Sharks with arms - exploring the transformation from natural phenomenon to innovation object, via applied bionics

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Today, many researchers see nature as an immense resource of inspiration for creativity, enabling engineers and designers to transform knowledge gained from observations -combined with conceptual intentions – into innovation objects. The transfer of technology between natural life forms and synthetic constructs seem increasingly attractive. But what kind of methodology do designers and engineers rely on when transforming a natural phenomenon into an innovation object, using "bionic" principles? This design case investigates some of these design methods.

BIONICS AS A RESEARCH ARENA

Bionics can be regarded as a creativity technique that tries to use biological prototypes to produce ideas for engineering solutions. This approach is motivated by the fact that biological organisms and their organs have been well optimized through evolution, and thereby proven its capacity.

There are many examples of bionics in engineering and product development. Velcro may be the most famous example, others include morphing aircraft wings, medical ultrasound imaging imitating the echo location of bats, sonar, radar, the hulls of boats imitating the thick skin of sharks and dolphins. Even closer to the human body, the shark's skin inspires the structure and design of fast performing swim suits for athletes, aiming for absolute maximum of speed.

This last example is the research arena for the international swimsuit company ***Speedo*** in their attempt to develop the fastest swimsuit possible for top athlete swimmers.

Figure 1. Athlete swimmer in action using Speedo swimsuit http://www.speedo.com

THE DESIGN CASE: THE SPEEDO FASTSKIN

The applications for synthetic shark skin surfaces range widely, from boat hulls and better-performing medical implants to faster swimsuits. The fact that the global swimwear market is estimated to be worth US$13.3 billion, explains why *Speedo* has focused on playing the role as an important provider in this market segment. Speedo has incorporated shark-inspired textures into their swimsuits in their attempt to maximize speed.

Developed in the *Speedo Aqualab*, the brand's research and development headquarters, a 3% improvement in swimming speed due to the original "shark-skin" suit has likely contributed to the fact that 80% of the swimming medals won in the 2000 Olympics were won by athletes wearing Speedo's Fastskin suits. Swimmers wearing the suit also broke 13 of 15 world records (http://www.speedo.com).

PHYSICAL CHARACTERISTICS – SKIN STRUCTURE

The shark's exterior surface consists of a complex dermal corset made of flexible collagenous fibres, which are arranged as a kind of helical network surrounding their body, unlike bony fish. In addition to saving energy, this works as an outer skeleton, providing attachment for their swimming muscles. Their dermal teeth give them hydrodynamic advantages as these teeth reduce turbulence when swimming. Observed in a microscope, they have a characteristic tooth-like structure (figure 2 and 3).

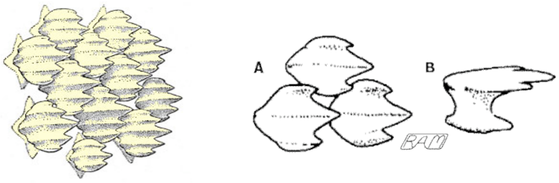

Figure 2. Dermal denticles of a White Shark. Left: Dental structure. A. Dorsal (top) view of the crowns of three denticles B. Lateral (side) view of a denticle. http://biology-online.com

Biologists William Raschi and Jennifer Elsom [1986] reviewed the drag-reduction properties of shark dermal denticles. Raschi and Elsom examined the denticles of 15 species of shark and found that those of fast-swimming species - such as the Shortfin Mako - are consistently smaller and lighter than those of bottom-dwelling species. Therefore, the small, light-weight dermal denticles of the White Shark are probably adapted for fast swimming more than armor-like protection — yet another compromise between form and function. Raschi and Elsom also found that, despite growth-associated increases in the crown size of denticles, the height and spacing of the scales' longitudinal ridges remained nearly constant in all species examined. That feature is very probably drag reduction. In a 1984 report, Raschi and ichthyologist Jack Musick discovered that the longitudinal ridge system created by shark dermal denticles is responsible for drag reductions as great as 8%.

Dermal denticles are built on the same engineering principles as fibreglass and reinforced concrete. The combination of a hard material inside a softer one combines the best properties of both, providing both *rigidity* and *plasticity*. Due to their microstructure, dermal denticles are about as hard as granite and as strong as steel (biology-online.org).

Figure 3. Shark's dermal denticles http://www.biology-online.org/articles/physical-characteristics-sharks/skin-dermal-denticles.html

Speedo Aqualab started with dozens of hypotheses about how to make a faster suit. The Speedo *Fastskin* and *Fastskin FSII* swimsuits are the result of many years of research, including the study of the preserved sharks at the Natural History Museum (NHM). Tests were also conducted on a high-speed flume at New Zealand's University of Otago. The shark was used as a model for the *Fastskin* and *Fastskin FSII* swimsuits. Due to the drag effect that occurs when an object travels through water, Fastskin fabric was constructed with built in ridges emulating natural sharkskin. Fastskin is also composed of super stretch fabric made to improve the suit's fit and compress muscles. The result is a reduction of drag and muscle vibration, which increases productivity.

The Speedo Aqualab carried out a global 3D body scanning exercise involving some 400 elite athletes to discover more about the precise shape of their bodies. This information was used to develop the most efficient pattern and construction for the swimsuit. By scanning digital images of swimmers in eight different positions, Speedo engineers were able to identify exactly how the body moves and stretches (figure 4). Using this technology, Speedo created the only three dimensional swim suit pattern in existence. It emphasizes good position in the water and reduces drag, compared to previous models.

Meanwhile, designers addressed the question of form-drag, or how to streamline or change the shape of a swimmer's body. The solution was compression. In this case, designers inserted panels made of laminated polyurethane within the bodysuit at specific points—such as the chest and buttocks—to smooth the body's silhouette like a corset. This allows a swimmer to hold their body position when they get fatigued over distance.

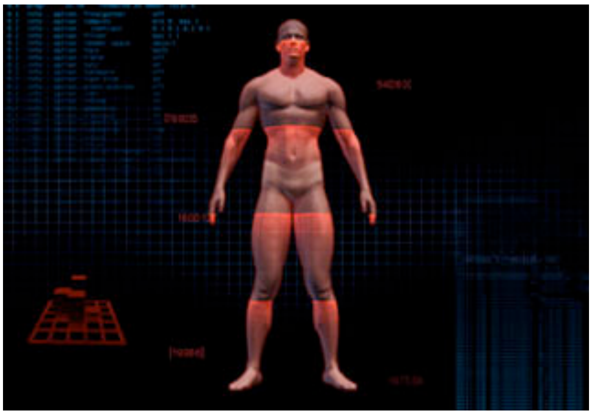

Figure 4. 3D Body scanning process.http://speedo.com

Computer Fluid Dynamics (CFD) analysis was used to indicate where most drag occurs on the swimmers (figure 5). To reduce hydrodynamic drag, Aqualab began testing totally around 60 different fabrics - both current and developed - with the help of a NASA wind tunnel, before coming up with a model made of extremely fine yarn that is densely woven together, then attached with nanomolecular plasma. When tested in athlete passive drag tests, the full body *Fastskin* is revealed to be 7.5% faster than all other suits tested.

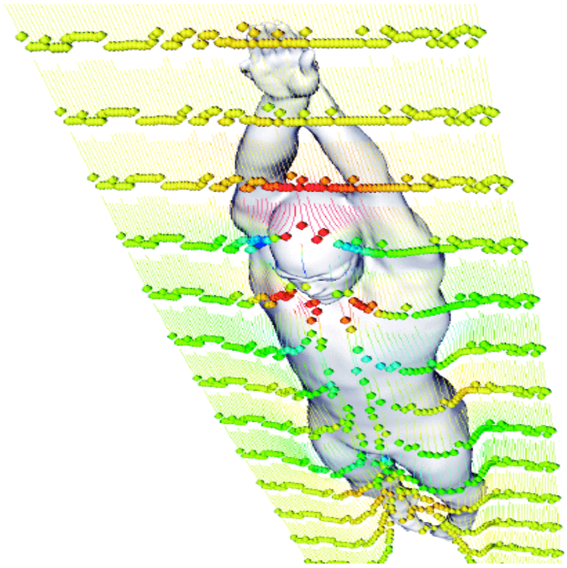

Figure 5. Pulsed waterflow pathlines over the body coloured by static pressure. http://www.biomimicryinstitute.org

All these efforts descibes the importance of using the *human body as a reference*, both on a micro-structure (skin friction) level, as well as macro-structure (form drag) level. The prototype resulted in lower overall passive drag, lower surface friction drag at a fabric level compared to other woven fabrics, lightweight and powerful stretch, as well as improved core stability, fit and compression, compared to other swimsuits on the market (http://www.speedo.com).

DESIGNERLY REFLECTIONS BASED ON THE CASE AND BIONICS PRINCIPLES

One intriguing aspect of the bionic principle, is the sophistication of both natural and human manufacture. This case gives us a good example of how biomimicry principles can be applied to extreme user environments, as it evidences a long range of advanced studies of natural phenomenon, which through research on microstructure level have been applied to a high tech innovation object, tailor-made for extreme use by top athletes. The ultimate aim is speed, and the ultimate proof of success is evidenced through breaking records. This case shows how the transfer of technology between life forms and synthetic constructs is aiming at optimization and efficiency, by pushing the limits of materials and technology.

Taking an 'industrial design' view, this bionic design case show that a typical design brief is not obvious from the starting point, as Speedo initially put up a long list of challenges before settling on those few aspects crucial for gaining maximum speed. Looking at evolution in a design methodology view, evolution - or ‘Darwinistic’ principles - could be regarded as coherent with “trial and error” methodology, being naturally iterative, and based on step by step evolution, as evolution seems to favour those species most likely to survive, being strongest, fastest, or most robust, by putting all changes to test.

Peter Forbes suggests in his book “The gecko’s foot” (2006:1): “Many scientists now believe that it is possible for us to close the gap between our technology and nature. Bio-inspiration is the new science that seeks to use nature’s principles to create things that evolution never achieved.”

When studying design methods, how can the design process in this specific case be characterized, and what kind of knowledge comes out of a comparison between this case and other characteristic design approaches? I suggest a comparison between two substantially different approaches:

A. “Evolution-type”. Experience based methods: Often based on experience from long-term evolution of previous models. Iterative approach and holistic view. Systematic evaluations by iterative “trial and error” methods. Focus on re-designs.

B. “Revolution-type”. Opportunistic, experimental methods: Often based on a fragmented or a reductionistic view, carrying out tests on specific components or materials under laboratory settings, ignoring the traditional conformity of established designs. A more innovative focus that often results in genuinely new, cutting edge design solutions.

Taking a holistic view, it seems that the process represents an evolution type of process, because of its focus on a step-by-step iterative - or even generative - approach to idea genesis. However, when taking a closer look at the process from an industrial design perspective, Speedo’s project with *Fastskin* seems to embody characteristics from *both* “evolution-type”, and “revolution type” design methods.

This because of the combination of an iterative process going through repeated tests, making small changes through *step-by-step* testing in laboratory environments with fabric testing, drag testing, compression testing, suit pattern construction, *and* the reductionistic view, represented by high-tech research on micro-level, aim for innovation, and search for optimized performance in new materials through experiments under laboratory settings.

Summed up, the process could be described as going from a reductionistic view on a microlevel structure (shark skin being the natural phenomenon), via holistic design (body garment / body suit), then returning to a fragmented implementation of microlevel components into the new fabric surface / texture (fabric actually being the final innovation object). The process seems to have focused on two parallell lines of activities; both the micro level (material surface level), and the macro level (body-shape level) (figure 6).

Being an industrial designer myself, my own professional terminology differs from terminology applied in natural sciences. However, the term 'design methods', commonly used in the professional discipline industrial design, seems to be

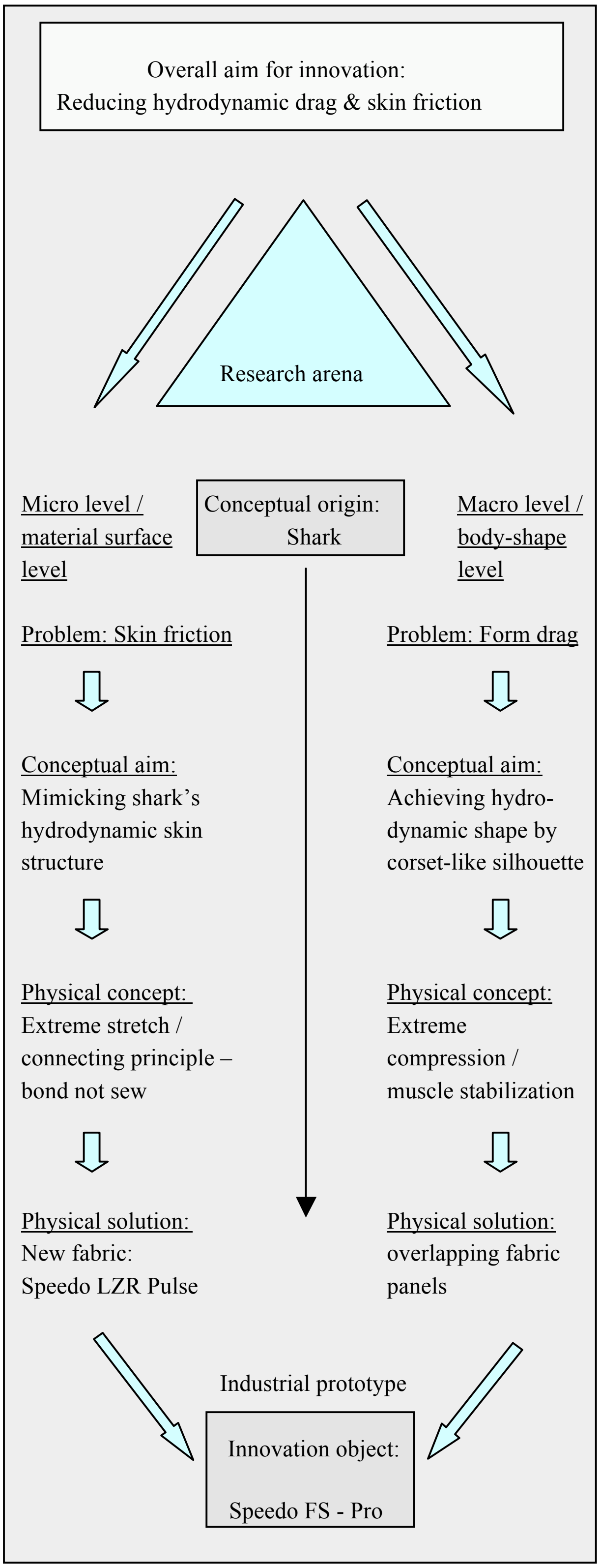

Figure 6. Graphic description / holistic view of aim and result of innovation, versus research activities and design methods. Source: Harald Skulberg

coherent with any of the working processes undertaken by the participants of the project group; garment engineers, material experts, swim coaches, specialists in fluid- and biodynamics, textile technology, sports science, and product designers.

In the paper *"Systematic technology transfer from biology to engineering"* (2002) Vincent and Mann describe the TRIZ project. Russian researchers working on the TRIZ (Teoriya Resheniya Izobretatelskikh Zadatch) method for inventive problem solving, have identified systematic means of transferring knowledge between different scientific and engineering disciplines.

TRIZ represents the biggest study of human creativity ever conducted, whose aim has been to establish a system into which all known solutions can be placed, classified in terms of function. The functional classification structure covers nearly 3 000 000 of the world's successful patents and large proportions of the known physical, chemical and mathematical knowledge base. Incorporation of these drag-reducing solutions into a systematic, functionally arranged knowledge-base would provide a means for all engineering sectors to access and benefit from these and other techniques for drag reduction. Biologists might also discover previously unsuspected drag-reducing adaptations in organisms.

TRIZ identifies solutions using a 'two-dimensional contradiction matrix', and then identifies the relevant two or three of the 40 `inventive principles' on which TRIZ is based. Comparing the conflicting parameters described in TRIZ with those found in the Speedo case, reveals similar contradictions - as conflicting parameters seem to have represented a tremendous amount of problems; the combination of *mechanical strength* and appropriate surface texture, enabling sufficient reduction of *hydrodynamic skin friction*. These parameters connect easily with the TRIZ parameters. (http://www.mazur.net/triz/)

On a case level, this concept illuminates the 'bionic' intention of applying biological principles to technological solutions. Several interesting questions emerge; for example, could an industrial designer contribute in processual, holistic super-vision or 'bionics management' of a project group, which mainly consists of scientists and engineers? If so, how could this be carried out? I believe that the designerly, holistic and methodological view would contribute greatly to such a group. When pushing technology to achieve maximum performance, are we also challenging a moral limit? Is the endless search for optimization a threat for fair competition in this case?

On a general level, other reflections emerge when realizing bionic philosophy as a valuable resource of 'design stimulus'. The potential for researchers and designers to gain knowledge and produce innovations by transferring technology between natural life forms and synthetic constructs, seems almost limitless. This should encourage designers to make efforts in extracting advantages from nature's immense diversity of lifeforms. When realising the potential of this 'design stimulus', the question seems more to be *how* rather than *why* could bionics be applied as a methodology into the development of different design fields; as everyday artefacts, environments, processes and systems.