are the implications for the design of our future ‘grown’ materiality? Will ‘grow-made’ materials facilitate the transition to sustainable fabrication?

Keywords

Mycelium; Textiles; Grow-Made; Self-Patterning; Sustainable.

Paradoxically, as we deepen our understanding of the impact of the human species on our finite planet, and as we acknowledge spiraling biodiversity loss and expanding pollution levels, we also witness record efforts to transition towards more sustainable and resilient ways of living: *“While environmental degradation continues there are also unprecedented signs that we are beginning to embrace a ‘Great Transition’ toward an ecologically sustainable future”* (WWF Living Report 2016, p.6). Design has a prescribed function in our manufacturing and consumption models, and therefore has, and will continue to play a pivotal role in shaping our future sustainable materiality. However, production strategies such as recycling, upcycling, optimising energy and material efficiency, and adopting environmentally-aware material sourcing may not be enough in a context of unprecedented levels of human population, and rampant consumption models. Researching alternative design models that transcend the conventional problem solving approach and explore new production paradigms can help transitioning to a more holistic and resilient future. We need to shift away from the so-called ‘Anthropocene’ era, where human activities have begun to impact on the geological planetary forces (Crutzen P, 2007). Rachel Armstrong argues that *“We need to enable the Ecocene – whereby human scale events augment and enhance the living ecosystems of our planet*” (Imhof, Gruber 2016, p. 12). Questioning and reinventing the very materiality we prescribe and script during the design process is becoming paramount to facilitate a transition towards the Ecocene. The research project ‘Mycelium Textiles’ is very much inscribed within that fundamental exploratory phase and aims at harnessing the qualities of living mycelium to re-imagine ways of growing and embellishing textiles. The design-led development of mycelium materials is a fairly recent yet fast expanding field. The artwork of Philip Ross and design studios like Maurizio Montalti at Officina Corpuscoli and Erik Klarenbeek have opened up a vast array of possibilites to develop new materials, from 3D printing to the recently launched leather mycelium (MycoWorks/Philip Ross, USA). Ecovative, one of the world leaders in mass manufacturing mycelium-based material produces packaging and insulation boards by growing mycelium onto agricultural waste such as corn husks, hence forging the way for circular sustainable models of production*: “The infrastructure, knowledge and technology needed to grow fungal materials are already here and in place. Putting them to work is mostly a matter of reconfiguring and joining together several different manufacturing processes as an integrated system.”* (Ross 2016, p. 258).

Textiles is a very impactful, energy hungry and oil dependent industry. Yet we cannot imagine a future world without textiles. Can we develop co-designing strategies with living systems such as mycelium to grow patterns, surface coatings and embellishments that could replace current oil-based textile processes? Can we develop a circular model that integrates local biomass waste for the production of local textiles for fashion? Section one of the paper will contextualize this project within the emergence of biodesign and discuss a critical framework for designing with the living. Section two will discuss the project ‘Mycelium Textiles’ to date. Finally, section three will elaborate on the emergence of the ‘grow-made’ paradigm in the context of future textile production and scenarios for circular production.

1 / Designing With Living Systems

In the past decade we have witnessed the rapid emergence of biodesign. This new field of design is driven by an inquiry into future living that arises from the intersection of biology and design.

> *Biodesign goes further than other biology-inspired approaches to design and fabrication. Unlike biomimicry, cradle to cradle, and the popular but frustrating vague ‘green design’, biodesign refers specifically to the incorporation of living organisms as essential components, enhancing the function of the finished work (Myers 2012, p. 8).*

With biodesign, the mainstream and conventional methodologies for research and development are radically altered by the notion of working with living systems as opposed to inanimate matter. Designers have begun to expand their roles from scripting the form-shaping of existing inanimate materials, to creating and growing new biological materialities.

As a design researcher, I began exploring methods of intersecting biology and design in 2007 as a means to inquire into new models for sustainable design. Apprehending principles of biomimicry led to unravelling the deeper implications of relating to the Natural world as a designer. Whilst grasping the notions of Nature as a model, mentor and measure (Benyus 1997, p. 0) I also became aware of the latest research in synthetic biology, and the unprecedented possibility of coding new genomes and creating new species designed to produce bespoke substances. As these two approaches collided, one emulating the values of life, the latter proposing the ‘hacking’ of life, I needed to situate the designer’s evolving role in working across biomimicry and biology.

> *Mastery of the formation and growth principles that are specific to living organisms has inaugurated a genuine meta-ecology. A profound transformation of the very concept of Nature has therefore been set in motion, which is indissociable now from artificiality, from technical and technological production.’ (Brayer, Migayrou 2013, p. 11).*

To address this transformation of our perception of the Natural world, I began to develop a framework for designing with the living that elaborated a critical stance and defines three strategies for advancing biodesign: ‘Nature as a Model’, ‘Nature as a Co-worker’, Nature as a Hackable system’ (see Fig.1). This framework emerged out of a mapping exercise that led to the curation of the exhibition ‘Alive, New

Design Frontiers' held at the foundation EDF in Paris in 2013. The exhibition applied the framework below as a means to engage with a critical lense to review the benefit of biodesign for future sustainable living.

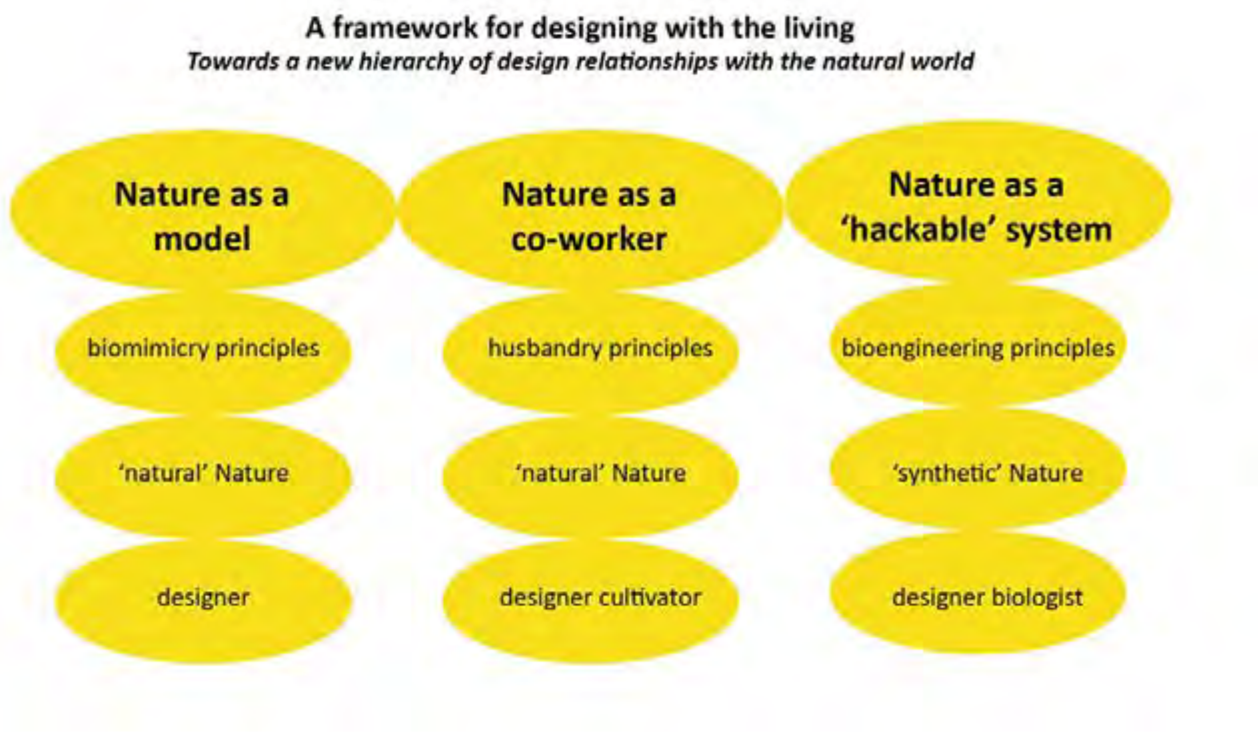

Fig.1 © Carole Collet 2013

Today, the field of biodesign is fast growing, and the fascination to explore biology through design permeates a new generation of designer, eager to engage with new techniques and technologies. Whilst not all biodesign projects are concerned with environmental issues, my design research is ultimately driven by an inquiry into disruptive and alternative models for sustainable design and fabrication. In this context, the three pathways highlighted in the framework above help identify a set of principles for collaborating with the living and help reposition the role of the designer within a sustainable discourse.

The first category 'Nature as a Model', relates to biomimicry principles that endorse the emulation of natural systems, and is based on the understanding that Nature's production system is pollutant free, operable at ambient temperature and relies on a circular cyclic material value system, where the waste of one entity becomes the food of another. The integration of biomimicry principles into architecture, design and manufacture is well established even if not a prominent model yet. Architects such as Michael Pawlyn have demonstrated that the study of the desert beetle can lead to engineering a building that generates its own micro climate. *'For virtually every problem that we currently face – whether it is producing energy, finding fresh water or manufacturing benign materials – there will be numerous examples in nature that we could benefit from studying'* (Pawlin 2011, p. 1). Research into the nano-structure of a shark's skin has led US-based Sharklet Technologies to develop synthetic wall coverings for hospitals that mimic this nano-structure to repel super-bacteria. In textiles, Interface, a carpet manufacturer, has led the way in deploying biomimetic principles to reduce the environmental impact of toxic chemicals used in carpet manufacturing. However, whilst the adoption of biomimicry principles has led to innovative achievements, too often the end-product integrates fossil-based materials and energy in its production chain. For example, Velcro, a material that can attach and detach infinitively and which was developed by mimicking the structure of the Burdock seed, is effectively bio-inspired, but not sustainable as such. It is actually produced in a conventional manufacturing system, and made from non-renewable, non-biodegradable oil-based polymer. So biomimicry, whilst a step in the right direction, does not always lead to sustainability per se, as we too often deploy biomimicry principles in the design phase, but have to rely on conventional production and sourcing in the manufacturing stage.

The second category, 'Nature as a Co-worker', integrates biomimicry principles with biology and husbandry principles and fosters the integration of living organisms in the creation or production process. The project 'Mycelium Textiles' sits in this category. Here the designer goes beyond imitating Nature as a model to become a 'cultivator' and engages with processes akin to husbandry and gardening. By biologising the design brief (Benyus, 1998), the designer sets a protocol for collaboration with a living organism, and thus relies on the inherent sustainable advantage of Nature's method of production. In a more conventional context, a designer will select materials, be they natural or synthetic, to either specify a set of manufacturing processes or to directly work with it, as an artisan. Here the designer engages with form-shaping strategies as the living material grows. The morphogenesis of the end-product is defined a) by the design intervention at the onset and/or during the growth period, b) by the ability of the designer to create and maintain the appropriate conditions to sustain a natural organism alive, and c) by the living organism itself. By directly collaborating with a natural organism (a living factory), the designer can incorporate properties of the living in the production of artefacts. Here, the designer becomes a cultivator, whilst manufacturing becomes 'horticulturing'.

The third category, 'Nature as a Hackable system' is a radical new proposition that emerges from advances in synthetic biology. Synthetic biology is defined by the Royal Society as *"The design and construction of novel artificial pathways, organisms and devises or the redesign of existing natural biological systems"* (The Royal Society, 2016). It is now possible to create new species by writing up new genomes on a computer, which is then synthetized in DNA form, and 'booted up' in simple living organisms such as yeast, bacteria, microbes and algae. By doing so, we can tune these genetically coded living factories to produce a chosen substance. For instance, a bacteria can be reprogrammed to produce biofuel, a yeast can make silk, or vanilla, whilst tissue engineering techniques enable us to grow leather in a lab. Since 2016, the textile industry has access to commercial silk produced by yeast, and companies such as The North Face and Adidas have begun to integrate these new bio-synthetic materials into their production lines. Innovative companies such as Bolt Threads (biosilk) and Modern Meadows (tissue engineered leather) argue that these new means to produce textiles are leading the way in terms of new alternative sustainable production strategies. The paradox here is that synthetic biology is effectively a form of extreme genetic engineering which is taking advantage of natural biological processes, but recoded to suit our industrial purposes. Whilst it is too early to fully assess the sustainable impact of such production, we also need to remind ourselves that currently *"Textiles is fourth in the ranking of product category which cause the greatest environmental impact, just after food & drinks, transport and housingfu"* (EU commission, 2013, p 1). Polyester and conventional cotton are the two most used fibres in the word (Ethical Fashion Source 2016, p. 2), the first is made from non-renewable oil, whilst the latter relies on damaging agricultural and heavy polluting practices with intensive use of pesticides and fertilisers. So any alternative propositions that enable us to reduce the environmental impact of the textile industry are worth exploring.

The following sections will present and analyse current work in progress of the *Mycelium Textiles* project and discuss the emergent paradigm of the 'grow-made' versus the hand-made and the man-made.

2/ Mycelium Textiles – Process and Development:

The project *Mycelium Textiles* is an experimental collection of materials and artefacts that explores the future of mycelium growth as a potential new sustainable surface treatment for textiles. As such the project explores the dynamic forces of a living system and its evolving resulting materiality more so than simply designing predetermined forms to constrain and shape matter.

The aims of this design-led material research are a) to produce both soft and structural textile qualities by experimenting with the environment of growth of the mycelium b) to develop new biodegradable, compostable coatings for textiles that can replace current oil-based finishing processes, and c) to develop protocols that encourage self-expression and self-patterning techniques in mycelium materials. The basic principle of growing mycelium material in a controlled environment relies on the ability of mycelium to absorb the substrate onto which it is growing and to transform it into a composite substance. A mycelium culture is introduced into a sterilised substrate, and depending on the type of culture, the temperature and humidity level, will take several days or weeks to colonize its food. Once the colonization process is complete, the material is baked to kill the living mycelium and to dry the finished material. Simply tuning the parameters of growth will result in a variation of materials. As Philip Ross, an artist and pioneer in developing mycelium-based materials, explains: *"fungi are very sensitive to their surroundings, and by altering subtle factors it is possible to make their tissue express a range of variably determined physical characteristics"* (Ross 2016, p. 255).

The design research project *Mycelium Textiles* uses a range of materials from waste coffee grounds, to agar and natural textile fibres such as hemp, sisal, soya bean fibre, raw silk, organic cotton and linen as a starting point (see fig 2). These foundational materials provide a transformative grid that harness, support or resist the life of the mycelium.

Fig.2: selected range of materials used to develop the *Mycelium Textiles project. Photography* © Carole Collet 2016

The symbiotic temporality of these pre-configured materials interacting with the living mycelium culture results in evolving a variety of surface tensions and textility. The project to date consists of a series of experiments that are derived from traditional textile surface patterning techniques revisited to incorporate protocols for mycelium growth. Methods such as mending, starching, screen printing, and resist-patterning techniques have been re-interpreted and adapted to a new context of use. Examples include:

Tartan Mycelium: Here the classic check pattern is created not by a woven construct of coloured yarns, but by using strips of natural unbleached hemp layered out in a check formation at the bottom of a mould containing waste coffee ground. As the mycelium culture slowly colonized the mould, the hemp strips began to deteriorate and effectively biodegrade. The mycelium incorporated part of the degrading hemp into its growth. After three weeks, the material was removed from the mould to be baked. The result is a striking colour difference with a rusty brown or a black where the hemp strips had been layered, and a white background where the mycelium only had coffee for food. We also notice on this sample a spill out of the mycelium which is overgrown in some part as it escaped the mould it was contained within (see Fig.3, left side of the photograph).

Fig.3: Tartan Mycelium © Carole Collet 2016

Mycelium lace. In this case, mycelium is used as a mending technique on damaged or vintage lace. By colonizing parts of the lace, the mycelium contributes to reinforcing its strength, as much as it can create a surface coating akin to starching, thus allowing to render a host material softer or stronger. By encouraging the mycelium to grow in some parts of the fabric more than in others, the growing skin can act as a repair mechanism (Fig 4). Fig. 5 shows how mycelium is used to create a permanent fold into the lace, this is done by growing mycelium in a part closed, part open mould. Traditionally a permanent fold is achieved by heat-setting a polyester-based fabric, using a paper mould, and is a high energy process. Here, 'growing' a single fold happens at ambient temperature over a period of twenty days. This is now being developed further to achieve a series of folds.

Fig.4: Mycelium Lace © Carole Collet 2016

Fig.5: Detail of permanent fold on Mycelium Lace © Carole Collet 2016

Mycelium velvet: One of the current experiment aims at emulating velvet qualities both in terms of shine and tactile qualities. Current results focus on two techniques: one consists of growing mycelium on a base cloth covered with a fine layer of waste coffee grounds (Fig.7), the other encourages mycelium to grow away from a central food point (Fig.6). While the shine and softness qualities are expressed with these techniques, the samples are not even, and not as fluid as a velvet cloth yet, and experimentation continues.

Fig.6 & 7: Mycelium velvet experiments © Carole Collet 2016

Self-patterning mycelium rubber: One of the characteristics of a living system is its autopoietic quality. As the work developed I found that I was as much resisting and combatting self-expressive qualities of the mycelium as I was trying to encourage them. In one experiment I developed a protocol that encouraged the mycelium to manifest its self-organised behaviour in the form of visible patterns, thus exploiting self-assembly qualities inherent to biological systems. As seen in Fig 8 & 9, the patterns, reminiscent of floral designs are actually produced by the mycelium itself, rather than being shaped by a mould. The flowers 'grew' over a period of three weeks on the open surface of the food substrate. In addition, this particular process resulted in the creation of a rubber like material, with very flexible and elastic properties. It is washable and biodegradable (for patenting reasons, the exact protocol cannot be revealed at this stage of the research). Here I have designed the environment of growth, but the mycelium itself created the floral patterns, so who is the designer? Can we speak of co-design in this context? As with all collaborations, it is the evolving creative tension between the partners, or the co-workers that is evidenced in the end-result. In this instance, balancing the act of nurturing versus controlling the growth of mycelium is the role of the designer 'cultivator'. The aesthetic and tactile qualities of the end-product are the result of this symbiotic evolution, not the mark of a predetermined design intention. In other words, the goal was not to attempt to design a floral pattern, but to let the mycelium express itself and take control of the final aesthetic of the material. It so happened that the mycelium expressed itself in a form of fractal patterns, akin to floral designs. This is very much a novel approach for designing textiles.

Fig.8: Self-patterned Mycelium Rubber, showing the flexibility of the material
© Carole Collet 2016

Fig.9: Self-patterned Mycelium Rubber, details of the self-grown floral patterns
© Carole Collet 2016

The examples above showcase some of the most successful experiments. These rely on a tacit understanding of traditional textile processes, and their creative re-interpretation in developing mycelium growth protocols. But for each successful experiment, there is a range of failed samples which are crucially important in developing new knowledge. Failure is a useful research tool. Each experiment is recorded in terms of process, type of mycelium culture, temperature, humidity level, and light conditions. Each failure helps to reassess the process to evolve new ones. By witnessing the morphologic evolution of the materials and establishing a dynamic dialogue between the design intention, and the dynamic autopoieitic characteristics of living mycelium, new materials can emerge. Below is a range of failed experiments which continue to inform current work in progress. One of the most common issues has been contamination of the samples. The materiality of contaminated samples are defined by dynamic prevalent forces, and by which organism wins the competition for life.

Below is a mycelium culture growing on vintage lace (Fig. 10 & 11) and mycelium culture growing on a cube of agar placed onto a linen cloth with waste coffee grounds (Fig. 12). In both cases, the microbial contamination (visible as grey powdered texture) has covered the surface of the cloth faster than the mycelium has grown, but after six weeks, the mycelium (seen as a white mesh) is starting to fight back and has begun to expand again. Could contamination therefore be used as a resist process?

Fig.10 & 11: contaminated mycelium sample grown on vintage lace and coffee ground.
© Carole Collet 2016

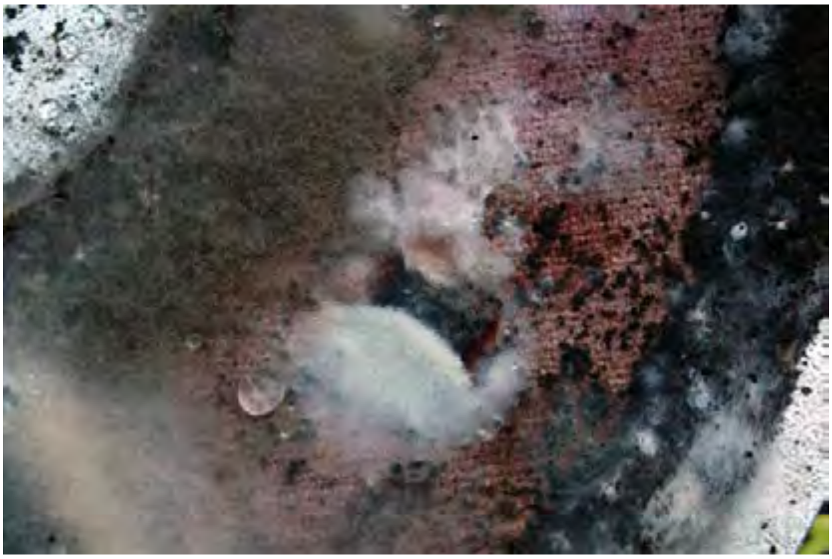

Fig.12

For designers, co-working with living organisms transcends the conventional definitions of the hand-made and the man-made. If as argued by Ingold, practitioners*, "are wanderers, wayfarers, whose skill lies in their ability to find the grain of the world's becoming and to follow its course while bending it to their evolving purpose"* (Ingold 2011, p. 211), then, by co-working with organisms such as mycelium, designers have the opportunity to evolve their purpose and develop alternative sustainable bio-materialities.

3/ Grow-made Textiles

We have a long-established history of cooperation with living organisms. Making wine, baking bread and maturing cheese are all evidence of a historical sustained ability to exploit the living qualities of yeast to make food. For designers, controlling the morphogenesis of living materials enables a new form of expanded design practice. However, *"not all aspects associated with life are welcome in technology. In our human-made systems, we strive for predictability, controlled processes and defined outcomes"* (Imhof, Gruber, 2016, p. 22). How can we then incorporate living dynamic qualities into our production systems? One option is to design fully controlled environments of growth to alleviate any variables, such as achieved by Ecovative and MycoWorks when mass-manufacturing mycelium packaging materials. The other is perhaps to apply soft control systems such as used in bread making. Fig.13 shows a monitoring board used to record the various ambient parameters in a sourdough specialist bakery in East London.

Fig.13. E5 bakery, East London. Photography Carole Collet

This board is used to compare the baking of bread from one day to the next. As the bread is sold at a fixed price, bakers aim at achieving some form of regularity even though the starter sourdough they work with will respond differently to daily changes in ambient temperatures. The monitoring board records the room, water, and flour temperature. On the left is the name of the different breads: MG stands for Multi Grain, HW is for Hackney Wild and so on. This board enables bakers to fine-tune their recipes in accordance with the results of the previous day. This picture was taken early on a Friday morning so the Friday column is still empty. Although the bakery does not operate within a fully controlled environment, by monitoring the day to day variables bakers can adapt the recipes and manage to produce loaves of bread that are consistently regular in forms and taste. This strategy is a means to address issues of control and predictability when manufacturing with living organisms.

So the integration of biology into material systems is both a historical practice as seen with baking, and a contemporary sustainable form of production as implemented by companies such as Ecovative and MycoWorks. In both models, the developmental morphogenesis of a material can become a site for design intervention. This requires a new approach to design and a need to revisit our understanding of creating forms. From an anthropological perspective, the process of co-designing with a natural organism resonates with Deleuze and Guattari's argument that *"the essential relation, in a world of life, is not between matter and form but between material and forces"* (quoted by Ingold, 2011, p. 210). As seen in the section above, developing mycelium textiles is the result of a tension between dynamic living forces, environmental parameters and materials. By encouraging metabolic functions or preventing them, grow-made protocols contribute to intersecting new material agencies.

This approach seems to challenge the unbalanced hierarchy between form and matter inherent to Aristotle's holomorphic model.

> *To create anything, Aristotle reasoned, you have to bring together form (morphe) and matter (hyle). In the subsequent history of Western thought, this hylomorphic model of creation became ever more deeply embedded. But it also became increasingly unbalanced. Form came to be seen as imposed by an agent with a particular design in mind, while matter thus rendered passive and inert, became that which was imposed upon'* (Ingold 2011, p. 210).

Co-working with living organisms allows us to incorporate active and dynamic qualities to matter, which is not rendered 'victim' of a shape-forming activity, but rather becomes the enabler of the morphogenetic process. *"Organisms are bundles of relationships that maintain themselves by adjusting their own behaviour in anticipation of changes to the patterns of activity all around them"* (Weinstock, 2010, p. 22). Understanding these behaviours is the main concern in engaging with grow-made materials. Designers will have traditionally learnt how to master hand-made techniques to shape materials, and they will have explored a range of manufacturing processes to control and exploit the properties of man-made materials. They are used to working with a material once it is grown, or killed and harvested (such as cotton) or once it is man-made (such as polyester). With grow-made textiles the hierarchy between matter and form is transformed into a symbiotic and evolving relationship. In 1917 scientist Wentworth D'Arcy Thompson argued that a form, living or not, is the result from the *'diagram of forces'* that have acted upon it. We can argue then that to grow-make a textile, designers have to understand and harness the forces that can influence the dynamic properties of life. This is a new paradigm both for the design discipline and for the textile industry. We can grow new biodegradable materials such as the self-patterned mycelium rubber above, or the mycelium leather launched by MycoWorks in September 2016. But we can also begin to explore how to grow finishing and coating processes that can replace polymer-based techniques such as pigment printing. We can use mycelium to repair and mend cloth, or to give it structural properties, and we can fine-tune a range of biodegradable coatings grown at ambient temperature. This is still very early on, but the potential of grow-made mycelium textiles can propose a new set of options for sustainable textiles, fit for the circular economy.

Conclusion

This paper discusses the emerging paradigm of the 'grow-made' arising from new practices in biodesign. Using a design research project 'Mycelium Textiles' as a focus to unravel the potential of developing alternative sustainable design and textile production models, the paper starts by positioning biodesign practices within a hierarchical framework. Going beyond biomimicry and the emulation of natural systems, the paper showcases how strategies for co-working with a living organism such as mycelium can lead to evolving a new bio-materiality that incorporates the advantages of biological fabrication. To fully explore the potential of biofacturing, designers need to expand their practice and incorporate a new skillset that enables them to nurture and control the behaviours of living organisms. Whilst the development of new materials has predominantly been the remits of engineers and material scientists, designers are now expanding their roles from shaping existing materials, to creating and growing new ones. Designers can now navigate the hand-made, the man-made and the grow-made to imagine sustainable alternative propositions for the future. As the 'Mycelium Textiles' project continues, the next step will be to grow a range of finished textile and fashion accessories that fully exploit the potential of slow-grown embellishments with mycelium colonization techniques.

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Carole Collet has dedicated her career to developing a new vision for design, and pioneered the discipline of Textile Futures at Central Saint Martins in 2000. She is now Professor in Design for Sustainable Futures and Director of the Design & Living Systems Lab at Central Saint Martins, University of the Arts. Her research focuses on exploring the intersection of biology and design to develop speculative and disruptive sustainable design proposals. Collet's ambition is to elevate the status of design to become a powerful tool that contributes to developing innovative paths to achieve the 'one planet lifestyle'. Her recent curation of '*Alive, New Design Frontiers*' (www.thisisalive.com) questions the emerging role of the designer when working with living materials and technologies such as synthetic biology, and establishes an original framework for designing with the living via the lens of sustainability. One of Collet's characteristics is that she takes on different research roles, from designer, to curator and educator. This enables her to develop an informed critique of both the design outputs and the design contexts, from making knowledge to framing knowledge. Her work has been featured in international exhibitions and she regularly contributes to conferences on the subject of textile futures, biodesign, biomimicry, synthetic biology, future manufacturing and bio-materiality, sustainable design and climate change.