Chapter

Frontiers of Adaptive Design, Synthetic Biology and Growing Skins for Ephemeral Hybrid Structures

Sandra Giulia Linnea Persiani and Alessandra Battisti

Abstract

The history of membranes is one of adaptation, from the development in living organisms to man-made versions, with a great variety of uses in temporary design: clothing, building, packaging, etc. Being versatile and simple to integrate, membranes have a strong sustainability potential, through an essential use of material resources and multifunctional design, representing one of the purest cases where "design follows function." The introduction of new engineered materials and techniques, combined with a growing interest for Nature-inspired technologies are progressively merging man-made artifacts and biological processes with a high potential for innovation. This chapter introduces, through a number of examples, the broad variety of hybrid membranes in the contest of experimental Design, Art and Architecture, categorized following two different stages of biology-inspired approach with the aim of identifying potential developments. Biomimicry, is founded on the adoption of practices from nature in architecture though imitation: solutions are observed on a morphological, structural or procedural level and copied to design everything from nanoscale materials to building technologies. Synthetic biology relies on hybrid procedures mixing natural and synthetic materials and processes.

Keywords: adaptive design, membrane technology, synthetic biology, ephemeral design, sustainable design

1. Introduction

Manipulation of the environment can arguably be considered as a natural trait of adaptation in a broad range of animals, from nesting and building of complex architectures to the use of tools in mammals, birds, reptiles, fish and some invertebrate species. Mankind remains however the undisputed leader in the field, and membrane structures encompasses a big share of the early tools employed by Man. First made of natural skins, then woven fabrics and as technology evolved, progressively more and more synthetic materials have been employed to manufacture membranes for wearables, packaging and shelters. In fact the end-use of membrane structures has not drastically changed since. The features and the complexity of the manufacturing however have.

Membranes are traditionally classified into synthetic or biological, and are in both cases essential for life on (and outside) Earth, being responsible for regulating all type of energetic exchange between a given organism and the synergetic system(s) it is part of. The nature of each membrane varies with its function, and can differ fundamentally in structure, size, transparence, etc. [1]. Today, in the age of nanotechnology and gene manipulation, technology prepares for a new paradigm shift where the borders between natural and artificial, designed and evolved, produced and grown become ever more indistinct.

Technological innovation and scientific intuition are strongly influenced by other fields, among others Design and Art, as (r)evolution in one domain impacts the others [2] and developing markets can powerfully drive innovation. As technology and science rediscover how performing Nature-evolved solutions actually are, and how important it is for us to design sustainably, preserving the balance of a system we are a part of, adaptivity becomes an interdisciplinary rising business and trend. Automated homeostasis and transient features to integrate in artificial artifacts become sought-after aspects even in Architecture, a very conservative sector, where design has for a long time been interpreted as in distinction or even in opposition to Nature. Innovations in materials and technologies are very rarely developed in this field: solutions are traditionally built to last for long times and are applied over very big scales, hence prioritizing cautious and low-cost solutions. Introducing change is risky and needs to be justified by consistently adding efficiency to the system. This new rising model is therefore bringing a true revolution to the whole sector: it involves on one hand an intellectual effort to rethink dogmatic preconceptions as longevity, stability, and performance in built environments, and on the other, the incorporation and adaptation of new technologies and materials [3]. Generally, new concepts and materials are first adapted in more progressive and experimental fields that are closely related to Architecture, as Art and Design, which dare to take bigger risks.

The field of Arts and Entertainment is wealthy and free enough from building codes, users' needs and requirements to allow experimentation. Being consistently smaller, artworks are generally far less expensive to manufacture than buildings, allowing more experimentation and a broader diffusion by being displaced and exhibited in nonstandard locations to reach a broader public. Art is therefore a great occasion to test and advertise ideas, raising the interest of users and developers. It is not a chance that many new solutions that have further developed in architecture have started as part of an artwork or an exhibition pavilion.

Industrial design is today going through huge changes due to the growing interest and demanding taste of consumers, the use of new materials and technologies, which allow the insertion of the most charming features, opening up to new dimensions of esthetically choreographing change. As expressed by designer Raymond Loewy, "Ugliness does not sell," and companies commit a lot of attention in designing every aspect of a product. Today a huge innovation potential is linked to new materials, which can develop entirely new concepts and markets: products become animated, adding character, life and desirability [4].

This chapter introduces, through a number of examples, the broad variety of hybrid membranes in the context of experimental Design, Art and Architecture. The case-studies are categorized following two different stages of biology-inspired approaches. The first, Biomimicry, is founded on the adoption of practices from nature in architecture though imitation. Solutions are observed on a morphological, structural and procedural level, then copied to design everything from nanoscale materials to building technologies. The second approach, Synthetic Biology, relies on hybrid methods mixing natural and synthetic materials and processes.

In order to enable to overcome old preconceptions and widen the conceptual boundaries, "Membranes" will in this context be defined in the more primitive sense of the word, *a thin selective barrier allowing some effects to pass, while halting others*.

2. Biomimetic, inspiration and imitation of nature

Biomimicry introduces the concept of observing, understanding nature, and learn from the fittest solutions instead of searching what to extract from nature or harvest parts of organisms as raw material. Ideas are borrowed and reinterpreted into another context leaving Nature untouched and available for others to draw inspiration from [5]. Inspiration often proceeds from biology to design, as a natural phenomenon suggests a new way of solving a challenge, but the process can also be inverted, from design to biology, where a challenge in the technical world is identified and a solution is searched for among organisms or ecosystems achieving similar functions.

These solutions are still very new to the market and, for a great majority, too expensive for being used in architecture. Useful applications can however be found in the near future, for temporary shelters, pneumatic membrane structures, adaptive facades as well as for multifunctional and responsive interiors. Our buildings are evolving towards a non-mechanic, material-integrated adaptivity allowing the structures to meet external and internal changes in climate and user behavior.

2.1 Biomimetic material structures

With the emerging field of nanomaterial technologies, scientists become the architects of matter. Materials are designed with unique proprieties observed in natural materials, "hacked" and artificially designed for man-made applications.

2.1.1 Membranes with enhanced performances

We are rediscovering how Nature proportionally outperforms synthetic man-made structures in almost all aspects: spider silk is 10 times more resistant than Kevlar [6], grass stalks are thinner and more flexible than any man-made bridge, etc. The observation and study of these structures on microscopic level allows a more thorough understanding of how Natures does it, and to copy the solutions. Thanks to nanotechnology, a whole new category of engineered materials is being manufactured with boosted proprieties: super resistant, ~absorbing, ~light, etc.

Spacer textiles, or 3D textiles, have a dual wall structure with a space in between of a few millimeters up to tens of centimeters, giving the possibility to create a specific microclimate in the cavity, making the material light and robust. These are used in a broad range of contexts, from functional clothing, furniture and vehicle design, construction and transport of temporary structures [7].

Drag reducing fabrics are highly flexible and light spandex/nylon composites with drag-reducing water-repellent features, mimicking the surface of shark fins, which have made them the new high-tech innovation in the field of competitive water sports, improving glide through water with a 38% reduction in resistance. Manufactured swimsuits are designed covering arms and legs, with bonded seams to further reduce drag, also providing compression to maximize muscle performance and reduce the entry of water between the suit and the body [8].

Soft organic photovoltaic cells (Soft PV) are a new rising technology in the field of Building Integrated Photovoltaics (BIPV). Researchers are testing printed polymeric PV cells fabricated onto carbon nanotube-based electrodes upon various flexible and translucent ethylene tetrafluoroethylene (ETFE) building components [9]. The prototypes are thought of as possible prefabricated shading systems, easy to integrate in energetic retrofittings of existing structures.

2.1.2 Propriety changing membranes

In imitation of many defensive adaptations in nature, a growing category of smart materials is being developed with propriety changing features. These materials change one or more of their characters in reaction to influencing factors as light, heat, humidity, etc., and have in the last years been emerging in functional design and clothing, not only at a conceptual stage, but are in some cases market ready.

Self-healing membranes are still a young research area, with an anticipated enormous economic and sustainability potential. These materials, polymers and elastomers in the case of membranes, autonomously counter degradation and micro-damage by adding a repairing agent or acting from inside, eventually in response to an external stimulus [10]. German and Swiss researchers are working on a biomimetic liana-plant inspired solution to realize a self-healing polymer membrane for load-carrying pneumatic structures for lightweight constructions. The principle is the expansion of a two-component polyurethane and polyester foam, as a temporary "first aid" layer autonomously expanding in the event of a hole in the pneumatic structure and a sudden exposure to a rise in pressure [11, 12].

Thermo-regulating textiles using micro-encapsulated Phase-Change Materials (PCM) are relatively new to the textile market, although they have been employed for about 30 years by Nasa. These textiles allow absorption, storage and release of thermal energy at pre-programmed temperatures, for widely diversified applications from sportswear to bed textiles [13].

The "*textile in a can*" patented technology allows to spray non-woven fibers (natural, synthetic, recycled or biodegradable), liquefied in an evaporating solvent, directly upon surfaces, allowing the fibers to bond forming an instant fabric. The material can be applied with varied degrees of hardness (even as casts for broken bones), is repairable (re-sprayable) and recyclable. Most of all, from a designer's point of view, this type of innovative application dispenses the realization process of any artifact from the constraints of cutting, stitching or fitting the surface to its support (**Figure 1**) [14].

Figure 1.
Dress realized with the sprayable textile technology [14], and the "Oricalco" shape-memory shirt [15].

Shape memory (SM) fabrics integrate smart fibers (mostly SM polymers or Nitinol, a Titanium alloy), with the ability to recover a pre-programmed shape, in reaction to changes in temperature (or in some cases to light). Applications in the field of Design include both wearables and furnishings [16]. A small-medium Italian enterprise manufactured a long sleeved shirt using SM alloys, programming its "autonomous ironing" if heated up under a flux of hot air, as that of a hairdryer [15].

2.1.3 Ecological membranes

In the case of certain applications, using a material, which automatically breaks down and dissolves after a set time, becomes an asset. Following the example of Nature, which lives and thrives in the same ecosystem where it manufactures and recycles its own substances [5], a growing number of natural and biodegradable films and surfaces are being developed for packaging first and foremost, but not only. Moving past petroleum-based artificial fibers, towards protein-based building blocks, we could be on the verge of a new textile revolution. In this case, man uses Nature as a co-worker, developing new techniques to craft materials in a way that is more similar to gardening and farming than to manufacturing [17]. As decaying processes are not reversible, the applications in design and architecture become not only interesting, but also extremely innovative.

Natural fiber membranes are developed in a huge variety of raw materials, in many formats and for different uses, from fire- and tear-resistant banana paper [18], mushroom leather used for surfaces from shoes to furniture [19], cork composites available even in thin flexible sheets and bark cloth lampshades [7].

Bioplastics and *biocomposites* are, from being considered as niche products, quickly developing and expanding in importance. A team from Barcelona's Iaac (Institute for advanced architecture of Catalonia) has developed bioplastics from food waste based on orange peels [20]. In a similar direction, Dutch designers developed an algae-based polymeric bioplastic fit to dry and process into a 3D printable material (**Figure 2**) [21].

Engineered spider silk has been attempted by many material researchers, as spider silk is known to be one of nature's strongest materials. As spiders cannot be farmed, scientists and companies are attempting to mimic this natural protein-based fiber. Researchers at the University of Cambridge have designed non-toxic highly tensile-resistant hydrogel fibers made 98% out of water. Apart from the proprieties

Figure 2.
3D printed cup with algae-based filaments (right), realized by Luma Foundation in collaboration with Musée Départemental Arles antique; (left) sample of Cladophora macroalgae [21].

mimicking those of the spider silk (although not nearly as strong), the new method has shown how synthetic fibers can be manufactured without relying on high-energy and toxic processes [22].

2.1.4 Interactive membranes

Interaction seems to be the new frontier for materials as well as in many other fields, in the Era of Informatics. Smart and interactive fabrics have enhanced virtual proprieties being enabled to sense and communicate information, taking us a few steps closer to Artificial Intelligent (AI) systems. Technology becomes wearable and integrated into all kinds of products from toys to life-saving devices.

Light emitting fibers are closing the technological efficiency gap with the organic LED (OLED) technology, offering however low-cost and low-energy manufacturing conditions. Light-emitting electrochemical cells (LECs), are generally single-layer devices sandwiched between two electrodes, area-emitting light in any color. These can be obtained from 100% environmentally friendly raw materials, promising cost-efficient applications that have so far been applied on or integrated with plastics, paper, textile, and metal [23]. Lightweight and flexible, the fibers can potentially be woven into textiles to create smart fabrics for any application from wearable electronics to next generation lighting.

Monitoring fabrics are still experimental and mostly rely on micro-electro-mechanical systems (MEMS) to measure physiological parameters for health monitoring and protection. This is the case of the stretchable ultrathin display consisting of micro LEDs mounted on a rubber sheet, designed by Japanese researchers to transmit wireless biometric data to a cloud platform [24]. A different case is the conductive cotton thread developed by researchers of the University of Michigan, "smartened" by infusing the fiber in carbon nanotubes and polymer solutions with added antibody anti-albumin able to detect blood, which has a potential use in high-risk professions [25].

*Electroactive polymer*s (EAPs) make artificial muscles. "ShapeShift" is a dynamic surface material to explore the potential of its application in Architecture. The elements are made of pre-stretched films on flexible acrylic frames, sandwiched between two compliant electrodes, and able to stretch under the action of high DC voltage. Through the connection of more elements maximization of the kinetic effect was enabled, allowing the structure to support itself (**Figure 3**) [26].

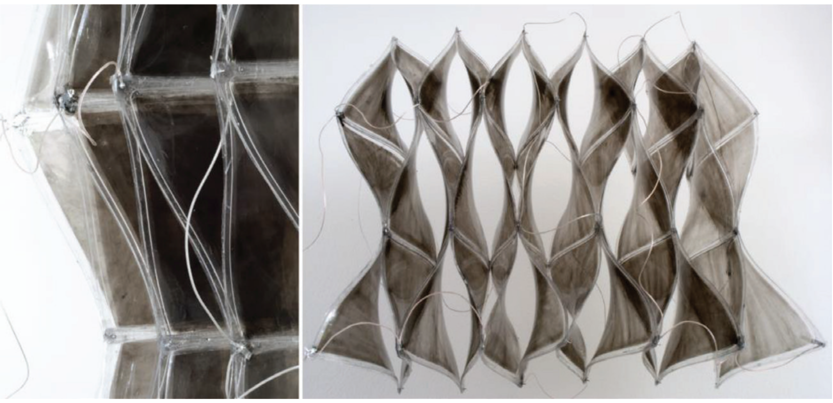

Figure 3.
Artificial muscle membrane "ShapeShift" [26].

2.2 Biomimetic design

Moving on from the microscopic scale of material design, to the scale of Industrial Design, Nature is used as a model of inspiration to craft man-made. For the future of architecture, the improved performances mean not only the chance to reinvent completely new aesthetics and cultural approach, as in every material revolution, but most of all it opens up to the possibility of imagining completely new, previously inexistent functions and uses.

2.2.1 Design with nature

Nature is in this case used as a partner. Organic materials are used fully or partially, and "crossbred" to create new solutions.

The *Edible water bottle* is a transparent spherical edible seaweed membrane designed by a British startup as an alternative to the petroleum-based plastic bottles that are producing huge amounts of waste. Looking like a giant water drop, which can be made in various sizes, the gelatinous capsule bursts under a light pressure delivering its content, which can also be used for soft drinks, spirits and cosmetics. The recipe is public and can be replicated by anyone who obtains the ingredients [27].

Concrete cloth is a 3D membrane structure combined with dry concrete and a waterproof PVC layer on one face. The cloth is first bent into the wished shape and then hydrated, allowing the concrete to harden and the fibers to reinforce it. Originally developed for erosion control and rapidly deployable shelters, it has been used by a number of designers pushing its strength and flexibility as far as possible, achieving light structures in total contrast to what is normally associated with concrete (**Figure 4**) [28].

Wooden textile is a hybrid combination of two kinds of natural materials aimed at conveying new sensory experiences. Half wood and half textile, the wooden tiles laser-cut and stuck to one side of a fabric, transform the material into a structured but soft and flowing surface. Flexibility, mobility and weight depend on the size and thickness of the combined wooden tiles [30].

Figure 4.
The Whorl Console made with the concrete cloth technology [29].

2.2.2 Imitation of nature

Specific characters that we recognize as features of living organisms are imitated, adding not only functionality but also beauty. The references to organisms and animal features become an integral part of the concept: although the features are abstracted, the achievement becomes all the more successful the more the plagiarism is evident.

BMW Gina is a concept car with a groundbreaking design and an external flexible skin in polyurethane-coated Lycra [7], an extremely durable, flexible, water-repellent textile fabric stretched across a movable metal wire skeleton. Functions are revealed when needed through the translucent material or moving the substructure, giving access to the service points in the engine [31]. The membrane imitates the mechanics and features of a natural skin, strengthening the association of the machine to a living animal.

The Moving Mesh is a project for an adaptive sun shading façade able to withstand wind loads thanks to its folded surface geometry. The prototype is realized in an aluminum composite sheet about 3 mm thick, enclosing a highly elastic material, which creates flexible hinges when exposed through milling, allowing over 80,000 damage-free bending cycles. The shading element works as a single perforated surface, inspired by the flexibility and porosity of the human skin. The geometry drives the opening and closure of the diamond shaped flaps in the same way as an origami surface (**Figure 5**) [32].

Tape Paris is a temporary installation displaying a stretched biomorphic skin made out of transparent packaging tape, forming 50 m long hollow passageways suspended at a height of 6 m from the ground. The "parasitical structure" is supple and elastic, revealing its interior visitors through its translucent surfaces [33].

The *Louis Vuitton Matsuya Ginza Facade*, realized with aluminum sheets coated with a pearlised fluoropolymer paint, is an imitation halfway between a natural skin and a textile, repeating an art-deco pattern as a reference to the brand [34].

Mushtari is a one-piece sculpture printed by MIT researchers in a combination of plastic materials with different transparence and density. Imitating the shape of human interiors, the sculpture's 58 m hollow tubes are filled with a bacterial luminescent liquid in view of combining future versions with organisms capable of photosynthesis. The idea is for this wearable energy generator is to allow interplanetary travel and survival [35].

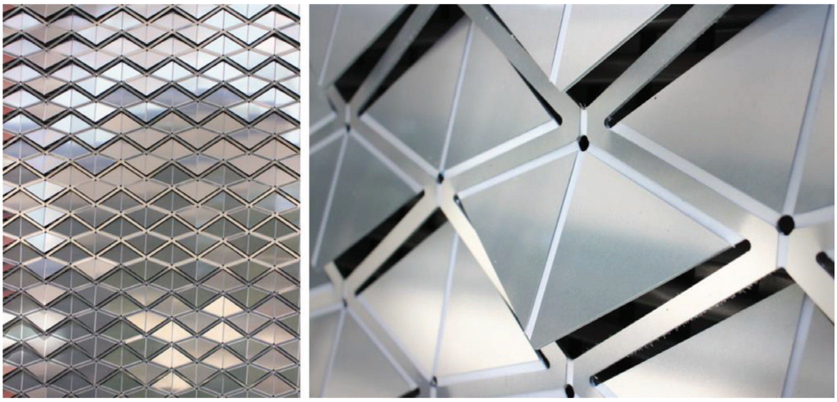

Figure 5.
"The Moving Mesh" prototype in scale 1:10 for a shading element [32].

2.3 Biomimetic processes

When imitating natural processes, it is not as much the final shape or the structure of an organism that is the focus of the analysis, but more time-related features as its creation and successive transformations. From an architectural perspective, research focuses on the potential of introducing behavioral patterns with envelope - and structural adaptivity on one hand, and on innovative production processes on the other.

2.3.1 Imitation of movement

Hylozoic Ground is an interactive sculpture environment installed within the Canadian Pavilion at the 2010 Architecture Biennale in Venice. It embodies a forest of suspended dynamic geotextile (acrylic) structures responding to its surroundings: a flexible transparent meshwork skeleton with ribbed vaults and basket-like stem allowing it to stretch, swell and bend composes the suspended artificial plants. The skeleton is made of partly flexible core parts and long rigid roller chain arms moved by Shape-memory alloy (SMA) wire rods. Pulling each rod, these tendons produce an upward curling motion lifting the latex membranes at the end of them in the air [36].

Hypermembrane is a standardized self-supporting structural system of adaptable shape and size designed for temporary to long-lasting lightweight architectures. The flexibility of the system is based on industrialized thermoplastic flexible structural components, which can be assembled in a three-dimensional interwoven structural mesh. The assemblage process allows not only adaptation of shape, but also reuse for different purposes [37].

In the *Experiment Cyclebowl* pavilion, the facade is made out of a series of three-layered Texlon foil cushions. A positive/negative leaf pattern is printed on the outer two layers of the system. The middle cushion is movable by changing the pneumatic pressure between the layers. By overlapping the pattern with the outer inversely printed cushion it transforms the facade from translucent to opaque to darken the interiors for the presentation of the shows inside the pavilion. Also, by assuming intermediate positions, variable ranges of shading are possible ranging from 45% light to complete darkness [38].

HygroScope: Meteorosensitive Morphology is a humidity-sensitive and responsive installation. The parametrically designed surface is built out of a multitude of maple veneer and synthetic composite triangles programmed to react differently depending on fiber direction, length, thickness and geometry. Absorption of water particles causes the distance between the fibers of the wood to increase, resulting in a swelling or lengthening of the material in the direction of the fibers: the composite triangular flaps curl, opening the surface's geometry. As the humidity rate drops, the panels reversibly straighten out closing the surface again (**Figure 6**) [39].

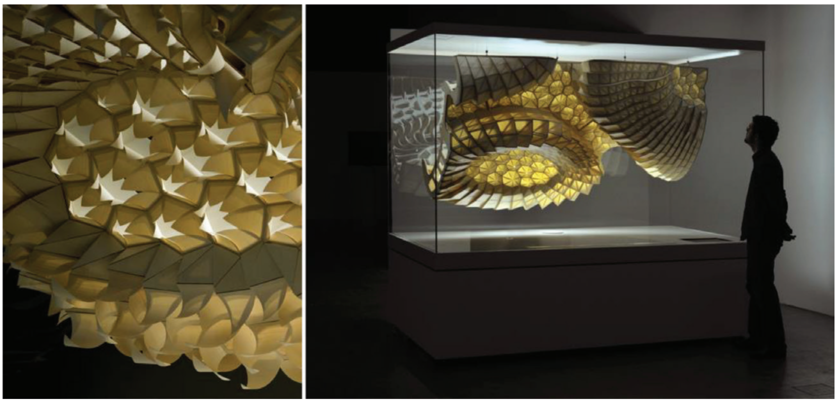

Figure 6.
HygroScope: Meteorosensitive Morphology at Centre Pompidou, Paris [39].

2.3.2 Digital fabrication

Digital fabrication, as a new tool for controlling additive design and manufacturing, is opening up an unprecedented potential to model and fabricate artifacts, realizing customized one-of solutions on industrial scale. In combination with parametric modeling and the introduction of new materials, 3D printing technologies open up the possibility to directly intervene and manipulate the structural and functional proprieties of artifacts. Features as size, geometry, translucency, elasticity and more can be closely shaped, functions are merged, and performances can be programmed all in one building block—as in natural structures, designed by evolution and built through biological growth.

Fluid Morphology is a translucent multifunctional 3D-printed façade element, developed at the Associate Professorship of Architectural Design and Building Envelope at TU Munich [40]. The research aimed to show the potential of additive manufacturing and 3D-printing technologies to close the digital chain loop in the industrial development of multifunctional building envelopes, from digital design and planning to the final product. The prototype is a one-piece rigid transparent polycarbonate shell; a façade element handling through its complex geometry heterogeneous façade functions as sun-shading, visual connection, acoustic deflection, load-bearing, insulation and ventilation (**Figure** 7).

The 3D printer allows the complex construction of a multiple compartmentalized element, interweaving façade functions, which are traditionally separated in layers in the contemporary building systems. This multiple functionality is not only material and energy saving, but also simplifies disassembly and recycling processes, reducing the need of separating technological parts made of multiple materials, with a consistent impact on the life-cycle of each single component, and by extension on the whole building.

In a similar way, the use of robotic construction technologies in architectural research is showing huge potential benefits over traditional construction methods in terms of speed, costs and complex custom-made geometries. The new methods of automatized distribution of material through the use of small semi-autonomous robotic agents open up new perspectives for the realization of on-site instantaneous and material-saving architectures.

The *Interactive Panorama* research pavilion developed at the University of Stuttgart [41] explores the potential of digital design and robotic construction applied to a bio-inspired method for pneumatic fabrication. The construction uses a

Figure 7.
"Fluid Morphology," 3D-Printed Functional Integrated Building Envelope built in a one piece transparent weather-resistant polycarbonate [40].

flexible pneumatic formwork inspired by diving bell water spider webs (*Argyroneta aquatica*). A robotic arm was placed inside a pneumatic ETFE envelope, which gradually stiffened by selectively applying layers of carbon fiber from the inside. The result is a thin rigid self-supporting carbon fiber composite shell.

Swarm Printing is an innovative approach to additive manufacturing technologies, where MIT researchers used live silkworms to grow a natural silk filament pavilion [42]. Robotic agents were used to rearrange the sticky and fast-growing filaments of 6,500 worms, following a hexagonal shell framework. As all worms were still available after the completion of the project, and potentially able to produce enough offspring to build another 250 pavilions, the process can be seen as a self-propagating material-producing colony.

3. Synthetic biology, hybridization of natural and artificial

In Synthetic biology (or *synbio*), Nature is no longer a simple inspirational model, but becomes the object of fabrication, as a new generation of Genetically Modified Organisms (GMOs). However, while genetic engineering is about copying, cutting and pasting DNA sequences, synbio rewrites and programs from scratch synthetic DNA to engender new applications, ultimately aiming to create "artificial life." Fostered by the engineering perspective on complexity, the practice reflects a highly systematized scientific approach to the understanding of biological procreation: biology is stripped to its bare bones, broken up into hierarchically abstracted parts (basic building blocks) that can be modeled using sequencing and fabricating, with the support of computer-aided-design (CAD) [43]. Unsurprisingly, the topic raises the same fears surrounding GMOs, concerning bioethics and security issues, as synthetized DNA is introduced in the food industry with self-replicating synthetic life forms [44]. As the limits between living and non-living blurs, questions are raised over where life begins, and how complex it must be.

In the field of Design and Architecture, the merging between biology, chemistry and nanotechnology is a farther-off reality where the hybrids are closer to the non-living than to the living. In an industry dominated by artificial petroleum-based products, the introduction of natural features and semi-natural organisms appear as less threatening, opening up to new ecological concepts and functional possibilities. Architects argue we are already in the Anthropocene, where it is no longer possible to distinguish where Nature begins and where it ends: we are part of a hybrid environment, a digital and rapidly urbanizing society where Mother Nature no longer exists and humans contaminate all ecosystems. The concept of "ecology" should therefore be revised and extended to embrace the biotechnological [3]. A synbio revolution in the construction field could lead to sustainable answers to our polluting and downcycling lifestyles, as factories are replaced by "biofactories," growing products with self-assembling, self-replicating, self-repairing, self-sustaining and self-degrading proprieties of living organisms.

3.1 Synbio materials

Synbio enables us to reconfigure living organisms, usually yeast or algae, to create man-made variants with pre-programmed features in order to perform specific tasks with a predicted outcome. These materials are still in their early stages of conceptualization and prototyping, but with great potential of future implementation also in architectural contexts, replacing the existing solutions with their biological highly efficient counterparts.

Protocells are basic non-living molecules that when stimulated by specific chemical cocktails can exhibit specific behaviors typical of living cells: response to pressure, light, heat, move, metabolize, reproduce, etc. The synthetic production of living material is therefore so far limited to basic applications, but has the potential to revolutionize the way we make materials and tools, blurring the gap between living and non-living.

A *synthetic bio leaf* is the first prototype of a silk protein-chloroplast based protein with photosynthetic capabilities developed by a London-based engineer [45]. As any natural leaf, this synthetic counterpart produces oxygen and absorbs CO_2 if provided daylight and water, with a huge potential of improving its efficiency with genetic modification. The energetic and environmental potential of this technology is huge if we think that light could be used as the ultimate energy source and carbon dioxide as the ultimate carbon source (**Figure 8**).

Engineered spider silk. A different attempt to create spider silk, other than the ones previously mentioned, has been attempted producing a protein-based synthetic silk through fermentation of GMO yeast, water and sugar. The ingredients are renewable and biodegradable, allowing to use cleaner manufacturing than the current technology [46, 47].

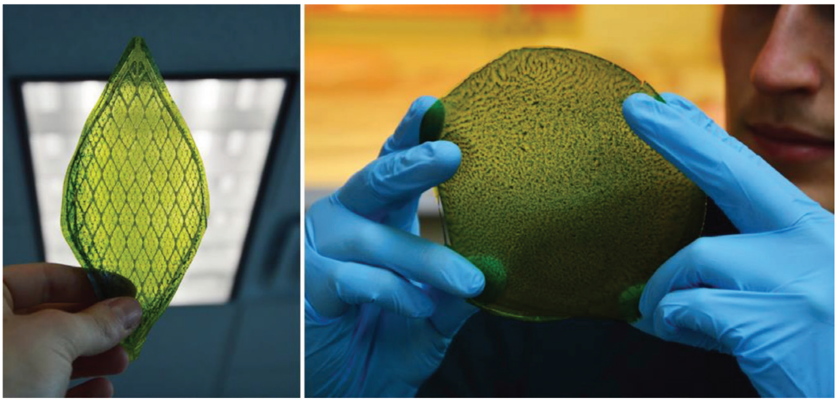

Figure 8.
"Silk leaf," the first biological membrane capable of photosynthesis [45].

3.2 Synbio design

Synthetic reprogrammed biological matter is introduced into Design and Architecture, envisioning tools and spaces with completely new, previously impossible functions, opening a window on a future of engineered living organisms. With synbio as a new design option, we face a new paradigm shift in the decades to come: how should we rethink our surroundings and our artifacts as they shift from mechanically dynamic to truly alive? In other words, becoming *semi-living tools*.

Amoeba running shoes is a speculative project for self-repairing shoe soles, based on a tailored protocell technology. These lab created non-living cells can be reprogrammed through chemical manipulation to acquire chosen abilities and behaviors of living cells: in this case inflation or deflation in response to pressure, adapting to the running substrate's texture providing cushioning. As the cells would be worn out after use, the application of a protocell liquid would allow the non-living organisms to regenerate [48].

Bioluminescent plant. Scientists have attempted a number of prototypal specimens of GMO light-emitting plants. A hale cress (*Arabidopsis thaliana*) has been provided genetic circuitry from fireflies [49], and fully functional bacterial luciferase pathways have been implanted in tobacco (*Nicotiana*) [50]. Although these biotechnologies are only at a prototypal level and scientists are working to improve the levels of light emission, the technology could revolutionize the world of lightning design.

3.3 Synbio processes

While biomimetic processes imitate natural procedures in artificial contexts, in Synbio the boundaries between the two have merged and closed the loop. The aim is to steer the natural processes towards prefixed goals. Most projects are however still at a concept stage.

Synbio fabric dyes are developed to manufacture environmentally friendly cost-effective long-lasting dyes entirely using genetically altered bacteria to fix dyes onto items of clothing. These innovative processes promise to consistently reduce water use and pollution of the conventional industrial dying processes [51, 52].

Synthetic biology and biology alike would greatly benefit from a deeper insight into the organized processes in cells, helping to understand how genes can amplify or inhibit its own expression [53]. Among the next frontiers of natural processes to imitate in synbio design:

Networks of metabolic reactions could theoretically be engineered from mammalian cells that have more complex structures. The idea would be to develop monitoring cell communities able to release therapeutic compounds [53]—in other words a new generation of monitoring substances.

Mutation control. Ideally, engineered designs should function for as long as possible, and neither crumble in the face of evolution, nor take unwanted paths. For that, microbial strains that are less susceptible to mutation can be used [53]—imagining in the future bio-artifacts with controlled aging processes. Our tools would not exhibit signs of age before their programmed end of use.

Reproduction of cells could revolutionize the way we manufacture, ideally controlling the timing of start and stop of reproduction, as well as the amounts. We can imagine this could be an alternative to healing materials, our facades and building surfaces autonomously replacing the broken and worn out parts with new material.

Programmed death of cells. As an imitation of the behavior of the lambda phage bacterial virus, which stays undetected for its host until it activates a program that ultimately kills the bacterium, engineers can use similar strategies to control cells not performing as engineered—or in the case of advanced materials and artifacts to program complex decay processes.

4. Conclusions

This chapter has reviewed cutting edge examples of membrane structures and materials used in the context of experimental Design, Art and Architecture. The categorization of membranes following a Biomimetic and a Synthetic biology approach has revealed, as could be expected, huge conceptual and technological differences between the two, and a great majority of case-studies that have been developed in the first category, while the second one is still at its very beginnings. These fields of study are the ultimate example of the effect of technological ephemeralization on our ability to do more and more with less and less.

From the analysis of this state-of-art, we can anticipate how there is a huge potential to introduce groundbreaking technological innovations, with both cultural and technical impacts on our everyday lives, and most of all on the environment.

From a functional perspective, more and more complex behaviors could be embedded in objects and components, ideally reducing the amount of tools and parts that we use. As our mobile phones today integrate multiple functions previously achieved by separate tools (phone, mail, camera, etc.), coming up with new uses and opening new markets, a rising integration of functions will be possible also in buildings.

From an aesthetic point of view, architects and designers need to accept change as a fundamental condition and rethink the nature of objects and environments. Time becomes an essential dimension to fashion, together with parameters as coordination and rhythm, which must be considered as central as function and form in our creations.

From a manufacturing perspective, materials might be grown sustainably and renewably, reducing polluting emissions on one hand and downsizing waste and over-production on the other, by growing materials only where and when these are necessary.

In the context of the building industry, there is the potential to overcome the constraints and the complex organization of traditional industrial and construction sites. By combining fabrication and construction in small-scale automatized solutions, large structures could be realized directly in urban areas, requiring the only presence of trained operators, the robots and any necessary material components.

Architects, designers and artists need to become increasingly part of these design processes, contributing with ideas and concepts, and most of all helping to shape a cultural and ethical approach to these topics. As sustainability, which is generally understood as a need for minimizing the impact of Man on the environment, the core of the question is to understand what we are sustaining, for whom and for how long. Technological advancements are transforming the world, but might not always do so towards the better—requiring a sound criticism towards the destined outcomes of an unleashed development. Solutions should not be predetermined but found pursuing a desired outcome.

Acknowledgements

The research has been funded by Ateneo Sapienza 2017; Scientific coordination Prof. A. Battisti, Operational coordination Ph.D. Sandra G. L. Persiani.

Conflict of interest

The authors declare that no conflict of interest exists, including any financial, material, personal or other relationship, which could influence the scientific work of this manuscript.

Author details

Sandra Giulia Linnea Persiani[1]* and Alessandra Battisti[2]

1 Chair of Building Technology and Climate Responsive Design, Department of Architecture, Technical University of Munich, Germany

2 Department PDTA, Faculty of Architecture, Sapienza University of Rome, Rome, Italy

*Address all correspondence to: sandra.persiani@yahoo.it

IntechOpen

References

[1] Mulder M. The Basic Principles of Membrane Technology. 2nd ed. Springer Science + Buisness Media, BV; 1996. DOI: 10.1007/978-94-017-0835-7

[2] Oxman N. The age of entanglement. Journal of Design and Science. 2016. Available from: http://jods.mitpress.mit.edu [Accessed: Mar 21, 2015]

[3] Kretzer M, Hovestadt L, editor. ALIVE: Advancements in Adaptive Architecture. Vol. 8. Applied Virtuality Book Series. Basel: Birkhauser Verlag GmbH; 2014. ISBN: 978-3-99043-667-7

[4] Ben Hopson, About Kinetic Design [Internet]. 2009. Available from: http://www.benhopson.com/?page_id=88 [Accessed: Feb 10, 2015]

[5] Benyus J. Biomimicry: Innovation Inspired by Nature. New York: Harper Perennial; 2002. ISBN: 9780061958922

[6] Agnarsson I, Kuntner M, Blackledge TA. Bioprospecting finds the toughest biological material: Extraordinary silk from a Giant riverine orb spider. PLoS One. 2010;**5**(9):e11234. DOI: 10.1371/journal.pone.0011234

[7] Peters S. Material Revolution, Sustainable and Multi-Purpose Materials for Design and Architecture. Basel: Birkhauser; 2011. ISBN: 978-3-0346-0663-9

[8] Tang SKY. The rocket swimsuit: Speedo's LZR racer. Science In The News (SITN), Harvard University, The Graduate School of Arts and Sciences [Internet]. 2008. Available from: http://sitn.hms.harvard.edu/flash/2008/issue47-2/ [Accessed: Apr 14, 2018]

[9] Zanelli A, Campioli A, Monticelli C, Beccarelli P, Hibraim HM, Maffei R. SOFT-PV: Creation of a Photovoltaic Organic Cell on Fluoropolymeric Substrate to Integrate into Smart Building Envelopes [Internet]. Politecnico di Milano: Textileshub; 2009. Available from: http://www.textilearchitecture.polimi.it/soft-pv.html [Accessed: Apr 19, 2018]

[10] Yang Y, Urban MW. Self-healing polymeric materials. Chemical Society Reviews. 2013;**42**(17):7446-7467. DOI: 10.1039/c3cs60109a

[11] Peter M. Self-healing membranes, nature shows the way. Empa Materials Science and Technology [Internet]. 2011. Available from: https://www.empa.ch/web/s604/nature-shows-the-way [Accessed: Apr 11, 2016]

[12] Rampf M, Speck O, Luschsinger RH. Self-repairing membranes for inflatable structures inspired by a rapid wound sealing process of climbing plants. Journal of Bionic Engineering. 2011;**8**(3):242-250. DOI: 10.1016/S1672-6529(11)60028-0

[13] Covered in Comfort. Report no. 20050031205. Nasa Technical Reports Server [Internet]. 2005. Available from: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050031205.pdf [Accessed: Apr 15, 2018]

[14] Fabrican. Fabric Form a Can [Internet]. 2018. Available from: http://www.fabricanltd.com [Accessed: Apr 10, 2018] (Photo credits: Fabrican Ltd, photographer Gen Kiegel)

[15] Grado Zero Innovation. Shape Memory Alloys [Internet]. 2017. Available from: https://www.gzinnovation.eu/material/7/shape-memory-materials [Accessed: Apr 11, 2018] (Photo credits: Grado Zero Innovation - Grado Zero Espace)

[16] Ritter A. Smart Materials in Architecture, Interior Architecture and

Design. Basel: Birkhauser; 2007. ISBN 978-3-7643-7327-6

[17] Collet C. En vie/Alive. Alive: New design frontiers. Exhibition. Espace Fondation EDF, Paris [Internet]. 2013. Available from: http://thisisalive.com/about/ [Accessed: Apr 14, 2018]

[18] Grado Zero Innovation. Pure Vegan Banana Paper-Layer [Internet]. 2017. Available from: https://www.gzinnovation.eu/section/11/materials [Accessed: Apr 11, 2018]

[19] Grado Zero Innovation. MuSkin—The Mushroom Peel [Internet]. 2017. Available from: https://www.gzinnovation.eu/section/11/materials [Accessed: Apr 11, 2018]

[20] Iaac Advanced Architecture Group. Piel Vivo/Bio-plastica—Material Explorations [Internet]. 2016. Available from: http://www.iaacblog.com/projects/piel-vivo-bio-plastica-material-explorations/ [Accessed: Apr 11, 2018]

[21] Atelier LUMA, Studio Klarenbeek & Dros. Labo Algues [Internet]. 2018. Available from: https://atelier-luma.org/projets/labo-algues [Accessed: Apr 11, 2018] (Photo credits: Antoine Rabb for Atelier Luma)

[22] Wu Y, Shah DU, Liu C, Yu Z, Liu J, Ren X, et al. Bioinspired supramolecular fibers. Proceedings of the National Academy of Sciences. 2017;**114**(31):8163-8168. DOI: 10.1073/pnas.1705380114

[23] Tang S, Sandström A, Lundberg P, Lanz T, Larsen C, van Reenen S, et al. Design rules for light-emitting electrochemical cells delivering bright luminance at 27.5 percent external quantum efficiency. Nature Communications. 2017;**8**:1190. DOI: 10.1038/s41467-017-01339-0

[24] TechXplore. Japanese Researchers Develop Ultrathin, Highly Elastic Skin Display [Internet]. 2018. Available from: https://techxplore.com/news/2018-02-japanese-ultrathin-highly-elastic-skin.html [Accessed: Apr 15, 2018]

[25] Shim BS, Chen W, Doty C, Xu C, Kotov NA. Smart electronic yarns and wearable fabrics for human biomonitoring made by carbon nanotube coating with polyelectrolytes. Nano Letters. 2008;**8**(12):4151-4157. DOI: 10.1021/nl801495p

[26] Kretzer M, Augustynowicz E, Georgakopoulou S, Rossi D, Sixt S. Shapeshift [Internet]. ETH Zurich: CAAD; 2010. Available from: http://materiability.com/portfolio/shapeshift/ [Accessed: Apr 10, 2018] (Photo credits: Manuel Kretzer)

[27] Skipping Rocks Lab. Ooho! Water You Can Eat [Internet]. 2018. Available from: http://www.oohowater.com [Accessed: Apr 15, 2018]

[28] Concrete Canvas [Internet]. 2018. Available from: https://www.concretecanvas.com [Accessed: Apr 15, 2018]

[29] Aaronwitz N. Whorl Console [Internet]. 2017. Available from: http://nealaronowitz.com/whorl-table/ [Accessed: Apr 15, 2018] (Photo credits: Miroslav Trifonov (left) and Kerry Davis Studio (right))

[30] Strozyk E. Wooden-Textiles [Internet]. 2018. Available from: https://www.elisastrozyk.com [Accessed: Apr 10, 2018]

[31] BMW USA. GINA Light Visionary Model [Internet]. 2008. Available from: http://www.bmwusa.com/Standard/Content/AllBMWs/ConceptVehicles/GINA/ [Accessed: Apr 10, 2016]

[32] Salvi R, Huygels B. The Moving Mesh. Performative Folding Master

Course, Associate Professorship of Architectural Design and Building Envelope, TUM. 2016. (Photo credits: Sandra Persiani)

[33] Numen/For Use. Tape Paris. Palais de Tokyo/Inside, 20.10.14-11.01.15 [Internet]. 2015. Available from: http://www.numen.eu/installations/tape/paris/ [Accessed: Apr 16, 2018]

[34] Aoki J. Louis Vuitton Matsuya Ginza [Internet]. 2013. Available from: http://www.aokijun.com/en/works/louis-vuitton-matsuya-ginza/ [Accessed: Apr 16, 2018]

[35] Oxman N. Mushtari, Jupiter's Wonderer [Internet]. 2014. Available from: http://www.materialecology.com/projects/details/mushtari [Accessed: Apr 9, 2018]

[36] Beesley P. Hylozoic Ground. Liminal Responsive Architecture, Cambridge, Ontario: Riverside Architectural Press. 2010. ISBN: 9781926724027

[37] Hypermembrane. European Union's Seventh Framework Program managed by REA-Research Executive [Internet]. 2018. Available from: https://www.hypermembrane.net [Accessed: Apr 14, 2018]

[38] Brueckner A. Experiment Cyclebowl: A Pavilion of Cycles at Expo in Hannover. Basel: Birkhauser; 2002. ISBN: 978-3929638653

[39] Achim Menges Architect, ICD University of Stuttgart, Transsolar Climate Engineering Stuttgart. HygroScope—Meteorosensitive Morphology. Centre Pompidou, Paris. 2012 (Photo credits: ©ICD University of Stuttgart)

[40] Mungenast M, Tessin O, Blum V, Khuraskina O, Morroni L, Gutheil T. Fluid Morphology, 3D Printed Functional Integrated Buidling Envelope. Associate Professorship of Architectural Design and Building Envelope, TUM, support of Rodeca, Picco's 3D World, Delta Tower. 2017 (Photo credits: TUM Associate Professorship of Architectural Design and Building Envelope)

[41] ICD/ITKE Research Pavilion 2014-15: Interactive Panorama [Internet]. 2015. http://icd.uni-stuttgart.de/?p=12965 [Accessed: Apr 10, 2018]

[42] Oxman N, Keating S, Kayser M, Duro-Royo J, Gonzalez Uribe C D, Laucks J. MIT Medial Lab. Swarm Printing, Silkworm Silk Deposition [Internet]. 2013. Available from: http://matter.media.mit.edu/tools/details/Swarm-Printing [Accessed: Apr 9, 2018]

[43] Balmer A, Martin P. Synthetic Biology, Social and Ethical Challenges. An independent review commissioned by the Biotechnology and Biological Sciences Research Council (BBSRC). [Internet]. 2008. Available from: http://www.haseloff-lab.org/resources/SynBio_reports/0806_synthetic_biology.pdf [Accessed: Apr 16, 2018]

[44] Non GMO Project. Synthetic Biology [Internet] .2016. Available from: https://www.nongmoproject.org/high-risk/synthetic-biology/ [Accessed: Apr 16, 2018]

[45] Melchiorri J. Silk Leaf [Internet]. 2014. Available from: http://www.julianmelchiorri.com [Accessed: Apr 16, 2018] (Photo credits: Julian Melchiorri 2014)

[46] Blain M. Synthetic spider silk could be the biggest technological advance in clothing since nylon. Quartz [Internet]. 2016. Available from: https://qz.com/708298 [Accessed: Apr 15, 2018]

[47] Bolt Threads [Internet]. 2018. Available from: https://boltthreads.com/technology/ [Accessed: Apr 15, 2018]

[48] Shamees Aden [Internet]. 2018. Available from: http://shameesaden.com [Accessed: Apr 14, 2018]

[49] Callaway E. Glowing plants spark debate, critics irked over planned release of engineered organism. Nature News. 2013;**498**(7452):15-16. DOI: DOI 10.1038/498015a

[50] Krichevsky A, Meyers B, Vainstein A, Maliga P, Citovsky V. Autoluminescent Plants. PLoS One. 2010;**5**(11):e15461. DOI: 10.1371/journal.pone.0015461

[51] Synthetic Biology in Cambridge. Cambridge SynBio Startup Colorifix Wins Rainbow Seed Fund “Breaking New Ground” Award at Bio-start Competition [Internet]. 2017. Available from: https://www.synbio.cam.ac.uk/news [Accessed: Aug 11, 2018]

[52] Chieza N. Reflections from Ginkgo’s First Creative-in-Residence, Assemblages 001, Ginkgo Bioworks [Internet]. 2017. Available from: https://www.ginkgobioworks.com [Accessed: Aug 11, 2018]

[53] Collins JJ, Maxon M, Ellington A, Fussenegger M, Weiss R, Sauro H. Synthetic biology: How best to build a cell. Nature News & Comment. 2014;**509**(7499):155-157. DOI: DOI 10.1038/509155a