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Hybrid Biomimetic Design for Sustainable Development Through Multiple Perspectives¹

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Abstract

In the bio-technological era the boundary between the biological world and synthetic world is increasingly fading, as well as, the limit between different disciplines in the perspective of multidisciplinary and anti-disciplinary.

Conversely, the overcoming of barriers is not to be considered as a symptom of homogenization or loss of complexity, but rather, as a paradigm, in which new forms of connection and intersection between design and science are created. In this vision, hybrid products can be generated in which nature and artifice co-exist: a change of paradigm that deeply revises the concept of environmental sustainability.

This paper aims to illustrate activities, methods and results of the Hybrid Design Lab-(HDL)- Department of the Campania University "Luigi Vanvitelli"- specifically dedicated to different forms of collaboration and intersection between design and bio-sciences, specifically aimed to environmental sustainability.

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1. Introduction

Presently, bioscience and biotechnology evolution prompts the dissolution of the frontier between the biological and synthetic world providing new opportunities for nature and artifice to cooperate and hybridize (Langella, 2007).

As a discipline, design is highly involved in decoding social, economic, scientific and technological transformations under the form of new productive solutions. This conceptual mutation is to be considered a possible opportunity to materialize new design system inspired by nature in the creation of products and processes integrated with environment. New biotechnological solutions aimed to repair human tissues and organs; systems to repopulate endangered species; bio-sensing systems able to detect human and environmental disorders and diseases: all examples of cooperation between humanity and nature able to realize new forms of propulsive sustainability; *i.e.* an improvement of past protective and conservative sustainability concepts (Mansel & Berger, 2017).

In this regard, environmental sustainability is not only considered the reduction of the human activity impact on the ecosystem or the ability to conserve resources; but also as the capability of developing new forms of human cooperation and integration with nature. In this vision, sustainability is transformed in the ability of science to "regenerate" and "enhance" nature (Mehaffy & Salingeros, 2017).

Design has become part of sustainability culture during a historical moment in which environmental degradation, inducted by human activity, emerges as a fact and begins to be officially cautioned and counteracted by the United Nations *via* protective environmental actions, environmental resource management and sustainable projects (Tyagi, Garg & Paudel, 2014). Successively, design for sustainability extended its intervention from product and service life cycle impacts to wider material and immaterial dimensions such as experience, lifestyles, consumption and behavioural models (Vezzoli et al. 2017). Thus, design begin to focus on all the aspects that are directly connected with user-product relations *i.e.* how products are loved and taken care of by users, or how products are resilient, adaptable, reactive and capable of self-organization to respond to society changes. Interestingly, these qualities and principles can be observed in nature, and are connected with something that can be defined as "intelligence" of natural systems from which the sustainability culture can be inspired.

Nature can help sustainable design not only teaching how to save resources or the way to realize lighter and structural optimized artefacts, but also showing the life principles

responsible of component integration and cooperation to create efficient resilient systems (Lucibello *et al.*, 2018).

Sustainable design must study these principles, as well as, the best way to transfer them into the project. In order to do this, it is important to establish a close collaboration with biologists.

The *Hybrid Design Lab* (HDL) has extensively experimented these new design frontiers through the development of an innovative biomimetic approach, in which designers and scientists collaborate together to obtain innovative and biunivocal results. The HDL biomimetic projects are carried out in collaboration with different fields of science, especially the biological sector, and are aimed to better understand the relationship between morphological, structural and behavioural features of natural systems (with all the "motivations" behind them) and to transfer functional details and principles into the project for realizing new sustainable hybrid design products.

In the HDL, the concept of sustainability is considered as a dynamic form of adaptation to the emerging needs of human beings. In nature, the evolution of species induces the development of new characteristics, systems, and functionalities, that make organisms increasingly adapted to the environmental change; in a similar way, design can drive the evolution of products to be more adapted for market environment and human needs that are equally subjected to quick and radical changes caused mainly by technological advancement and socio-economic dynamics.

The hybridism is the key of the HDL for this new sustainable direction and it is correlated to the creation of products that emerge from the hybridization between biological and synthetic dimension, as well as, between the different competences and disciplines that made this possible. The HDL involves designers, chemists, biologists, engineers, neuroscientists and even psychologists, who work together with the aim to bring the most advanced scientific discoveries closer to people's everyday life through the development of new design products that try to respond to emerging needs of contemporary life.

In order to facilitate the dialogue and collaboration among researchers coming from these highly different contexts, for each HDL project it is important to clearly define common objectives, common languages, as well as establish emphatic relations. This approach can bring progress and advantages in both science and design field creating mutual and bi-univocal collaborations.

2. Hybrid Design. A new vision of sustainable innovation

Since 2006, new forms of mutual collaboration between design and life sciences have been experimented in the HDL (Langella, 2007). In this association, biology provides inspirations and strategic principles drawn from nature resulting in a sustainable innovation of products and processes (*e.g.* manufacturing innovation driven by new forms of adaptability, flexibility and resilience); design, on the other hand, helps biology to approach society and its dynamic needs translating functional aspects of their research of natural systems into new products (Langella, 2019).

The results of this biunivocal interaction are original biomimetic products, in which principles, strategies and structures of natural systems are transferred into the design of more sustainable artefacts (Kennedy & Marting, 2016), suitable to complex and changing needs arising from the transformations of society *e.g.* the intensive use of technologies, the aging of the population, the dynamism of people.

In other terms of sustainability, biomimetic design can even contribute and support studies in bio-diversity and endangered species preservation. In fact, all the interpretative and representative biology and design tools provide useful contributions to morphological, structural or functional studies of biological systems aimed to understand and counteract the effects of climate change, human intervention and pollution. Biologists carry out different studies and practices for restoring damaged or destroyed ecosystems and habitats. In this context, the designer can help biological research providing new tools such as 3D models and printings. As an example, 3D printing technology is presently used for coral reef restoration: reefs are dying out and, as an alternative intervention, many researchers are turning to 3D printing in support of their restoration. In this light, the Australian group “Reef Design Lab” designed a modular reef structure printed in ceramic submerged in the Maldives in August 2018 (presently the largest printed reef in the world).

The approaches and methodologies used in HDL are continuously updated in function of the scientific research and literature evolution and adapted to specific standards *i.e.* biomimetics ISO TC / 266.

HDL methodology applied in biomimetic design projects foresees two possible different approaches: *Biology to Design* and *Design to Biology*. The first proposes natural models induced by biology to design projects that correspond to the approach also defined as *solution-based* (Badarnah & Kadri, 2015), *solution-driven* (Vattam et al., 2007), *biology push* (ISO / TC 266 2015), *biomimetics by induction* (Gebeshuber & Drack, 2008). The second approach commences from specific design problems and explores the most suitable solutions in nature, an approach also defined as *problem-driven* (Fayemi et al., 2017), *problem-based*

(Helms, et al., 2008), *challenge to biology* (Baumeister, 2014), *technology pull* (ISO / TC 266, 2015), *top down* (Speck, et al., 2008) or *biomimetics by analogy* (Gebeshuber, 2008).

In the HDL biologists and designers operate in conjunction; through the observation and subsequent interpretation of biological subjects -using optical microscopes, scanning electron microscopes and x-ray tomography- they deal the phase of study nature. The choice of perspective and details to observe are strongly oriented by design according to the project's aim. The interpretation of instrumental images is also conducted in cooperation and translated into nature models (Chakrabarti et al., 2005). These could be 2D or 3D, static or dynamic, virtual or physical, and are mainly obtained using digital tools; they represent biological structures, their behaviour, movements and functional elements that could possibly be transferred to the product project.

3. Biology to Design

This approach regards all the cases in which biologists, for increasing exploitation or communication of their research or achieving other strategic aims (e.g. the safeguard of endangered species), propose to designers the possibility to transfer new interesting functional characters deduced by their research into the project of artefacts (Badarnah & Kadri, 2015; Vattam et al., 2007; Gebeshuber & Drack, 2008).

The steps proposed for this approach are:

a) Selection of scientific content to be translated into products

Biologists, after identifying the potential transferable contents of their research, submit to designers the scientific motivations of their choice of which they verify the applicability in design driven sectors. In this initial selection, to ensure the scientific relevance of the project, it is particularly useful to choose innovative topics, such as research content with high international value due to its discoveries, primates and innovations that can be attested by official rankings and bibliometric parameters.

b) Intersection meetings, representations and coaching

In this phase, designers deeply explore the scientific contents that must be transfer supported by biologist. Designers can be facilitated by visiting the biologist research institution, where they can "live" directly the environments, protocols and approaches of the research. These are particular meeting sections, defined as "intersection meetings" and oriented to identify objectives and shared languages (Chiu & Shu, 2007), as well as, to acquire research data in an experiential manner. Biologists can also offer a selection of the most relevant scientific

literature of their research, possibly using a more accessible language (Nagel *et al.*, 2010), and provide sketches or diagrams of the main representative concepts. These sketches are redesigned and reinterpreted by designers, who schematize them into 2D or 3D natural models that visually and descriptively reproduce principles (Pahl and Beitz, 1996), phenomena, functions, processes and structures that may be transferred.

Hybridization of biological characters to be transferred. After the in-depth step, the analogy approach between nature and artefacts (Moreno, Yang & Wood, 2014) is applied. This is carried out by the “analogy transfer matrix”, in which biological systems opportunities and limits can be correlated with design products to foresee different possible application scenarios according to the evolutionary needs of market and society (ElMaraghy & AlGeddawy, 2012). It can be figure out as a cartesian system in which are assigned: at the ordinates, the biological elements with their potentially transferable characteristics (*e.g.* iridescent / camouflage effect; porous structure / filtering; stratified structure / structural optimization; etc.); at the abscissas, the corresponding design analogous problems of artificial products that can be solved with biological solutions, for example chromatic variability, breathability, lightness, resistance, etc. Thus, based on the emerging matrix systems and market requirements evaluation, designers can easily elaborate different innovative concepts of products.

d) Proposal of new concepts that interpret, express and enhance science

These design concepts are then submitted to scientists in order to validate them, and evaluate together the most appropriate areas of application identifying potential production partners interested in bio-inspired innovation opportunities.

e) Development of the project

In this phase, the project of products is developed based on the nature models (Chakrabarti *et al.*, 2005). It is important that designers remain coherent with the nature principles that have inspired the project; thus, to support this, the “coherence matrix” must be realized. In this matrix are considered: the application field (*e.g.* furniture, lighting, fashion, biomedical, sports, tourism and cultural heritage, food, etc.), the type of product and the specific design issues addressed to productive and user needs inspired from biological solutions.

f) Prototyping and feasibility

Once verified the project coherence by checking the matrix, it is possible to define the final project (possibly in collaboration with the scientists), and translate the concept into products. In this phase, prototyping takes a particularly important meaning, because it is configured as

a planning tool, as well as, a verification tool. Details, ergonomics, materials and processes are mainly defined in the physical modelling phase, through a direct approach to the project. Generally, different types of models are created corresponding to progressive degrees of definition, which are then verified and evaluated through tests that involve in some cases the stakeholders to assess specific aspects such as usability, satisfaction of needs, etc.

4. Design to Biology

In this second approach, design search in the biological field the answers to problems (Fayemi et al., 2017; Helms, et al., 2008; Baumeister, 2014; Speck, et al., 2008; Gebeshuber, 2008). These problems emerged from specific requests and needs of companies, institutions, market and society, their solutions can be found by analogy of function in natural systems. In this approach, biologists are selected and involved according to the chosen topics. From this point of view both design and biology are conceived as strategic problem-solving cognitive activities (Farrel, Hooker, 2014). This approach is the one most frequently used in the design and engineering professional activity or in the companies that generally rely on a problem solving approach.

For Design to biology, the proposed steps are:

a) Biomimetic design brief

Designers, autonomously or hired by company or other institutions, elaborate a brief according to needs that are not sufficiently satisfied by existing products.

Once identified the unsolved design problems, a “matrix of analogies” is elaborated and completed in a similar way to the “coherence matrix” of the first approach.

In this matrix are identified: application sector (e.g. furniture, lighting, fashion, biomedical, sports, tourism and cultural heritage, food, work, etc.), type of products and the specific design issues raised by market and society (ElMaraghy & AlGeddawy, 2012). It is necessary a statistical surveys based on data collection or interviews aimed to deep identify the point of view and needs of users.

b) Design research and scientific references

Beginning from the matrix of analogies, it is necessary a deep online research on existing products that respond to the identified needs, and list their respective limits and opportunities (highlighting the reasons for which they do not fully satisfy the identified problem). Thus, in this phase, a list of products is draw up inserting the name of designer, company, target market, solving strategy of design problem, technologies, materials used and cost.

Then, the moment to query nature comes. Through an online researches of words and key concepts (with strategic-planning intent) and the expert biologist consultation, designers can select different scientific references of natural systems that seem to contain in their logics, structures and behaviors, the solutions necessary to solve analogue design problems. For this purpose, designers need to ask specific questions, trying to investigate different areas of biology at different scale by searching possible bioinspired solutions on generalist or specialized platforms using specific keywords. In the case in which designers involve biologists, the research of natural solutions occur through specific intersection meetings illustrated in the previous Biology to Design approach. In such circumstance, biologists, led by designers to search in specific directions, find the most appropriate biological references to be use as models (generally, employing less time). Once identified the natural solutions, biologists can also provide more detailed scientific information by inherent scientific articles, graphs and data.

c) Design strategies and references in-depth

Once selected and analysed design references products with all their limits and advantages, designers can identify the areas of intervention to realize new concepts e.g. possible scenarios to propose new solutions for unresolved problems, related use / experience models and other design strategies to be pursued. Based on these elements, (which implement the matrix of analogies), the analysis of scientific references can be deepened identifying the biological principles and knowledge from which draw inspiration, as well as, the modalities of biological transfer and the possibly to collaborate with expert scientists. The intersection meetings, begun in the previous phase, and the activities of representation and interaction with scientists (as it is illustrated in the Biology to Design approach) continue and intensify in this phase. Also there, it is important that designers and biologists collaborate sharing solutions and objectives in order to achieve mutual advantages. At the same time, the project must converge to feasible and achievable results considering the technologies of productive process and the economic point of view.

The following phases coincide with those of the Biology to Design approach:

d) Proposal of new concepts that interpret, express and enhance science

Taking into account all the previous steps, designers can proceed to the definition of one or more concepts that respond to the design scenarios hypothesized using the matrix of analogies. Different design concepts are then proposed to biologists, who check the consistency and coherence with the scientific principles, and to the companies, which ascertain their usefulness and feasibility. After these validations derives a single concept that is launched to project phase and developed in the demanding producers and users context;

when it is possible, a human-centered approach is advisable, consisting in focus design process on personal, human characteristics of users via interviews, observations, in-depth investigations. The chosen concept is generated by the assessment and integration of: needs, existing solutions, biological references, selection of strategies and processes to be transferred.

e) Development of the project

Starting from the initial science models, the project is generated through different degrees of definition. At this stage it is important that the work of the designers remains coherent with the scientific principles that have generated it. The checklist of the matrix is elaborated.

f) Prototyping and feasibility

Through the matrix of analogy, it is possible to define of the final project (possibly in collaboration with the scientists, companies and eventual representatives of user category), and translate of the concept into the final product by modelling, prototyping and feasibility assessment.

5. Biomimetic Driven Innovation

The HDL pay particular attention to processes, in both *Biology to Design* and *Design to Biology* approaches. In order to reach original trajectories, designers are induced to pursue hybridizations even between different processes, tradition *versus* innovation, materials. For this reason, different prototypes are developed, starting from more theoretical and conceptual models up to final products that can be reproduced in limited or massive series by the company.

In these approaches, it is important that the project raise the interest of science. The translation of science principles into projects is not just a goal of designers, but made it significant also for scientists that can see how their research is transformed into innovations, products and start-ups. The role of designers as facilitator and indispensable actuator in these processes can motivate scientists to collaborate with.

6. Resulting Products and Discussion

One of the most interesting references in the field of biomimicry is the *Biomimicry DesignLens* which suggests to designers some principles of life used by nature which can be used in design *e.g.* use life-friendly chemistry; be locally attuned and responsive; adapt to changing conditions; evolve to survive; integrate development with growth; be resource efficient and related strategies like break down products into benign constituent; use feedback loops;

embody resilience through variation, redundancy, and decentralization; cultivate cooperative relationship; self-organization (Biomimicry Guild, 2016). In the HDL, all these principles, as well as, other strategies identified during observation of nature and experimentation in lab, are considered and translated. Thus, the resulting products are sensibly variable in their conceptual essence, logical process and sustainable aspects: waste ennoblements, new materials, reacting to environmental factors, integration of biosystems, characteristics and principles bioinspired.

6. 1. + Design – Waste

Nature reduces wastes and reuses all its waste following a closed loops. The project “+ Design – Waste” is aimed to learn from nature the ability to recover and regenerate materials and energy ennobling by design the waste in order to raise the final economic value through the realization of products such as jewellery, furniture, fashion accessories for which people is willing to pay a cost that makes the upcycling process convenient.

The HDL designers analyse the production cycles of different activities, especially local productive processes, identifying the typologies of waste in terms of quality and identity, as well as, their potential in form of new products. Also the limits and the weakness are seen as opportunity to identify the best sector of application.

In the *Diaglass*¹ project, waste glass were upcycled and enriched with gold dust through a process of heating becoming precious jewels. The concept was inspired to diatoms (fig. 1). Similarly in the project *Nature Imprinting*², volcanic stone powder, incorporated in polymer clay, was used to make jewellery obtaining the shapes from molds realized imprinting natural textures like cabbage or corals imitating the natural process (fig. 2). Disused glass sheet was also aesthetically valorised in the project *Innesti* with the embedding of plant partly burnt that leave a suggestive slight visual trace. The process was inspired by the fossilization processes³. Another project of waste ennoblement was *Fragmens*⁴: waste from a marble company was retrieved and used to make jewels inspired by Pompeian jewellery. In all these cases the waste materials that has a very low value becomes precious (fig. 3) .

1 Design: Serena Miranda; Scientific coordination: Carla Langella.

2 Design: Livia Sorgente; Scientific coordination: Carla Langella.

3 Design: Michela Carlomagno; Scientific coordination: Carla Langella, tutors: Francesco Dell'Aglio, Enza Migliore.

4 Design: Francesca Liquori. Scientific coordination: Carla Langella, tutors: Francesco Dell'Aglio, Enza Migliore.

In the exhibit project *Mute Azioni*⁵, with a more figurative way of wasted material, the tragic fire of *Città della Scienza* Museum have been interpreted through an interactive installation in which materials involved in the fire conceptually tell the story of their experience and trauma. With the help of a chemist and a psychologist, the exhibit was designed to show how the different materials, as well as different people react to traumas. Some people come out of the traumatic experiences more tenacious than they were in the past, other people change their external appearance becoming without changing inwardly, and others are modified in their intimate essence. Similarly, it occurs in materials that go through a catastrophic event. The project was carried out as part of the international exchange with the California College of Arts of San Francisco led by Mariella Poli. Italian and American students worked in the museum area for a week and proposed various different ways of narrating the history of materials through works of art, communication products, new materials for the new museum and interactive exhibits. (Langella, 2015).

6.2. Sustainable Biomedical Design

HDL products characterized by reduced life cycles, such as orthopaedic supports used in a limited therapy time, are designed in a planned degradation *i.e.* releasing substances that are not only less harmful but also benign for the environment thanks to their fertilizing, balancing and regenerating properties. *Thumbio*⁶ is a perfect example of these promising product (fig. 4) it is an orthopedic brace for therapeutic immobilizations of hand and wrist in case of inflammatory and degenerative diseases. It is made with a biodegradable bioplastic based on starches and waste liquid from the production of buffalo mozzarella, functionalized with natural anti-oedematous and anti-inflammatory herbal ingredients and reinforced with hemp fibres. The advantage of bioplastic in a brace is relevant since this type of therapeutic supports, generally made with conventional polymeric materials, are used in the acute phase of the pathology and then dismissed. Therefore, the life of this product, -is quite limited and, for hygienic reasons, is unlikely to be reused by others. For this reason, it is highly

5 *Mute azioni* was the italian design section of an international workshop developed inside the *Summer Study Abroad in Italy* titled *Environmental Dialogs* ideated and realized by Mariella Poli of California College of Arts, in collaboration with Hybrid Design Lab , Città della Scienza. And le Nuvole. The italian students were tutored by Francesco Dell'Aglio, Nicola Di Costanzo and Francesco Amato, coordinated by Carla Langella. The workshop was held in the june 2015 in Città Della Scienza, Napoli with the scientific contribution of Dario Aquilina (psycologist), Mario Malinconico (chemist, IPCB, CNR), Fabio Borgese (creactivitas) and the support of some company: 3D Factory, Enjina, Hiltron

6 Design: Clarita Caliendo; Coordinator: Carla Langella, developed with the collaboration of Carlo Santulli and Antonio Bove.

advantageous to use a biodegradable material. *Thumbio* was developed by the collaboration of designers, material scientists and an orthopaedist which advanced an unusual bio-composite: multisensory, coloured, thickness differentiated, singular textures and transparencies, functionalized with active phototherapeutic components in form of roots, leaves, fibres or flowers for topical use.

6.3. Designers in lab: new bio-based bioinspired material

The HDL dedicates particular attention in the research of new materials in order to obtain new sustainable solutions enhancing the natural materials and interpreting their biological multi-functionality in a singular design view. The relationship between design projects and nature is here bivalent because the new materials contain natural component, but are also inspired by principles and logics of natural system where they evolved. Complex qualities of nature are translated into the hybrid material such as cyclic life, adaptability, self-organization, redundancy, stratifications, non-homogeneity, porosity and hierarchical organization (all characteristics that make them suitable to meet the complex needs of contemporary design). In the HDL, these projects were developed directly by designers in laboratories of chemical institutions in collaboration with chemists and engineers of matter. Designers bring new points of view to chemistry and new visions leading to sustainable innovations that can respond to market demands. This deviation from conventional biomaterial research brings results also for chemical scientists who discover alternative and unconventional innovations. The research is here not limited to development and creation of new material or material system, as usually happens in chemical laboratories, but also reaches direct application into products that verify their feasibility and usability properties. In the project *New materials form the sea*⁷ (European project PIER in collaboration with the IPCB Institute of CNR) 60 new materials were developed by HDL designers in a chemistry laboratory with this bio-inspired design approach embedding components of marine organisms such as algae, diatoms, crustaceans, mussel valves (fig. 5). The materials obtained are highly sustainable and emulate the complex properties of natural materials, resulting in non-homogeneous, anisotropic and multi-chromatic materials specifically tailored to be applied in lamps, accessories, furnishing elements.

7 Design Francesco Amato, Clarita Caliendo; coordinator design: Carla Langella; coordinator material science: Mario Malinconico.

6.4. Interact with nature

Hybrid products are designed to constantly adapt to external changes and feedback loops. This approach corresponds to HDL products that incorporate materials that can react to environmental factors such as humidity, light or the presence of polluting factors, by modifying their characteristics and performances.

One of the first projects of this field was Edo, a photovoltaic shelter inspired by the physiological processes of diatoms to extract energy from the sun to perform photosynthesis. The concept proposed is a multifunctional shelter that provides shade during the day, light at night, energy to charge portable devices and information on environmental data aimed to sensitize people on the atmospheric pollution. The project was awarded with an honourable mention in *The best image of the year 2008* competition promoted by the journal *Science* and the *National Science Foundation* (De Stefano, Langella, Auletta, 2010).

6.5. Nature inside the process

In the HDL nature is not conceived just as a source of raw materials, but also as component of the product and its realization process.-Biological and synthetic components coexist in hybrid products, triggering synergistic and cooperative relationships according to a co-evolutionary and mutualistic approach. This happens, for example, in a photovoltaic lamp that incorporates the natural sponge *Euclpetella*⁸ activating a cooperation between natural factors, such as solar energy and the sponge ability to act as “biological optical fibres” focusing the light, with artificial factors such as photovoltaic panel, resin and digital manufacture processes (fig. 6).

The result of a synergy between nature and artifice is also the lamp *Loofalight*⁹ in which are integrated: recycled component, coming from the recovery of a disused appliance, natural component (the loofa), cultivated by the user, and designed component that guarantees the universal connection between the elements (7).

Another example is the *fruit packaging DIApaper*¹⁰ that responds to the need to eat healthier and to increase fruit consumption. The folded structure inspired by origami allows ~~you~~ to transport a single fruit in a mechanically protected way. The packaging paper has been

8 Design: Simona Sbriglia, coordinator design: Carla Langella; parametric design e 3D model: Gabriele Pontillo; Biology: Valentina Perricone.

9 Design: Piera di Marino, coordinator design: Carla Langella.

10 Design: Mara Rossi, scientific coordinator: Carla Langella.

specifically designed also to increase the fruit life thanks to the inclusion of diatomaceous earth flour (diatomite) able to absorb substances responsible of the fruit rotting processes.

Another natural component that has been functionally integrated for the realization of innovative products is the hemp. "Hempy Campania" is a project aimed to promote the basis for hemp production retrieval in Italy and a "design based" creations that reinterpret it as traditional material. Hemp is indeed a material of the past, however, for its properties of renewability, profitability, multi-usability, ability to regenerate land, it is proposed as an ideal material for a sustainable future. The examples of products born of this project are numerous, including benches¹¹ (fig 8; fig. 9), lamps¹² (fig. 10) and jewels developed using untreated hemp fibres, while with the fabric were created new bags and multi-functional clothing.

6.6. Biological flows in design

The HDL experience and research is also resulted in new forms of hybrid activities aimed to reduce environmental impacts of society and market through the integration of the multiple discussed paradigms of sustainability. The generative bio-inspired approach applied to design process, assisted by parametric modelling and digital fabrication technologies, allows to develop a new generation of hybrid products that are customizable (on request) adhering to specific needs, optimized in terms of consumption of matter and energy, therefore more sustainable. The hierarchical structure of properties such as porosity, density; elasticity, makes designed products able to adapt more easily to changing conditions and to different types of loading and stress distributions.

An excellent example is the bioinspired bicycle helmet¹³ designed to increase the performance of sportive helmets imitating the hierarchical and alveolar structure of the diatom cell valve able to reduce weight, improve breathability and absorb better the energy of potential impacts. The helmet is made of three layers in different materials printed in 3D and joined together by a ribbing as happens in diatoms.

The inspiration to biological structure regards not only the mechanical behaviour but also the hydraulic behaviour. In the project *Aguaviva*¹⁴ a hydroponic vase inspired by the hydraulic

11 Hempbench. Design Angela Bonanno, scientific coordination: Carla Langella. Pancan. Design Domenico Napolitano; Scientific coordination: Carla Langella, Biology: Valentina Perricone.H

12 Hemplamp. Design Nicola Esposito, Laura Guarino; scientific coordination: Carla Langella.

13 Diatom Helment. Design: Paula Studio (Valerio Ciampicigligli e Simone Bartolucci).

14 Design: Valentina Pianese; Scientific coordination: Carla Langella.

structure of the pharyngeal basket of tunicate was developed to reduce the consumption of water necessary for the cultivation of domestic plants (fig. 11).

In addition to the described mechanical properties, some HDL products embody other characteristics and principles inspired by nature such as the variation, redundancy, and decentralization strategies.

An example of this principles is the HDL *Auxetic neckbrace* , an innovative solution for tech pathology correlated with the intense use of digital mobile devices (Parasuraman, 2017). Women are more susceptible to this pathology and must be assume a correct neck posture wearing a collars for about 10 days (12). The design solution arises from the need to overcome the discomforts caused by existing cervical collars, such as the lack of breathability and freedom of movement, the non-adaptability to different anatomies, the difficulty in carrying out some daily activities and, finally, the outward appearance that does not facilitate its daily use (Santulli & Langella 2016).

This project proposes a collar for women structurally inspired by the auxetic structures observed in the skin of salamanders and other reptiles that allow large expansions without breakage. It is a geometrical property that determines an atypical mechanical behaviour: when the structure is pulled, it expands in the four directions and, when compressed, it compresses in all four directions. Thanks to this property the collar is particularly comfortable continuously recall maintain the correct posture. The use of auxetic structure, compared to conventional materials and structures, makes this collar more resistant, flexible, transpiring, and adaptable to the anatomy of the neck because it supports movements in different postures, like a second skin.

The same approach, using different geometry, was applied into the design of an unstable chair that helps the training of abdominal muscles like the ball-chair: The *Auxetic chair*¹⁵ (fig. 13) is designed and created as highly dynamic seat that adapts to different anatomies and respond to principles as flexibility, extensibility and mechanical resistance of the auxetic structures.

7. Nature details. Introducing biology to designers

The changes in the design approach, and the hybrid design research and experimentation processes with other disciplines in order to face need a revision of the university teaching methods to prepare students to learn and interact with other disciplines, Design university

15 Design: Martina Panico Relatore: Carla Langella, correlatore: Carlo Santulli.

must change and renew itself in this direction. At this aim, in HDL students and researchers are introduced, even immersed, in other disciplines with the formula *designer in lab* to undergo a process of deconstruction and reconstruction approach, to make designers and researchers more flexible, adaptable, curious, open and collaborative. The HDL also developed an innovative teaching methods called “Nature Details” aimed to foster these processes.

Nature details is an educational module in which designers and biologists teach together how to learn and inspire from nature, deeply observing and admiring its ability to adapt, to self-organize, to answer to variable conditions, to generate organized form of complexity, as well as, to visualize and respect its high but limited resilience. For this purpose, students of the course “Bio-innovation” course of the Master degree in “Design for Innovation” at University of Campania “Luigi Vanvitelli” are induced to focus on details of different biological constructions through micro- and macro- scales observations. Focusing on details is a strategical choice: they are important for design, especially in *made in Italy* design, as well as in natural systems; nature details can show the precision and the complexity of biological systems subliming principles, equilibrium and processes of natural selection and evolution.

Thus, different biological constructions are submitted to student’s attentions such as flowers, leaves, sponges, insects, shell of bivalve, gastropods, cephalopods, vertebrate bones, *etc.*; then, they are analysed at different scales, from real (naked eye) to magnified scales, using a magnified glass and digital microscopes.

The didactic value of these observations are assured and enhanced by the assistance of multidisciplinary guides: a biologist, who describes the biological motivations of each observed details such as shapes, stratifications, textures, layers, porosities and hierarchies; and a designer, who illustrates and interprets the possible constructive and generative choices, as well as, different examples of their biomimetic transfers into design projects. These two different points of view allow intensive and suggestive dialogues between disciplines (Thiel *et al.*, 2015) maintaining coherent the analogies, the intuitions and the way of thinking nature.

Many projects raised from these activities and several students, fascinating by the new ways to view natural systems, decided to further approach and dialogue with scientists.

HDL promotes these dialogues with scientists also by guiding students in laboratories and scientific institutions. Students are here stimulated to works with scientist in different ways such as realizing digital bi- and tridimensional models that are useful to better understand how scientists research principles and laws in nature and especially how to transfer them in possible innovative products. As noted in previous paragraphs, for each project raised from science, also scientists benefit from translating their research into innovative design projects

and, moreover, from design modelling they can obtain scientific models usable for publication, promotion, teaching and research itself. In the diatom projects, for example, a design student realized 3D models starting from electron microscope images that physicist and biologist used for their specific mechanical, fluid dynamic and optical simulations. As consequence, these didactic activities are transformed in another successful form of mutual and bi-univocal collaborations between disciplines.

8. Conclusions

The described design experiments and approaches reveal how contemporary design has to deal with scientific and technological culture in order to adapt its products to the complexity of current living conditions. It is therefore necessary that designers and scientists share skills and tools to collaborate and develop adequate methodological approaches to evolve new systems of production more integrated with nature (Oxman, 2016).

Design must adapt to a new way of perceiving sustainability, in its quantitative and qualitative aspects. There is a contrast between quantitative impact assessment methods, that are based on measurements of the amount of matter and energy used or substances and chemical components involved (such as the Life Cycle Assessment), and the qualitative-interpretative methods that try to include the immaterial, aesthetical aspects and property that are generally used by design but not quantifiable. Nonetheless, design in collaboration with science, and in particular with biosciences, can develop new methods and indicators that are more comparable and reliable.

Moreover, a new principle of sustainable smartness inducted by nature must be added to these qualitative and quantitative evaluation systems according to an analogy between biological and production evolution. A smartness that is made up of resilience, adaptability, self-organization, as well as, empathy intended as the ability to make people to love products. Qualities that determine a greater and lesser impact both on social and environmental systems. Design must take these factors into account, and must be able to implement them in a sustainability assessment, developing specific indicators for identified biological qualities.

In function of these evolutionary scenarios, the designer must be able to manage the extension of his field of intervention with new technical-scientific skills, greater elasticity, and spirit of experimentation and prefiguration capability. Schools and universities must adapt to these training needs and aim to generate new hybrid professional figures with the right tools and skills to manage processes of disciplinary intersection, to understand new worlds induced by science and to translate them into possible innovations.

Finally, designers have a great opportunity: they can explicit the materials and production processes used in products, induce appropriate use patterns, make the intentions of the companies transparent. In the context of sustainability where there are many misunderstandings and the information are frequently camouflaged or manipulated, design can tell the truth.



Figures 1 *Diaglass*, jewels realized upcycling glass with gold dust through heating process.
Design: Serena Miranda. Scientific coordination: Carla Langella.



Figures 2 *Nature Imprinting*, jewels realized upcycling volcanic stone powder, incorporated in polymer clay, obtaining the shapes from molds realized imprinting natural textures like cabbage or corals. Design: Livia Sorgente; Scientific coordination: Carla Langella.



Figures 3 *Frammenti*, jewels realized upcycling waste from a marble company (Alfa Marmi). Design is inspired by Pompeian jewellery. Design: Francesca Liguori; Scientific coordination: Carla Langella.



Figure 4 *Thumbio*, orthopaedic brace realized to be used in therapeutic immobilizations for inflammatory and degenerative diseases of hand and wrist made with functionalized biodegradable bioplastic. Design: Clarita Caliendo; coordinator: Carla Langella, developed with the collaboration of Carlo Santulli and Antonio Bove.

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Figure 5 *New materials form the sea.* Design Francesco Amato, Clarita Caliendo; coordinator design: Carla Langella; coordinator material science: Mario Malinconico.



Figure 6 Photovoltaic lamp integrated with the natural sponge *Euclpetella*. Design: Simona Sbriglia, coordinator design: Carla Langella; parametric design e 3D model: Gabriele Pontillo; Biology: Valentina Perricone.



Figure 7 *Loofa Lamp*. lamp made with artificial material and cultivated matter. Design: Piera Di Martino, coordinator: Carla Langella.



Figure 7 *Hempbench*, bench made of raw hemp fiber. Design Angela Bonanno, Scientific coordination: Carla Langella.

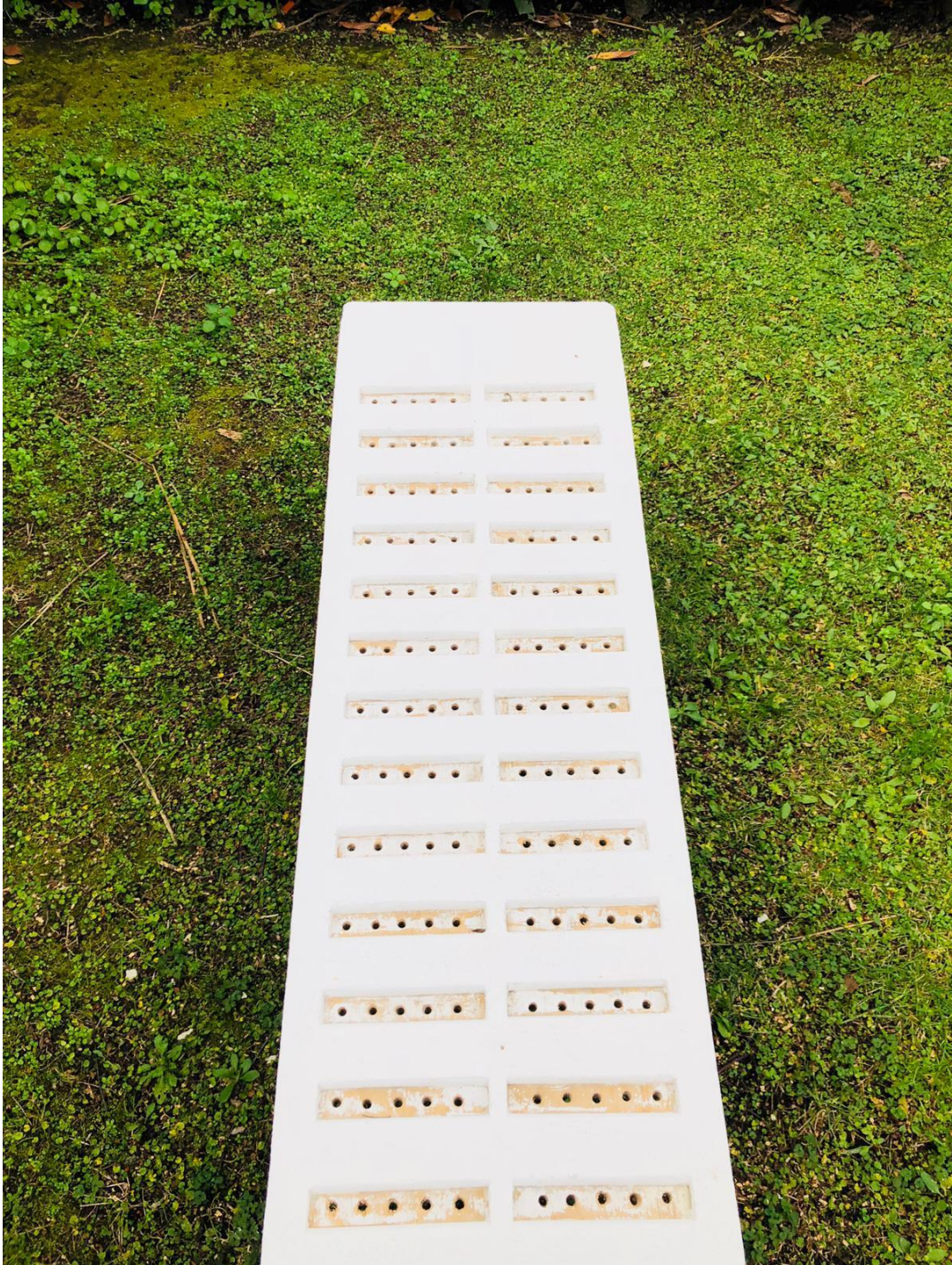


Figure 8 *Pancan*, bench made of hemp fiber and cement, inspired by the structural optimization of diatoms. Design Domenico Napolitano; Scientific coordination: Carla Langella, Biology: Valentina Perricone.



Figure 9 Hemplamp, lamp made with raw hemp fiber and liquid ceramic, inspired by traditional spindles. Design Nicola Esposito, Laura Guarino; Scientific coordination: Carla Langella.



Figure 10 *Aquaviva*. Design: Valentina Pianese; Scientific coordination: Carla Langella.



Figure 11 *Auxetic neckbrace, Auxetic cervical collar.* Design: Martina Panico, coordinator: Carla Langella, material science: Carlo Santulli.



Figure 12 *Auxetic chair*, dynamics session adaptable to different anatomies. Design: Martina Panico, coordinator: Carla Langella, material science: Carlo Santulli.

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