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HOW BIOMIMICRY HELPS COMPANIES NAVIGATE THE ORGANIZATIONAL TENSION BETWEEN PRODUCT PERFORMANCE AND ENVIRONMENTAL IMPACT

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Abstract

The environmental crisis we are living brings massive pressure on many businesses in moving towards more sustainable business models. In their attempt to respond to multiple and oftentimes conflicting goals, many organizational tensions may arise along decision-making processes, especially gaining an efficient product performance while achieving a positive environmental impact. In this context, biomimicry is increasingly spread among companies as a means to solve the tension, as Arnold Glas and Interface successfully shows. By mimicking nature's efficient and effective strategies experimented for 3.8 billion years, the science can help firms preserving the ecosystems, being profitable, and increasing their overall resilience.

Keywords

Biomimicry, Organizational Tensions, Dialectic, Environmental Impact, Product Performance

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1. Introduction

Rapid economic growth in the past century has brought great achievements, learning and benefits to the human population, but at a cost: the business approach implemented so far has been clearly based on consumption with no limits and it caused a huge imbalance between economy, society and environment (Farnsworth 2021a). The world is now affected by challenging trends, including rising population, scarcity of resources, loss of biodiversity and the continuous increase of pollution and degradation of the ecosystems (Manwaring et al. 2013). The numbers tell a clear story: in 2007, we used 1.5 planets' worth of sustainable resources, a figure that rose to two planets by 2030 and over 2.8 planets by 2050 (WWF 2010). According to the World Economic Forum's Global Risks Report 2020, a huge amount of business risks will materialize in many industries due to the increasing scarcity of natural resources, especially the most vulnerable to ecological destruction, namely construction, agriculture, energy, fashion and textiles. Within this rapidly changing environment, the Agenda 2030, published in 2015 by United Nations, plays a relevant role as a plan of action for people, planet and prosperity. Specifically, it provides 17 Sustainable Development Goals (Appendix 1) to be achieved by countries, organizations and individuals in the next decade, which, together with the Paris Agreement, drives the demand for better performance in relation to the protection of the environment and society. Businesses are facing massive pressure to transit towards sustainable business models and they recognize that the development of humanity, our health and well-being depend on the resilience of the natural systems. The long-term sustainable value depends now on leveraging and integrating environmental, social and economic drivers: value creation can no longer be based on exploiting finite resources and externalities, instead it should be driven by innovation, multiple stakeholders' relationships and the creation of positive impact along the triple bottom line (Manwaring et al. 2013). This call of action is gradually turning some traditional firms into socially responsible businesses, which aim to pursuit financial sustainability while contributing to the welfare of the environment and society. In their attempt to respond to multiple and oftentimes conflicting goals, many organizational tensions may arise along decision-making processes (Smith et al. 2013). Specifically, the dichotomous nature of socially responsible businesses which

lies on product performance and environmental impact is central to many firms, whose ultimate goal is combining technical efficiency and profitability of certain innovations with the preservation of ecosystems. Scholars propose different approaches to manage this organizational tension. However, a new paradigm-shifting idea is slowly finding attention among scientists: biomimicry. Defined as a science that offers "an empathetic, interconnected understanding of how life works and ultimately where we fit in" (Biomimicry Institute 2021), biomimicry learns from and mimics the strategies used by living organisms to create designs that contribute to solve human challenges profitably, sustainably and in solidarity with nature (Biomimicry Institute 2021). Biomimicry is increasingly adopted by many organizations to overpass the tension between product performance and environmental impact, since the science implementation brings relevant benefits to both companies and the environment. On the one hand, individuals can observe, emulate, and deploys nature strategies to solve their challenges more efficiently and at less cost. On the other hand, nature is preserved, since the outcomes of biomimicry processes are highly sustainable and respectful of nature's operating conditions (Farnsworth 2021a). Background theory has been largely explored, even though the science is constantly evolving and widening. However, literature does not provide concrete frameworks that link theory with practical examples of its implementation, therefore it is not clear by virtue of what biomimicry manages the organizational tension. Thus, the goal of this research is to analyse how organizations overpass the tension successfully by imitating nature's strategies, therefore exploring the potential of biomimicry in enhancing sustainability outcomes. This will be done by studying which biomimetic approaches are already being utilized by two highly different companies, Arnold Glas and Interface, and which outcomes arise along their triple bottom line. The following research question is therefore formulated:

"*how does biomimicry help companies successfully manage the organizational tension between product performance and environmental impact?*".

2. Literature Review

2.1 Organizational Tensions & Paradoxical Thinking

According to Smith & Lewis (2011), critical trends, including globalization, competitiveness, multiple goals pursuit and increasing complexity of internal companies' processes, produce organizational tensions which become widely persistent and salient. Tensions may be exhibited through organizational identities, allocation of resources, stakeholder management, market positioning and other crucial issues that seem contradictory and difficult to resolve in the organizational environment (Ismail & Johnson 2019). To find frameworks that deal with competing demands within firms, researchers increasingly adopted a paradox perspective (Smith et al. 2012). Lewis (2000) defined *paradox* as contradictory yet interrelated elements that exist simultaneously and persist over time, meaning demands that conflict with one another and whose perspectives seem opposing. Specifically, two elements defined as *A* and *B* are logical when considered in isolation, but irrational or inconsistent when juxtaposed (Lewis et al. 2014). According to Hahn et al. (2015), the first step to manage tensions lies in their identification and understanding. A common approach to solve organizational paradoxes consists in the prioritization of the tensions (Lewis 2000), namely choosing between two seemingly opposing forces. A more radical approach concerns instead avoiding the tension to evade confrontation (Smith & Lewis 2011). Battilana et al. (2015) focused their research in exploring spaces of negotiation in their attempt to solve tensions. Clegg and Cunha (2017) emphasize instead a dialectic strategy for tackling opposing forces by integrating them into a new synthesis. In their attempt to build an approach towards paradoxical thinking, Smith and Lewis (2011) proposed an integrative model that engages simultaneously competing demands, which can bring innovative and creative synergies as well as long-term sustainability (Smith et al. 2012).

2.2 Product Performance *versus* Environmental Impact

With the increase of social and environmental challenges worldwide, crucial organizational tensions have risen for commercial companies which follow traditional business practices (Gandhi & Raina 2018). There has been a relevant growth in the number of firms that aim to achieve a balance between being profitable and contributing to the welfare of society and the environment (Investopedia 2020). As stated by Doherty et al. (2014), socially responsible businesses deal at their core with multiple and, eventually, conflicting

organizational goals. Central in this context is the duality between environmental impact and product performance (Haigh et al. 2015). The pursuit of financial gains and environmental objectives requires the generation of sufficient revenue to invest in business activities while creating social value and drive forward social change (Mason & Doherty 2014). A small number of scholars identified methods and strategies which focus on the management of the tension within companies (Ismail & Johnson 2019). According to Mason & Doherty (2014), mission and objectives need to be clearly articulated across organizational members and stakeholders to ensure an optimal decision-making. Jay (2013) believes that designing goals and systems of the firm to be flexible and adaptable can further strengthen the management of the organizational tension. Smith & Lewis (2011) agreed that there is not always one single best answer to manage the paradox, indeed multiple and diverse approaches may be more appropriate. Scholars are increasingly adopting an out-of-box thinking in the attempt to overpass the tension between purpose and profit. Specifically, viewing issues broadly, multi-directionally and nonlinearly may help in shifting from problem-solving to possibility-finding, thus encouraging the innovative use of alternative resources (Smith et al. 2012).

2.3 Biomimicry Theoretical Background

Based on specific principles and fundamentals, biomimicry is increasingly adopted by companies as a tool to manage the organizational tension between product performance and environmental impact. The term biomimicry derives from the Greek *bios*, which means life, and *mimesis*, which means imitation: "*to imitate life*" (Farnsworth 2021a). According to Janine Benyus (1997), scientist and author of the book "Biomimicry: Innovation Inspired by Nature", "when we look at what is truly sustainable, the only real model that has worked over long periods of time is the natural world". Nature has been creating for 3.8 billion years conditions conducive to life, taking into account all the deep patterns present on Earth, which results today in perfect solutions for resilience and survival (Manwaring et al. 2013). From the initial writing of Benyus's book, biomimicry has continued to evolve, refine and detail. Nowadays, this field can be defined as "an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested strategies" (Biomimicry Institute 2021). Specifically, biomimicry aims at coping how living

organisms adapt and survive in changing environments, it learns and understands the deep patterns behind every single strategy, and it finally uses these principles to solve human issues sustainably.

2.3.1 Core Values

Three essential principles need to be understood as they represent the core values of biomimicry at its essence. The first principle lies in *emulating nature*, "the scientific, research-based practice of learning from and then replicating nature's forms, processes, and ecosystems to create more regenerative designs" (Biomimicry Institute 2021). Specifically, this principle helps define the types of levels where biomimicry operates. The form or organism level requires the researcher looking at shapes and forms of living organisms and analysing how they work, allowing the mimicry of a part or the whole organism. The behavioural level involves the imitation of the processes and series of operations implemented by organisms. The ecosystem level regards mimicking and comprehending how an organism interacts with the environment and how many components work together (Nkandu & Alibaba 2018). The second principle at the base of biomimicry is *ethos*: "the philosophy of understanding how life works and creating designs that continuously support and create conditions conducive to life" (Biomimicry Institute 2021). According to Farnsworth (2021a), living organisms have an innate desire or instinct to continue their species over time, which means being resilient, surviving and facing challenges constantly. How nature works always brings to optimal outcomes and sustainable solutions, therefore at the base of this principle lies the understanding of approaching issues as nature would do. Finally, the last principle is to *re-connect*, which means regaining the understanding and recognition that two separate identities are deeply intertwined; it is the concept that "we are nature and we find value in connecting ourselves to our place on Earth as part of life's interconnected systems" (Biomimicry Institute 2021).

2.3.2 Nature as Model, Measure, Mentor

Biomimicry offers a new way to consider and value nature: if people decide to consciously emulate its genius, a different perception of nature is needed (McGregor 2013). Specifically, Benyus (1997) suggests looking at nature as model, measure and mentor. Considering nature a model stands in the definition of

biomimicry itself, where researchers emulate its forms, processes and systems to solve human problems sustainably. Besides providing the model, nature is also providing the measure. Biomimicry teaches how nature can offer an ecological standard to judge the sustainability of humans' innovations (Lipholt 2019), which Benyus (1997) refers to as the *Life's Principles*. These principles represent patterns used by nearly all species to survive and thrive on Earth (Biomimicry for Social Innovation 2021). Thus, they can be used as parameters, behaviours, and requirements for innovations to function more sustainably (Patel, Mehta 2011), since they respond to all nature's deep patterns or operating conditions, which serve as a background context for any problem-solving process (Farnsworth 2021a). The operating conditions are the following: Earth is in a state of dynamic non-equilibrium; Earth's living organisms are water-based; Earth is subject to limits and boundaries, necessitating the efficient use of natural resources; life inhabits the same space where it synthesizes; life adapts and evolves according to changes in the external environment (Patel, Mehta 2011). Thus, to create conditions conducive to life in this complex context, nature applies the *Life's Principles* (Appendix 2) and biomimicry suggests people to do the same in their innovations: the more principles are applied, the better the solutions can integrate in the environment. Specifically, the *Life's Principles* include (Farnsworth 2021a): use life-friendly chemistry, integrate growth and development, be locally attuned and responsive, be efficient with both materials and energy, adapt to changing conditions, evolve to survive. To conclude, this analysis leads inevitably to ultimately consider nature as a mentor (Appendix 3). Nature becomes a source of learning, innovation and inspiration, a teacher with 3.8 billion years of knowledge, which evolved and gained experience of living organisms in creating complex, efficient, resilient and adaptive systems (McGregor 2013). By simply asking "*how would nature do…?*", businesses have the chance to learn and find new ways of doing their work more efficiently, while engaging in a deep relationship with nature based on reciprocity and mutual benefits (Farnsworth 2021b).

3. Research Methodology

Due to the lack of relevant knowledge on how biomimicry can help companies navigate the tension between product performance and environmental impact, this exploratory research aims to fill the gap through the

Eisenhardt multiple case studies approach (Eisenhardt 2021; Appendix 4), extremely useful to find common patterns that demonstrates the science's effectiveness, as well differences between the approaches deployed and the consequent results. Thus, two different companies and their biomimetic solutions have been carefully chosen to allow a comparative analysis on how biomimicry can effectively manage the organizational tension, namely Arnold Glas and Interface. Specifically, the organizations have been selected based on differences in principles and levels of biomimetic applications, availability and richness of information, relevance in the biomimetic field, positive environmental impact generated as well as their track record of financial sustainability. In addition, the companies belong to different industries, which is helpful to demonstrate the applicability of biomimicry for any potential challenge or need. For each case study the Gioia methodology (Gioia et al. 2013) has been used to treat information (see Appendix 5), whose data collection derives from interviews as primary sources and books, articles from journals, analysis of existing case studies, and company reports as secondary sources (see Appendix 6). After providing a brief overview of each company and its industry sector, the analysis of organizational tensions was carried out by identifying each company's environmental and product performance desired goals. The problem-solving approach was instead executed according to the Design Spiral Methodology (Appendix 7) provided by the Biomimicry Institute (2016). Finally, an analysis of the outcomes derived by each biomimetic solution has been developed, using attainable KPIs which are specific and relevant for each case study. Consequent discussion and conclusions have been executed according to the results.

4. Case Studies Analysis

4.1 ARNOLD GLAS

4.1.1 Company & Industry Overview

As one of the Germany's largest insulating glass manufacturers, Arnold Glas is constantly committed in researching new areas of use and improved production methods (Biomimicry Business Intelligence 2016a). The company was founded in 1959 by Alfred Arnold in Germany, who created for the first time in history the standard model of insulating glass, ISOLAR (Arnold Glas 2021b; Appendix 8), which played a critical

role in reducing the energy consumption inside buildings as well as carbon emissions in the manufacturing process (Grand View Research 2020). Nowadays, Arnold Glas works closely with architects and planners to develop new technologies and applications for their products (Arnold Glas 2021a). However, the company's biggest effort lies in taking action to preserve the environment for future generations, which include prioritization of waste avoidance over waste disposal and recycling, staff training that incorporates directives associated with environmental protection, and the supply of environmental-friendly and cost-effective products and services (Biomimicry Business Intelligence 2016a). Nowadays, there is an array of glass market drivers that pushes companies to invest in research and development activities to develop sustainable and advanced glass insulation materials, such as the rise in demand for green buildings as well as cost-effective solutions to lower carbon dioxide emissions in manufacturing processes (Transparency Market Research 2021). Thus, the glass industry is now experiencing a shift towards a better natural resource management as well as greater investments in projects which aim to build a restorative environment.

4.1.2 The Challenge

Despite the glass industry shifting to greener technologies, a critical challenge linked with its products is having greater attention among public. According to American Bird Conservancy (2019), between 365 million and 1 billion birds are annually killed by glass collisions only in the United States (Appendix 9). This relevant problem finds its roots on the glass' characteristics whose reflectiveness and transparency are dangerous for birds. Specifically, birds perceive glass reflections of vegetation, landscapes or sky to be real, thus they do not recognize glass as an obstacle, differently from humans (American Bird Conservancy 2021a). Thus, the impact often results in instant death or serious injuries (Appendix 10). According to Santos et al. (2017), birds' collisions with man-made structures are the second greatest source of bird mortality worldwide and they consequently represent a crucial source of negative anthropic influence on nature (see Appendix 11 & 12 for more information). The effects of the issue can be different for each bird's species and their biological characteristics, however studies underlined an increasing general loss of biodiversity which can be detrimental to the overall ecosystem. Furthermore, the consequences of birds' collisions

comprehend also the negative psychological effects on human population which is translated in greater concern from advocacy groups, non-profit organizations and local governments (Biomimicry Business Intelligence 2016a; see Appendix 13 for further information). In the late 90', Alfred Arnold was truly shocked by the number of birds killed each year by its and other companies' glass products (Schon 2018). As a glass manufacturer, he felt responsible for having profited by contributing to the problem, thus he proactively looked for a solution. Despite the great intentions of some organizations, creating effective products while preserving the local fauna could have been highly challenging. First, at the time there was literally no market for a bird-friendly glass, thus highly investing in R&D could have turned out in no sales and consequent losses in assets (Ank 2021). For this reason, founding partnerships and collaborations with experts in the field as well as established non-profit organizations was essential. In this sense, the increase of public awareness on birds' collisions would have been a hot topic for Arnold Glas, since an incorrect perception of the issue could have easily zeroed sales (Ank 2021). The allocation of resources was the hardest thing to handle. As a glass manufacturer, Arnold Glas needed to create a product comprising all the traditional technical functions required to easily sell it, especially transparency which was the main cause of birds' collisions, while being visually appealing. However, this focus on environmental impact had also to make sense commercially, since its success would have meant creating a new market whose product sales could repay investments and highly increase the company's margins (Ank 2021; Appendix 14). Arnold Glas' R&D team therefore adopted an explorative mind-set to find innovative solutions that could be effective in creating a product efficient in its technical functions as well as market performance, while preserving the local habitat, which led the company discovering and approaching biomimicry.

4.1.3 Biomimicry Implementation

In the late 1990s, Dr Alfred Meyerhuber, a German attorney with a personal interest in birds and science, showed his friend Mr. Arnold a scientific article about how spiders prevented birds from colliding with their webs (Biomimicry Business Intelligence 2016a). The information provided was immediately perceived by both as a potential source of inspiration for Arnold Glas in achieving the environmental goal desired. What

was unique in Dr Meyerhuber's research, concerned the fact that a possible answer to the challenge was discovered in natural models, which allowed the company to enter the wide world of biomimicry. By consulting literature and the expertise of biologists, Mr. Arnold came to know the unique capability of orb-waver spiders in defending their webs. This species of arachnids, highly common in North America and Europe, builds their webs in concentric circles with spokes radiating out from the centre, whose goal is to capture preys. However, even though these webs have outstanding mechanical properties, they are often subject to bird collisions. For this reason, orb-wavers developed a defensive behaviour which consists in decorating their webs with UV-reflective threads called *stabilimenta* (Appendix 15 & 16), resulting in a huge reduction of birds and wasps crashing into the webs (Blackledge & Wenzel 2014). What crucially differentiates humans from birds in the perception of UV light is that people discern light with wavelengths ranging from 400nm to 700 nm, while birds are also capable of sensing ultraviolet light that varies from 400 nm to 100 nm (Biomimicry Business Intelligence 2016a; Appendix 17). Amazed by this nature's strategy, Mr. Arnold led his company to invest in research and collaborate with experts of the field, to create a glass product with the same UV-reflecting qualities of orb wavers' webs (Biomimicry Toolbox 2013). Biomimicry was therefore introduced within the company, thanks to many scientific consultancy meetings whose aim consisted in emulating nature, namely observing its processes and consequently applying the lessons learnt to solve the challenge addressed. Christian Irmscher, Arnold Glas' Head of R&D, was put in charge of developing a UV-reflective coating to be applied on glass only visible to birds and other organisms that can detect UV light, therefore not affecting human perception of glass transparency. Together with a specialised solar coating company, he tested different coating types and discovered that the patterned coating, which made the contrast of glazing more intense unlike a solid coating, could produce an UV-light reflective effect, while gaining transparency (Biomimicry Business Intelligence 2016a). The coated parts reflected UV light while the interlayer sandwiched between two layers of glass absorbed the UV light. With this technology, the two functions together enhanced the reflective effect (Biomimicry Toolbox 2013). Arnold Glas had to consider consequently which kind of pattern was both effective and practical in the coating

application process, which firstly resulted in vertical lines of UV-reflecting coating. Thus, in 2001, ORNILUX SB1 Bird Protection Glass was patented. Vertical lines were however sometimes perceptible even if very subtle and not visually distracting. In 2009, after many collaborations with scientists and product testing, Arnold Glas introduced a new pattern and an improved coating following scientists' recommendations: ORNILUX Mikado (Appendix 18) was a random crisscrossed UV pattern that, differently from the first one, was nearly invisible to the human eye (Biomimicry Toolbox 2013; Appendix 19).

4.1.4 Managing the Tension

The effectiveness of the biomimetic products in relation to the prevention of birds' collisions has been carefully tested by Arnold Glas in cooperation with American Bird Conservancy and ornithologists through the years (ORNILUX Bird Protection Glass 2021). Specifically, flight tests were conducted at a flight tunnel facility in Western Pennsylvania and in Russia between 2003 and 2010, where bird flew down a completely dark space toward light at the end of the tunnel, which was structured with side-by-side panels of glass that appeared to offer exit routes (ORNILUX Bird Protection Glass 2021; Appendix 20). One of the panels was invisible to the bird, while the other one was the ORNILUX Mikado. Tests were conducted following the ABC rating system (see Appendix 21 for more information) and results were excellent (Ank 2021): on average, 76% of the birds tested avoided the ORNILUX panel and flew towards the normal glass panel (AskNature 2016; Appendix 22). It is important to mention that birds which did not recognize the patterned glass were stopped before the collision by a net (American Bird Conservancy 2021b). The biomimetic innovation demonstrated that birds recognize the ORNILUX glass as an obstacle due to its reflective UV coating. The conducted tests therefore proved the positive impact created on the ecosystems: through the adoption of this solution in commercial buildings and private homes, millions of birds' lives are protected, as well as wildlife biodiversity. Despite Arnold Glas' great achievements, no glass product can guarantee the elimination of windows' collisions, results vary depending on local bird populations, landscape conditions, product used and building design (Ank 2021). Nevertheless, Arnold Glas is currently improving its product

to achieve a broader impact in cooperation with scientists and ornithologists, whose findings and recommendations are constantly integrated in the manufacturing process (Ank 2021). It is also worth to mention that ORNILUX Mikado has been constructed following the insulating glass model, whose chemical composition, which is eco-friendlier than conventional glass, allows the product to be reused as a raw material at the end of its life cycle, in addition to reducing the energy consumption during its lifetime (Zelazna & Pawłowski 2011; see Appendix 23 for further details). Thus, due to the great integration of the innovation with nature, ORNILUX Mikado meets successfully high standards of environmental impact (Ank 2021).

As Farnsworth stated (2021b), "the effectiveness of a biomimetic solution always starts with business: no business, no impact". In the first year of the product's market launch, 2009 (see Appendix 24 for more information on the product development timeline), ORNILUX Mikado was still a niche product, mainly used by innovation driven architects in ecologically sensitive zones. Arnold Glas in fact started to work with early adopters in zoos as well as animal-friendly architectural projects, where remarkable differences in the number of bird strikes have been noticed through monitoring programs (Ank 2021). The firm right after engaged with universities and government institutions (see Appendix 25 for further details), which have proven to be great supporters of sustainable design, and then it extended the product to private houses and commercial buildings. ORNILUX Mikado was clearly perceived as more expensive by customers compared to standard glass products, the total premium for bird-friendly windows indeed ranged, in 2016, between 15% and 25% above the cost of traditional glass windows of comparable characteristics (Biomimicry Business Intelligence 2016a). Therefore, it was relevant to educate customers and help them understanding that birds' collisions were a real issue. "A big part of our job was creating awareness on the problem", stated Natalie Ank (2021), Arnold Glas' Europe export manager, "we actively partnered with non-governmental organizations in spreading the issue, then things started to change in the U.S.: the first local laws and regulations came into life". Several major cities in the U.S. passed various ordinances which required the use of bird protection measures for all new or changed buildings facades as well as glass monuments or bus shelters (Biomimicry Business Intelligence 2016a). Thus, the demand for greener glass

products in relation to bird protective measures quickly increased year by year, turning ORNILUX Mikado into a consistent part in U.S. and Europe tenders, thus not a niche product anymore (Ank 2021). By buying Arnold Glas' biomimetic glass, customers could respect local environmental laws, while having access to a technologically sophisticated window (Biomimicry Business Intelligence 2016a). Furthermore, the new crisscrossed patterned coating brought relevant benefits in the amount of waste generated during the production process, which consequently notably lowered production costs. The environmental mission of Arnold Glas, together with greater pressure of buildings' ecological standards and the very well-rated aesthetics of the product itself, made the biomimetic innovation the best seller of the company among many other technical products, and ultimately the most popular and effective bird-friendly glass on the market, both in America and Europe (Biomimicry Business Intelligence 2016a). The competitive advantage achieved with ORNILUX Mikado lies on its extreme transparency, which highly differentiates the product from other bird-friendly companies' non-biomimetic innovations that include acid-etched markers or ceramic frit (Ank 2021). As Natalie declared, "the awareness on the issue is much bigger now, bird protective measures are successfully part of many architectural projects and that is a big achievement for us – and for birds" (Ank 2021; see Appendix 26 for an overview of ORNILUX Mikado outcomes).

4.2 INTERFACE

4.2.1 Company & Industry Overview

In 1956, the first ever carpet tile was created by PJ van Heugten in Europe and this crucial event captured the attention of Ray Anderson, who recognised its potentiality in modern offices. In 1973, Anderson founded Interface in Georgia, bringing the concept of free lay carpet to America and starting a commercial floorcovering revolution which has made the company a global leader in the sector since 90's (Interface 2021a). Interface competes both in the commercial arena and in residential product lines, however it focuses mostly on the first category where traditional broadloom carpets are becoming less common due to their lack of durability and difficulty in replacement (Biomimicry Business Intelligence 2016b). What makes the firm unique is a journey started in 1994, when Anderson realized that he had the power to make the company an

environmental success as well. Indeed, after reading "The Ecology of Commerce" by Paul Hawken, he decided to set Interface on a path towards sustainability, thus addressing the company's enormous footprint of energy and waste (InterfaceFLOR 2012). The carpet industry has been recently innovating product lines to create eco-friendly and more efficient products that do not require the traditional petroleum-based carpet manufacturing process, which is highly dangerous for the environment as well as humans. Some companies are in fact looking to use renewable energy sources to power the industry, while others are focusing in finding ways to reduce waste and water consumption in the manufacturing and installation processes (Biomimicry Business Intelligence 2016b). This mind-set shift raised many concerns on companies' profitability, indeed it made salient the organizational tension between product performance and environmental impact, which led Interface rethink its current practices and exploring potential opportunities.

4.2.2 The Challenge

As a whole, the carpet manufacturing is a petroleum-based and environmentally unfriendly business that creates large amounts of waste and pollution (Biomimicry Toolbox 2010). Specifically, carpets are mostly made of synthetic fibers, that include nylon, polyester and acrylic, materials refined from chemical substances derived from petroleum (Biomimicry Business Intelligence 2016b). The manufacturing process therefore constantly releases into the environment more than 900 different pollutants, in addition to hundreds of gallons of toxic wastewater (Biomimicry Toolbox 2010). Besides the use of non-sustainable and non-renewables materials, many of the petrochemicals used are carcinogenic, a potential threat to both workers and nearby communities (Health Stuff 2018). Most of these materials are not recycled or re-used, thus they end up in landfills for decades (Biomimicry Toolbox 2010; Appendix 27). Synthetic fibers are also a major cause of the micro-plastic pollution in the oceans, where the materials are then easily integrated in the food chain (Greenperforming 2020; see Appendix 28 for more information on the issue). Another source of waste in the industry concerns dye lots. If they do not match after their mixing, they are frequently rejected, raising production costs. Furthermore, mis-matched dye lots mean that companies need to keep higher quantities of stock to ensure consumers replacing worn-out sections in the future (Biomimicry Business Intelligence

2016b). Faced with these issues, Ray Anderson issued a greener vision for the company future: "we realized that we were part of an industrial system – a take, make, waste linear system – that's literally digging up the Earth and converting it to rubbish" (Ray Anderson 2009). David Oakey, a design consultant for Interface in the mid 1990s, was truly concerned over how to embark in this mission, nature's cycles seemed incompatible with the industrial textiles at that point (Farnsworth 2021a). The designer could not connect the move to environmental sustainability with the economic realities required by the billion-dollar company, however sustainability would have to take place regardless, in accordance to the CEO's vision (Farnsworth 2021a). Thus, Anderson formed a task force to launch a sustainability movement within the company, challenging his employees to turn Interface into a restorative business. Many challenges could arise at this point: Oakey feared that sustainability meant in first place designing with natural materials, whose consequent demand he knew would be cost prohibitive (Farnsworth 2021a). Furthermore, the carpet tiles' extremely functional technology needed to be maintained to ensure sales. Another crucial point would have concerned switching to greener technologies as well as renewable sources of energy, whose success would have required relevant investments both in engineering and mechanical department, since the carpet industry was a highly traditional sector. Finally, renewing the whole value chain would have meant creating different products with a consequent huge unpredictability in future sales, that until now were secured by a strong brand. Thus, the mission pursuit clearly meant navigating the tension between preserving its great business and profit margins, strongly related to the capacity of delivering a high quality and functional product, and the desired environmental impact to be achieved (Appendix 29).

4.2.3 Biomimicry Implementation

To become a restorative business, the company needed to reconcile manufacturing practices with nature cycles, thus respecting its operating conditions (Farnsworth 2021a). Paul Hawken recommended the Interface task force for sustainability to read Benyus's book, which introduced the concept of biomimicry to the company (Biomimicry Toolbox 2010). Thus, in 1999, a series of workshops were organized with the consulting company Biomimicry 3.8, from which Interface CEO and employees learned about how other

companies and innovators successfully applied its principles. The workshops participants were challenged to go outside and asking the question "how would nature design floors?" (Farnsworth 2021a). Oakey saw an answer: "if you look at anything in nature – leaves, flowers, rocks – it's diversity" (Oakey 2014). He observed that in nature nothing is the same, every individual unit is unique, different in size and shape, thus a natural and beautiful randomness emerges in the arrangement of individual units (Appendix 30). The design consultant reflected on how uniformity is a concept created by humans, meaning designing each product with the same colour and texture: "what we called *quality* was going against nature's grain and the result was waste" (Oakey 2014). Besides diversity, the task force managed to identify other crucial principles that guide ecosystems' efficiency. Firstly, all waste has value in other production processes, which means that everything can be reused, recycled or reclaimed. Secondly, nature involves current solar income to feed its processes, thus it uses renewable sources and it is energy efficient (Biomimicry Business Intelligence 2016b). Designers began therefore to experiment with carpet tile patterns while introducing the principles identified in the manufacturing process and the result was an innovative biomimetic design called Entropy – organized chaos (Biomimicry Toolbox 2010). Differently from traditional carpets that must all match exactly, installed uniformly and in the same direction, the new carpet tile, inspired by nature colours and patterns, could be placed randomly in any direction while still creating a visually appealing (Appendix 31). In this sense, savings in installation costs, for both consumers and Interface, and waste linked with mis-matched dye lots were significant (InterfaceFLOR 2012). Another important point concerning recycling and the use of toxic chemicals had been identified in the conventional glue used to connect tiles. Traditionally, carpets are installed by applying glue and adhering them directly to the floor, which can lead to many problems, namely health issues post-installation due to its toxic chemicals as well as no possibilities to recycle tiles or reuse them (Biomimicry Business Intelligence 2016b). Thus, another biomimetic innovation was realized after two years of collaboration with scientists to manage these issues, TacTiles, a glue-free design that keeps effectively together carpet tiles without the use of toxic chemicals (Interface 2021b). Specifically, the design consists in releasable adhesive squares that adhere tiles to each other, which once connected

gravity keeps securely on the floor without be permanently attached (InterfaceFLOR 2012; Appendix 32). TacTiles finds its inspiration from the intermolecular force that allows animals like the gecko to seemingly adhere to surfaces, namely the Van der Waals force (see Appendix 33 for more information). In molecular physics, this force is a distance-dependent interaction between atoms or molecules, which does not result from a chemical electronic bond, differently from ionic or covalent bonds (Wikipedia 2021). In this sense, as the million tiny hairs on geckos' feet help maximize contact with surfaces by employing Van der Waals force (Appendix 34), TacTiles adhere carpet tiles to each other as opposed to the floor, creating a dimensionally stable "floating floor" (InterfaceFLOR 2012). With this biomimetic innovation, there is no damage to the subfloor and no sticky mess during the installation, TacTiles makes in fact installing modular flooring easy, quick and clean (Interface 2021c). Interface's task force also worked hard in applying another biomimetic principle to its manufacturing process, using life-friendly chemistry, which means utilizing benign chemical components, therefore soluble in water, as nature does in all its processes. Thus, the company began to incorporate both recycled and bio-based fibers in carpet tiles, replacing petroleum-based nylon with bio-polymer fibers (Biomimicry Toolbox 2010; see Appendix 35 & 36 for more information on natural fibers and their environmental benefits). Finally, Interface has been successful in moving to renewable energy as well as reducing water usage (Farnsworth 2021a; see Appendix 37 for an overview of Interface biomimetic solutions).

4.2.4 Managing the Tension

In April 2000, Entropy product was released in the carpet tile market by Interface and, three years later, the entire product line i2 was introduced, which accounted over 80 designs in 2010 (Biomimicry Toolbox 2010). Entropy's ingenious tiles became quickly a top selling product, due to its many benefits to both company and consumers. On the one hand, since the manufacturing process no longer required the rejection of mismatching dye lots, recycling and disposal costs for raw materials widely decreased. Furthermore, the biomimetic design allowed more tiles to pass quality assurance checks. On the other hand, consumers could avoid installation costs due to the possibility of positioning tiles in multiple directions, enabling previously

wasted pieces to be fitted into the finished carpet (InterfaceFLOR 2012). In addition, consumers could also avoid costs related to identical dye lots replacement. Specifically, Entropy saved customers $110 for every 100 yards ordered (Farnsworth 2021a), which highly increased Interface loyalty and popularity, together with the extremely positive opinions on the nature randomness patterns. Indeed, the task force noted how people feel relaxed when they are outside in the wild, enjoying the randomness nature of the environment, thus they perceive Entropy design as extremely comforting (Farnsworth 2021a). This resulted in a significant growth in sales between 2004 and 2009 equal to 85 million square yards. In 2009, the company's avoided costs from its waste activities were $433 million. Furthermore, in 2012, i2 product line sales covered 25-30% of the modular carpet market (InterfaceFLOR 2012). By applying biomimicry principles to its manufacturing process, Interface not only has been able to grow its bottom line year-over-year, it highly preserved the environment. As the company began mimicking nature processes, they looked at cycles where waste becomes opportunity and energy usage is efficient. What resulted from Entropy introduction in the market was in fact a tiles' total recycled content equal to 74%, in addition to millions of pounds of material diverted from landfills which accounted for a reduction of 92% in 2018 (Interface 2018; Appendix 38). Indeed, when Interface was not mimicking nature's patterns and principles, it ended up creating more waste, specifically it moved from 14% of waste in traditional carpets production to 1.5% in nature inspired carpets (Farnsworth 2021a; Appendix 39). Furthermore, Interface recognized and profited from the fact that nature runs off solar income, thus they moved to renewable energy, which accounted in 2018 for the 89% of global energy sources, while the total energy use at the manufacturing facilities was down 46% (Interface 2018). The percentage of recycled bio-based materials used by Interface accounted for the 50% in 2015, with consequent relevant cutting in costs (Interface 2018; Appendix 40). The TacTiles invention brought an environmental footprint that is equivalent to more than 90% lower than traditional carpet adhesives (Interface 2021d). Consequently, greenhouse gas emissions have been reduced by 96%, water intake by 89% and carpet carbon footprint reduction was down 69% per production unit in 2018 (Interface 2018; Appendix 41). In addition, the company developed training programs to keep biomimicry inspiration and processes in the

forefront (Farnsworth 2021a). Interface therefore made biomimicry a flagship tool to reconcile financial sustainability with nature and its operating conditions (Farnsworth 2021b; see Appendix 42 for a summary of biomimicry environmental and economic benefits in Interface). As the head of Interface Science and Technology Office stated (Bradford 2014), "the ideal would be that we could all realize we are a species in a closed system […] Then, we could figure out, like nature, how to grow together in that closed system". Despite the passing away of the original CEO Ray Anderson, the biomimetic strategies implemented by Interface continue to inspire the company with extreme success. Interface indeed released many collections using the biophilic design, thus bringing elements of the natural world into the built environment. *Biophilia* literally means "love of life", commonly interpreted as the love to be surrounded by nature, which makes humans feel reconnected with Earth, bringing numerous health benefits and positive feelings (Farnsworth 2021a). Biophilic workplaces report in fact better well-being, higher productive employees and more creativity (Finch Beak 2017). As Interface successfully achieved the Mission Zero project which aimed at decreasing significantly its environmental impact by 2020, the company is now embarked on a new journey, Climate Take Back, which aims to reverse global warming (Interface 2021e; Appendix 43 & 44). Interface is currently partnering with the consulting company Biomimicry 3.8 on a pilot project, Factory as a Forest (Appendix 45), that studies methods to convert factories in nature well-integrated places that operate like a forest, meaning providing services such as water filtration and carbon sequestration with the same positive impact as the ecosystem provides (United Nations Climate Change 2021). Furthermore, Interface supports social projects that include the supply of clean, safe water and cook stoves to rural communities in Africa and Latin America, as well as funding further projects and technologies that are needed to address climate change. The company also started a partnership with nylon supplier Aquafil and the Zoological Society of London, to buy discarded fishing nets from some of the poorest communities in the world to recycle them into new yarn for Interface carpet tiles, resulting in fewer ghost nets, more reused materials and a new source of income for the communities (United Nations Climate Change 2021). Finally, Interface currently mentors other companies to encourage them establishing their own sustainability agenda (Farnsworth 2021b).

5. Discussion

5.1 Differences & Similarities Between Companies

Arnold Glas and Interface are successful examples of companies that embraced biomimicry to create a positive environmental impact while being financially sustainable, through a production of biomimetic innovations that demonstrated to be highly efficient and profitable. Despite the positive outcomes achieved, the firms approached biomimicry in different ways, underlining the science potential adaptation to any company identity, sector and challenge addressed. Both went through the typical phases of a biomimetic approach, which include identifying the issue, observing and discovering natural models, emulating strategies with the help of consultants and experts of the specific biological field, and evaluating the outcomes in terms of environmental impact and product performance (see Appendix 46). However, critical differences lie in the biomimetic operating level implemented: while Arnold Glas adopted a behavioural approach that involves the imitation of the processes and behaviours developed by organisms, Interface drew inspiration from the ecosystem level, mimicking how nature works on Earth in closed-loop systems, following its overall rules and principles. The dichotomous strategies can be justified by the nature of the challenges addressed. On the one hand, Arnold Glas committed to resolving a single and locally attuned issue, a direct consequence of its finished and installed product, whose solution was already available in nature. On the other hand, Interface aimed to totally modify its manufacturing process whose polluting consequences were contributing accelerating climate change worldwide, that led the company modify its values and sources and adopt more than one biomimetic solution. The different environmental strategies followed highly permeated the companies' business philosophy. Arnold Glas committed the firm in further investing in research to improve its current products, both economically and ecologically, which meant strictly focusing on the R&D department. The case of the glass company is common in many businesses where biomimicry is used on the product level to create innovations both efficient and impactful and it is ultimately perceived as tool for sustainability and enhanced business outcomes, as biomimicry helped the company differentiating and asserting itself on the market. Interface instead embraced the all principles of biomimicry to transform its

business from restorative to regenerative, implementing a wide variety of environmental and social projects. The textile company succeed in going beyond the biomimetic product development, letting nature's principles influencing the entire organizational culture towards a *biophilic* mind-set and the consequent company's managerial strategies, which resulted in achieving greater impact among different stakeholders. Interface case can be ultimately considered as an example of a deeper philosophical relationship with nature founded on the *ecological reciprocity*, namely "the attendant action of giving back to a habitat or its larger ecosystem because it has already given much to us", which can be defined as the end game of biomimicry (Farnsworth 2021b).

5.2 A Dialectic Approach

Despite differences and similarities between the two cases analysed, the companies' biomimetic approach in solving the tension between product performance and environmental impact can be defined as a dialectic behaviour, as it merges highly conflicting goals in a new synthesis that functions harmonically (Smith & Lewis 2011). Ecological and financial goals are indeed simultaneously achieved, without struggling on the resource allocation. As it has been widely investigated in literature, the dialectic approach turns thesis and anti-thesis, which can be seen in this case as organizational competing demands, into a new form of synthesis that transcends the opposites (Clegg & Cunha 2017; Nonaka & Toyama 2002; Bledow et al. 2009; Appendix 47). Biomimicry provided immediate benefits to the triple bottom line through a partnership with nature, that, seen as a mentor, helped Arnold Glas and Interface achieving the environmental impact desired as well as an effective and efficient product performance. Many biomimetic principles have been respected in the creation of the innovative designs illustrated as well as the restoration of Interface polluting manufacturing process. Here stands the greatness of the science in managing the tension, since each principle presents an effective strategy whose nature has been applying for 3.8 billion years. Nature is able to efficiently and effectively govern its processes using the least amount of energy, strictly renewable, and transform waste into new opportunities for other living organisms. Furthermore, nature is cost-efficient, which means that is able to avoid any redundant and not needed expense, and it only uses life-friendly chemistry. With billions

of years of experience over humans, nature has been able to create ecosystems which work in the most efficient way possible, ecosystems which are highly resilient and adaptable and which do not produce negative impact. The natural diversity superimposed with Darwinist trial and error iterations ultimately converges to better solutions, making nature creations smarter than many artificial innovations. Companies that decide to mimic these principles ultimately find themselves successful in cutting costs, being energy-efficient, increasing sales and margins, while highly benefiting and preserving the ecosystems, as the case studies demonstrated. Balance between product performance efficiency and positive environmental impact is gained: the organizational tension is now seen as a synthesis governed by nature's rules.

Despite the biomimetic powerful outcomes, little knowledge about the science is spread among organizations, thus its adoption so far resulted very slow. The awareness issue might find its roots in the humanity' disconnection from nature, which ultimately led us learning *about* nature, instead of learning *from* nature. Humans have always been part of Earth system: the numerous benefits linked with *biophilia* shows how people feel an important affinity for other living things and living systems, which highlights our mutual connections and interdependence with the planet (Farnsworth 2021a). However, our evolution might have pushed us far from the concept of reciprocity with the living world, which could explain why biomimicry, although firstly historically adopted in the fifteenth century, still finds weak awareness among businesses. Among the reasons for which humans' modern life became disconnected with nature, scholars find the exponential urbanization of the last decades, technological progress, highly processual innovations, virtual recreation options and the elevate speed of metropolitan life (Kesebir & Kesebir 2017). These factors may add to other relevant causes of slow biomimicry adoption, including a lack of interdisciplinary knowledge as well as relationships with external stakeholders, such as biologists or engineers, and the eventual organizational inertia in exploring opportunities and innovation (Farnsworth 2021b).

6. Conclusion

The exploratory research shows how biomimicry allows the organizational tension between product performance and environmental impact to come from a paradox perspective and turn into a dialectic mind-

set, where conflicting goals are harmonically synthesized. By observing patterns in nature and applying its principles, the science can help businesses enhancing environmental positive impact, being profitable and cost-efficient, and helping humans increase their resilience to an array of critical challenges to which we are progressively subjected, in the respect of nature's balance and operating conditions. Along the biomimetic approach, some companies find themselves utilizing the science to enhance outcomes on a R&D level, in other firms biomimicry appears instead to affect the entire business. Interface case showed in fact how the biomimetic product design may be an entry tool that positively changes the entire organizational culture as well as some managerial practices, including raising the well-being of employees and investing in external environmental and social projects. The more the *Life's Principles* are applied within a company, the more that company starts to behave as a living organism highly interconnected with the surrounding ecosystem, which turns into integrating different stakeholders and aggregating higher value propositions, patterns which are highly close to hybrid organizational models, as well as the eventual necessity to work on problems' public awareness to enter markets. Biomimicry requires expertise in many scientific fields, thus is essential for companies to establish partnerships and collaborations. Nature, however, could keep secrets of biological strategies still unknown to humans, investments in research are therefore continuously needed. Arnold Glas and Interface demonstrated how asking the right questions to nature can be beneficial to the overall closed-loop system we live in, by letting humans become more resilient and highly interconnect with the surrounding environment, and they paved the way for many other businesses to do the same.

7. Limitations & Future Research Suggestions

The work project is based on two case studies, which limits the generalization of the results presented. Furthermore, the research outcomes are restricted by the limited number of conducted interviews. Thus, to increase the validity of the research, more case studies should be addressed, with a consequential larger number of interviews. Additionally, it might be suggested to investigate on which extent companies can evolve as the case of Interface, namely approaching biomimicry as a design tool and ultimately finding themselves changing other areas of the organization by applying nature's principles deeply and broadly.

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HOW BIOMIMICRY HELPS COMPANIES NAVIGATE

THE ORGANIZATIONAL TENSION BETWEEN

PRODUCT PERFORMANCE AND ENVIRONMENTAL IMPACT

APPENDIX

FRANCESCA STABILE

Work project carried out under the supervision of:

Miguel Alves Martins

Appendix – Table of Contents

Appendix

Appendix 1 | **Sustainable Development Goals**

Source: https://investiresponsabilmente.it/glossario/sdgs/.

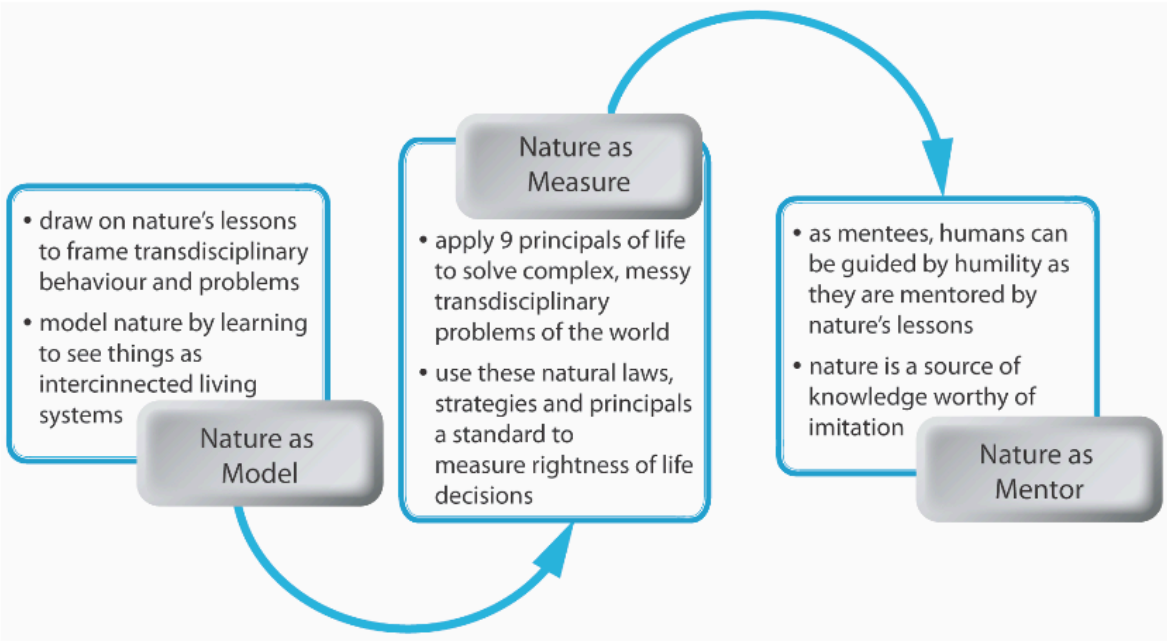
Appendix 2 | **Life's Principles**

EVOLVE TO SURVIVE	ADAPT TO CHANGING CONDITIONS	BE LOCALLY ATTUNED AND RESPONSIVE
Continually incorporate and embody information to ensure enduring performance.	Appropriately respond to dynamic contexts.	Fit into and integrate with the surrounding environment.
Replicate Strategies that Work Repeat successful approaches.	**Incorporate Diversity** Include multiple forms, processes, or systems to meet a functional need.	**Leverage Cyclic Processes** Take advantage of phenomena that repeat themselves.
Integrate the Unexpected Incorporate mistakes in ways that can lead to new forms and functions.	**Maintain Integrity through Self-Renewal** Persist by constantly adding energy and matter to heal and improve the system.	**Use Readily Available Materials and Energy** Build with abundant, accessible materials while harnessing freely available energy.
Reshuffle Information Exchange and alter information to create new options.	**Embody Resilience through Variation, Redundancy, and Decentralization** Maintain function following disturbance by incorporating a variety of duplicate forms, processes, or systems that are not located exclusively together.	**Use Feedback Loops** Engage in cyclic information flows to modify a reaction **Cultivate Cooperative Relationships** Find value through win-win interactions.

INTEGRATE DEVELOPMENT WITH GROWTH	BE RESOURCE EFFICIENT (MATERIAL AND ENERGY)	USE LIFE-FRIENDLY CHEMISTRY
Invest optimally in strategies that promote both development and growth.	Skillfully and conservatively take advantage of resources and opportunities.	Use chemistry that supports life processes.
Self-Organize Create conditions to allow components to interact in concert to move toward an enriched system. **Build from the Bottom-Up** Assemble components one unit at a time. **Combine Modular and Nested Components** Fit multiple units within each other progressively from simple to complex.	**Use Low Energy Processes** Minimize energy consumption by reducing requisite temperatures, pressures, and/or time for reactions. **Use Multi-Functional Design** Meet multiple needs with one elegant solution. **Recycle All Materials** Keep all materials in a closed loop. **Fit Form to Function** Select for shape or pattern based on need.	**Break Down Products into Benign Constituents** Use chemistry in which decomposition results in no harmful by-products. **Build Selectively with a Small Subset of Elements** Assemble relatively few elements in elegant ways. **Do Chemistry in Water** Use water as solvent.

Source: Constança Belchior & Gil Penha-Lopes (2020).

Appendix 3 | **Nature as Model, Measure, Mentor**



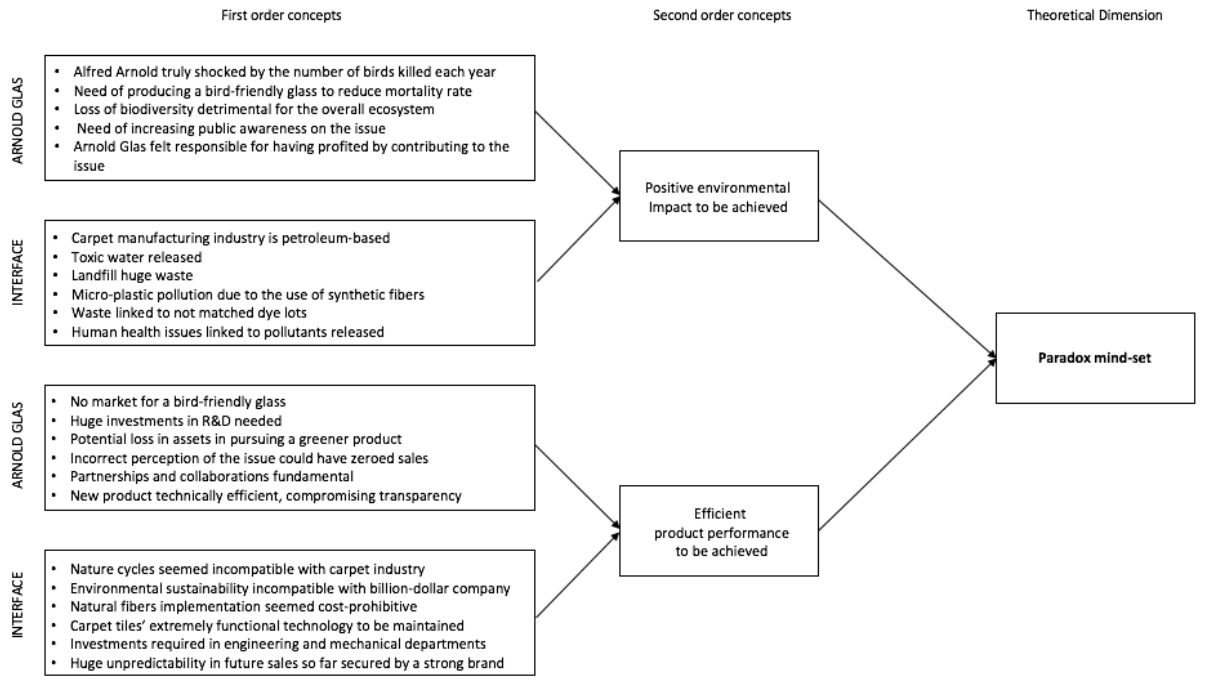
Source: McGregor (2013).

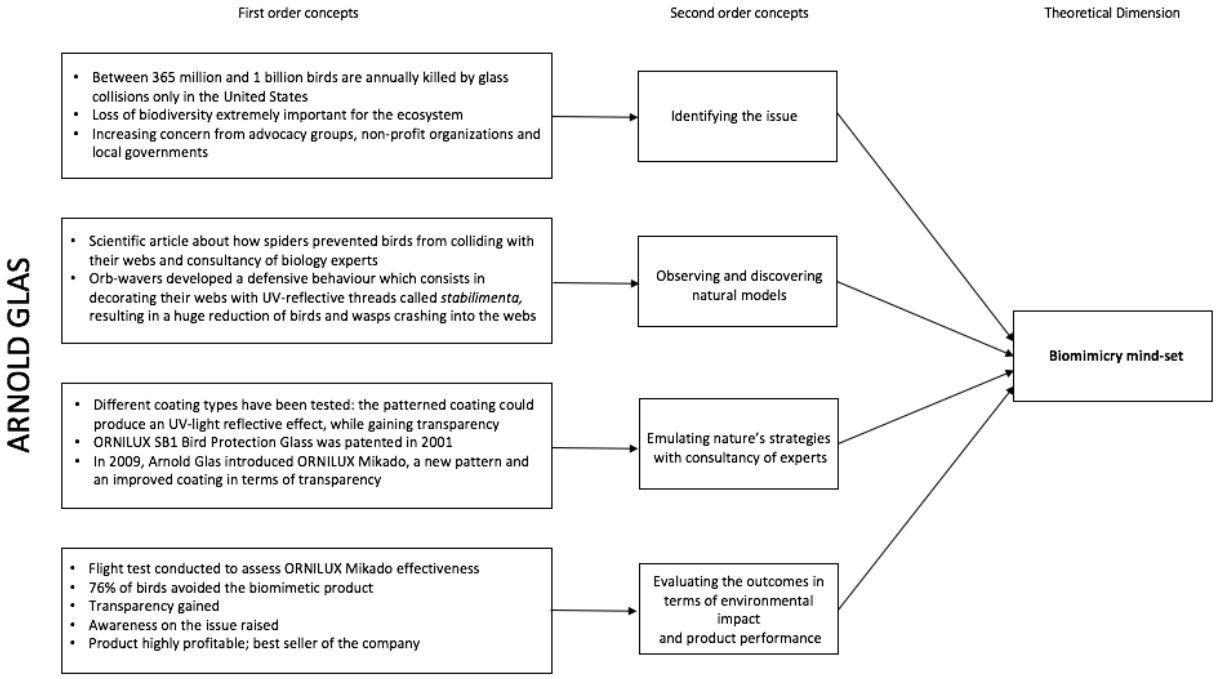
Appendix 4 | **Eisenhardt Multiple Case Studies Approach**

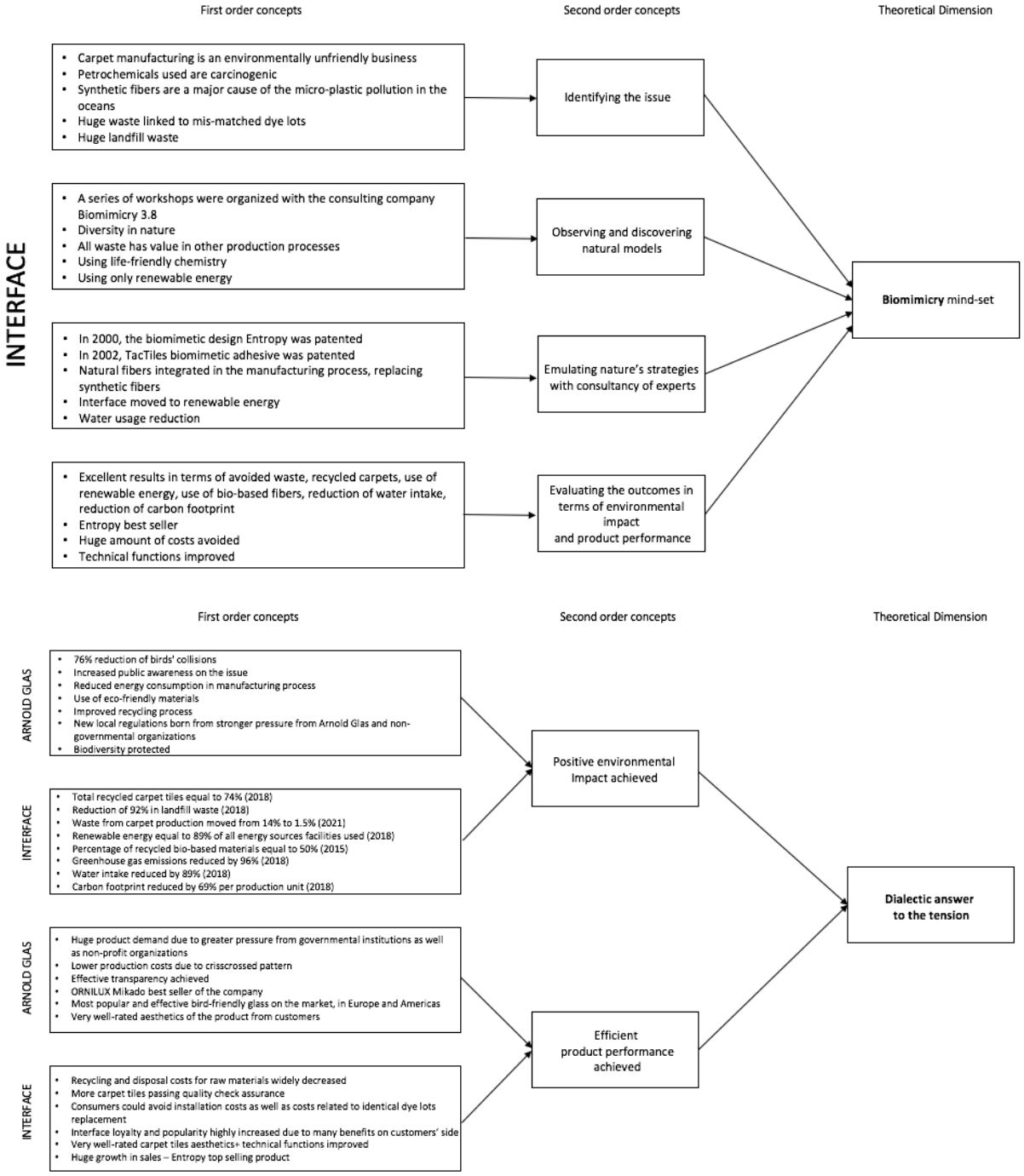
Step	*Activity*	*Purpose*	*Approach*
Define the research problem	Define question A priori constructs Neither theory nor hypotheses	Focus research Provide grounding of construct measures Retain theoretical flexibility	Barriers to the application of the health outcomes approach. Conditions that need to be met in order to use health outcomes.
Select cases	Specified population Theoretical, not random sampling	Constrain extraneous variation and sharpen external validity Focus efforts on theoretically useful cases	"Revelatory" cases were selected because they allowed an in-depth understanding of the research problem
Collect data; develop instruments and protocols	Multiple data collection methods Combine qualitative and quantitative data Ideally, multiple investigators	Strengthen grounding of theory by triangulation of evidence Foster divergent perspectives Speeds analyses and reveals helpful adjustments to data collection	Multiple data collection methods used across both case study sites.
Analysis of data	Within-case analysis Cross case pattern search using divergent techniques	Gain familiarity with data and preliminary theory generation To forces investigator to look beyond initial impressions and see evidence through multiple lenses	Within case analysis – presented as an analysis at the end of each chapter Cross case analysis – presented in chapter 6.
Shaping propositions	Iterative development of evidence for each construct Replication, not sampling, logic across cases Search for evidence for 'why' behind cases Comparison with similar and conflicting literature	Sharpen construct definition, validity and measurability Confirms, extends and sharpens theory Builds internal validity, raises theoretical level and sharpens construct definitions Sharpens generalisability and raises theoretical level	Propositions arising from the cross- case analysis of the two case studies Verified against existing literature described in Chapter 2.

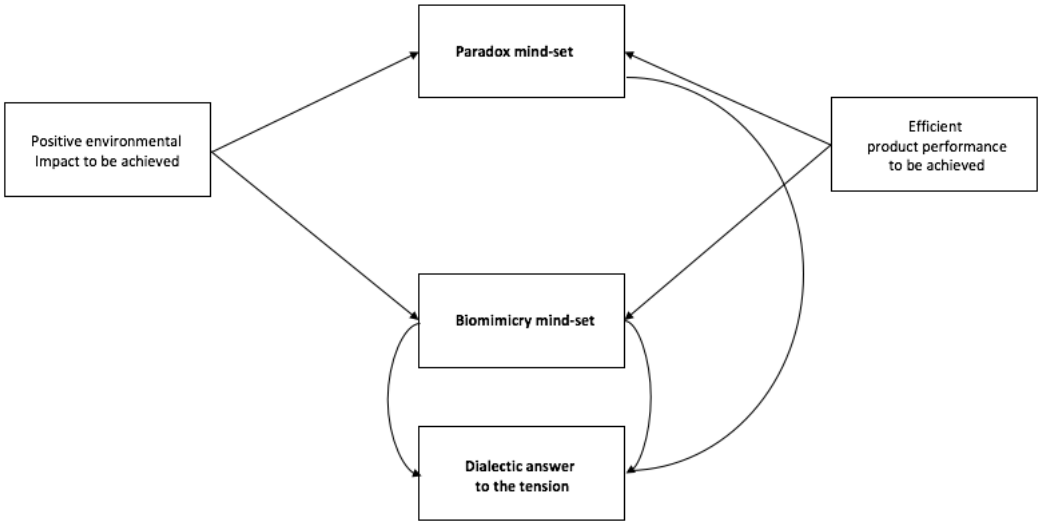
Source: https://www.researchgate.net/figure/1-Eisenhardts-case-study-road-map-as-it-is-applied-in-this-thesis_tbl3_234094068.

Appendix 5 | **Data Treatment**






First order concepts
Second order concepts
Theoretical Dimension
INTERFACE
Carpet manufacturing is an environmentally unfriendly business
Petrochemicals used are carcinogenic
Synthetic fibers are a major cause of the micro-plastic pollution in the oceans
Huge waste linked to mis-matched dye lots
Huge landfill waste
Identifying the issue
A series of workshops were organized with the consulting company Biomimicry 3.8
Diversity in nature
All waste has value in other production processes
Using life-friendly chemistry
Using only renewable energy
Observing and discovering natural models
In 2000, the biomimetic design Entropy was patented
In 2002, TacTiles biomimetic adhesive was patented
Natural fibers integrated in the manufacturing process, replacing synthetic fibers
Interface moved to renewable energy
Water usage reduction
Emulating nature's strategies with consultancy of experts
Excellent results in terms of avoided waste, recycled carpets, use of renewable energy, use of bio-based fibers, reduction of water intake, reduction of carbon footprint
Entropy best seller
Huge amount of costs avoided
Technical functions improved
Evaluating the outcomes in terms of environmental impact and product performance
Biomimicry mind-set
First order concepts
Second order concepts
Theoretical Dimension
ARNOLD GLAS
76% reduction of birds' collisions
Increased public awareness on the issue
Reduced energy consumption in manufacturing process
Use of eco-friendly materials
Improved recycling process
New local regulations born from stronger pressure from Arnold Glas and non-governmental organizations
Biodiversity protected
INTERFACE
Total recycled carpet tiles equal to 74% (2018)
Reduction of 92% in landfill waste (2018)
Waste from carpet production moved from 14% to 1.5% (2021)
Renewable energy equal to 89% of all energy sources facilities used (2018)
Percentage of recycled bio-based materials equal to 50% (2015)
Greenhouse gas emissions reduced by 96% (2018)
Water intake reduced by 89% (2018)
Carbon footprint reduced by 69% per production unit (2018)
Positive environmental Impact achieved
ARNOLD GLAS
Huge product demand due to greater pressure from governmental institutions as well as non-profit organizations
Lower production costs due to crisscrossed pattern
Effective transparency achieved
ORNILUX Mikado best seller of the company
Most popular and effective bird-friendly glass on the market, in Europe and Americas
Very well-rated aesthetics of the product from customers
INTERFACE
Recycling and disposal costs for raw materials widely decreased
More carpet tiles passing quality check assurance
Consumers could avoid installation costs as well as costs related to identical dye lots replacement
Interface loyalty and popularity highly increased due to many benefits on customers' side
Very well-rated carpet tiles aesthetics+ technical functions improved
Huge growth in sales – Entropy top selling product
Efficient product performance achieved
Dialectic answer to the tension



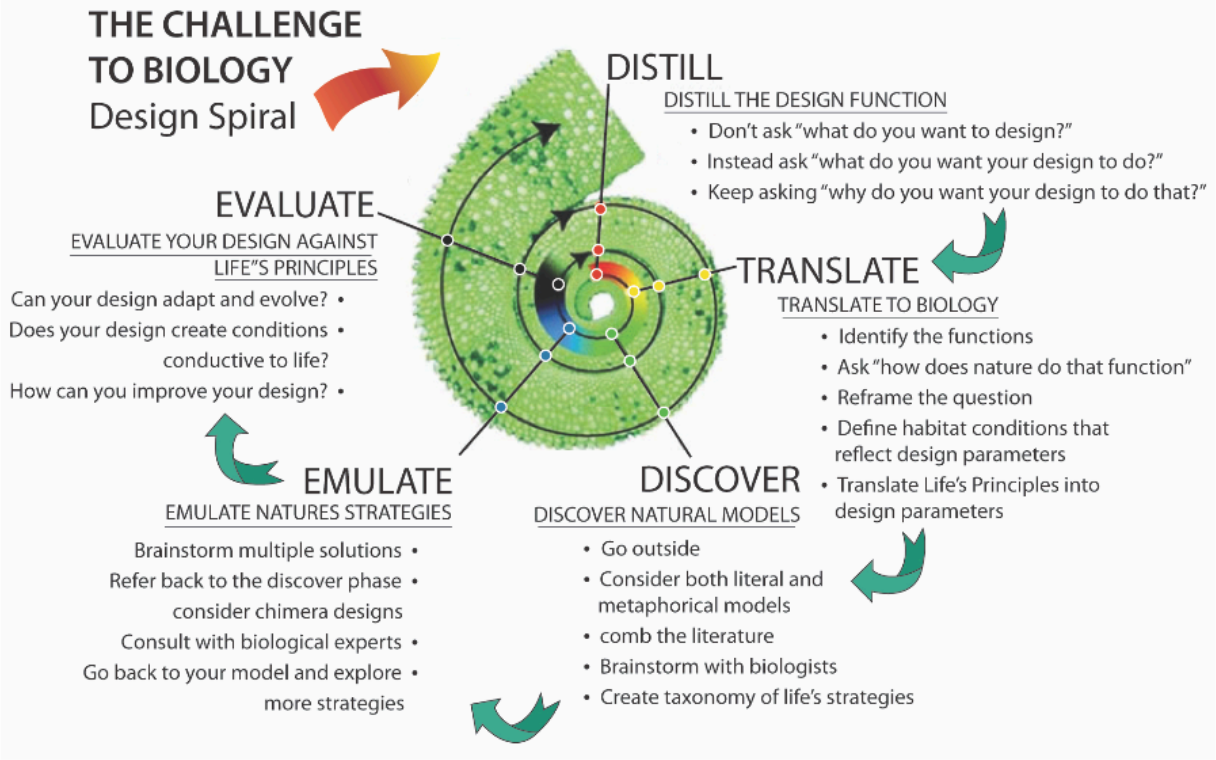
Source: Content developed by author based on the Gioia Methodology (Gioia et al. 2013).

Appendix 6 | **Data Sources for Gioia Methodology**

Type		
Interviews		
	Employee	1
	Writer/Collaborator	1
	Environmentalist	1
Documents		
	Articles, Books, Press	26
	Transcribed Videos, Interviews, Podcasts	4
	Internal/External Reports	5

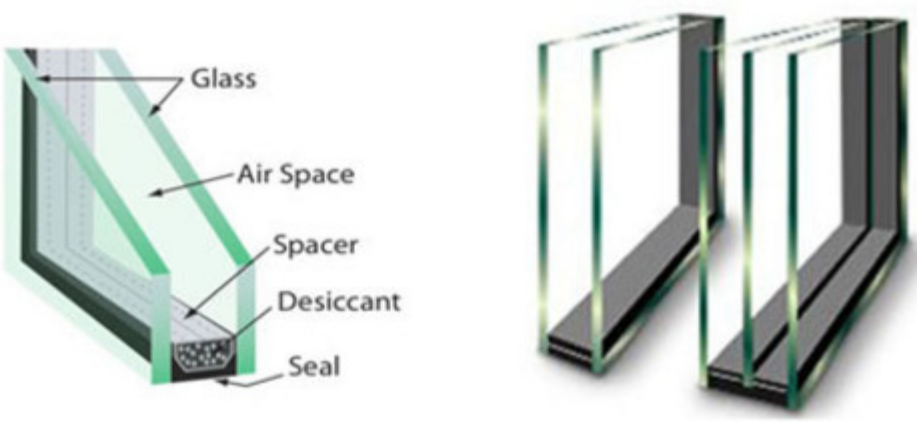
Source: Author.

Appendix 7 | **Design Spiral Methodology**



Source: McGregor (2013).

Appendix 8 | **Standard Model of Insulating Glass**



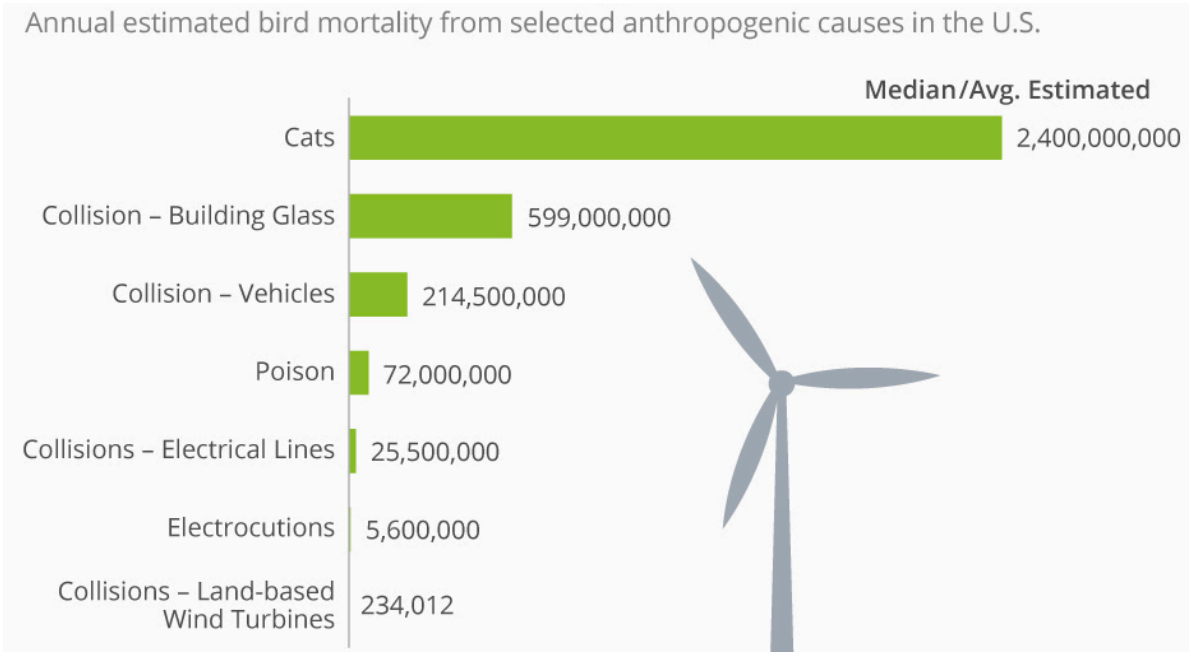
Source: https://www.indiamart.com/proddetail/insulated-glass-unit-12892520588.html.

Appendix 9 | **A Bird's Collision Print on a Window and Several Birds Died Classified**

Sources: Biomimicry Toolbox (2013);

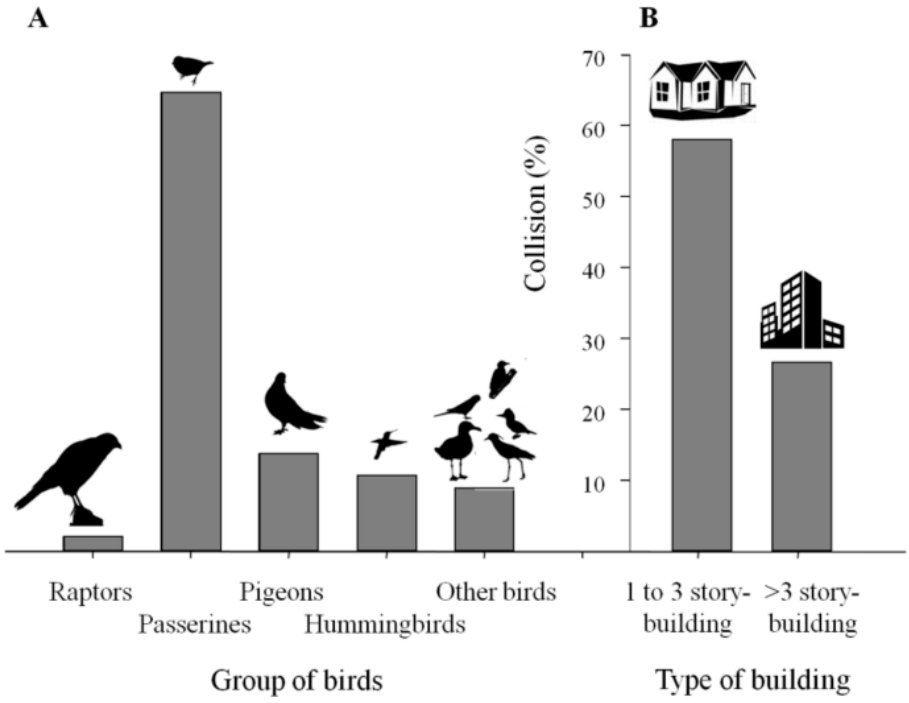
https://www.irishtimes.com/news/science/the-terrible-toll-of-bird-collisions-with-modern-buildings-1.4161584.

Appendix 10 | **Birds' Mortality Causes in the U.S.**



Source: https://www.statista.com/chart/15195/wind-turbines-are-not-killing-fields-for-birds/.

Appendix 11 | **Birds' Collisions Depending on the Species and Type of Building**



Source: https://www.nature.com/articles/s41598-019-54351-3.

Appendix 12 | **Public Awareness and Birds' Protection Initiatives**

Three main drivers strive to increase the awareness on the issue and find potential solutions to be adopted worldwide. Firstly, non-profit organizations and advocacy groups, including American Bird Conservancy and Bird & Building Forum, promote research and educational programs, as well as reports for bird-friendly

building designers. Furthermore, universities, research centres and wildlife reserves highly invest in research and innovation, in order to pave the way to bird-friendly glass adoption. Finally, local governments have recently implemented policies and legislation to incentivize bird-safe architecture and increase public awareness. Some of the requirements developed in the U.S. include the Chicago Bird Safe Design Guide and the San Francisco Standards for Bird-Safe Buildings, which both promote a market for bird-friendly glass.

Sources: Biomimicry Business Intelligence (2016a);

https://sfplanning.org/resource/standards-bird-safe-buildings-design-guide;

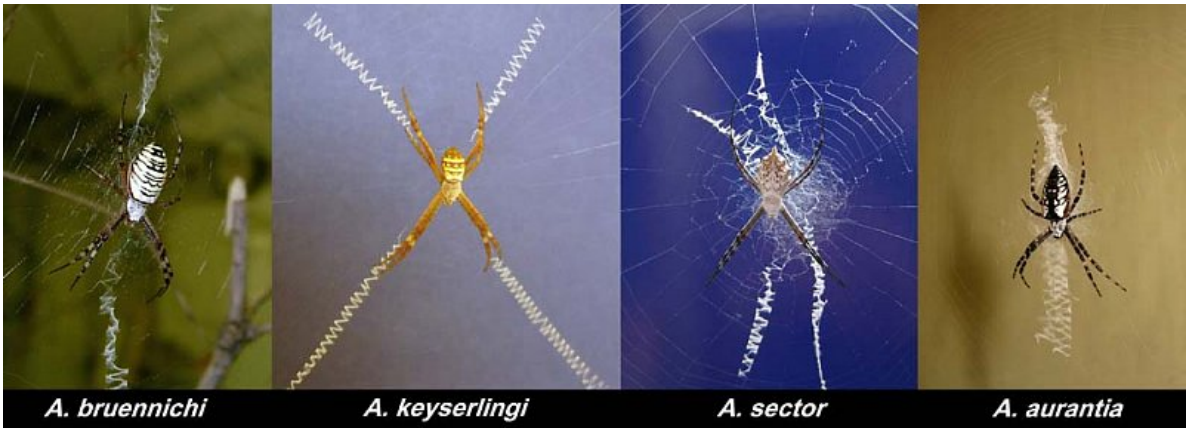
https://www.thecenterforbirdsofprey.org/visit/education/.

Appendix 13 | **Arnold Glas Organizational Tension**

ARNOLD GLAS ORGANIZATIONAL TENSION	
Environmental Impact to be Achieved	**Product Performance Goals**
Producing a glass effective against birds' collisions to reduce the mortality rate	Producing a glass comprising the traditional technical functions (insulated glass transparent and visually appealing)
Protecting biodiversity by highly investing in R&D	Enhancing sales with the new product to repay investments and increase margins
Increasing public awareness on the issue by collaborating with experts and non-profit organizations	Creating a new market to sell bird-friendly glass

Source: Author.

Appendix 14 | **Stabilimenta – Different Kinds of Patterns**



Sources: https://en.wikipedia.org/wiki/Web_decoration;

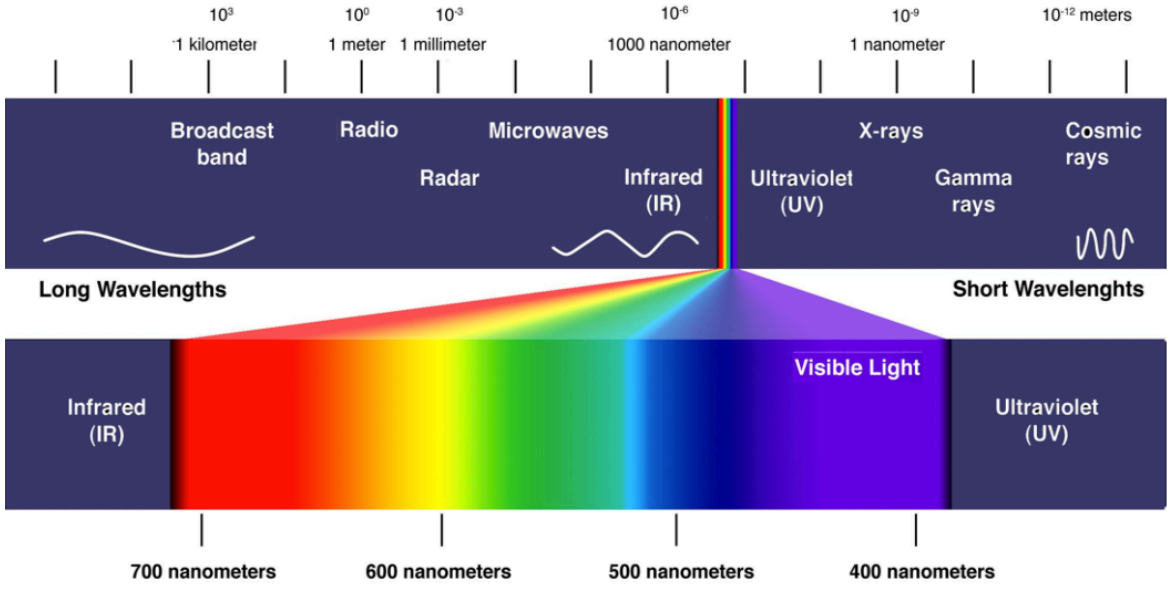
https://www.mol-ecol.uni-halle.de/research/former_topics/stabilimenta/.

Appendix 15 | **Stabilimenta – Ultraviolet Reflectance**

Sources: https://www.jstor.org/stable/3706267?seq=1;

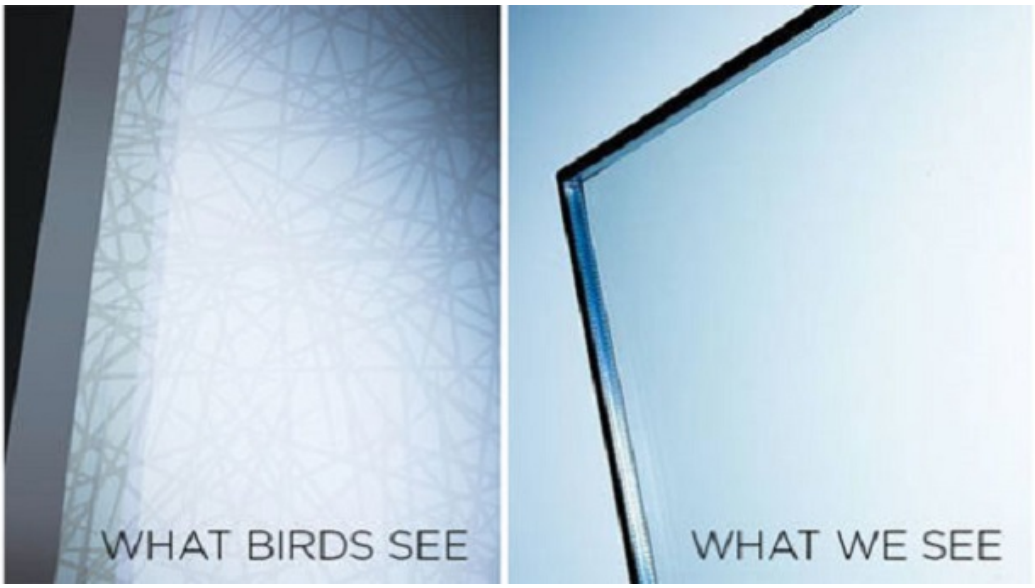
https://www.pinterest.at/pin/291537775853141198/.

Appendix 16 | **Light Spectrum**



Source: Biomimicry Business Intelligence (2016a).

Appendix 17 | **ORNILUX Mikado – Prototype**



Source: https://inhabitat.com/scientists-finally-create-bird-friendly-glass/Ornilux-mikado-bird-protection-glass/.

Appendix 18 | **ORNILUX Mikado – Private Residence Project**

Source: http://Ornilux.com/projects.html.

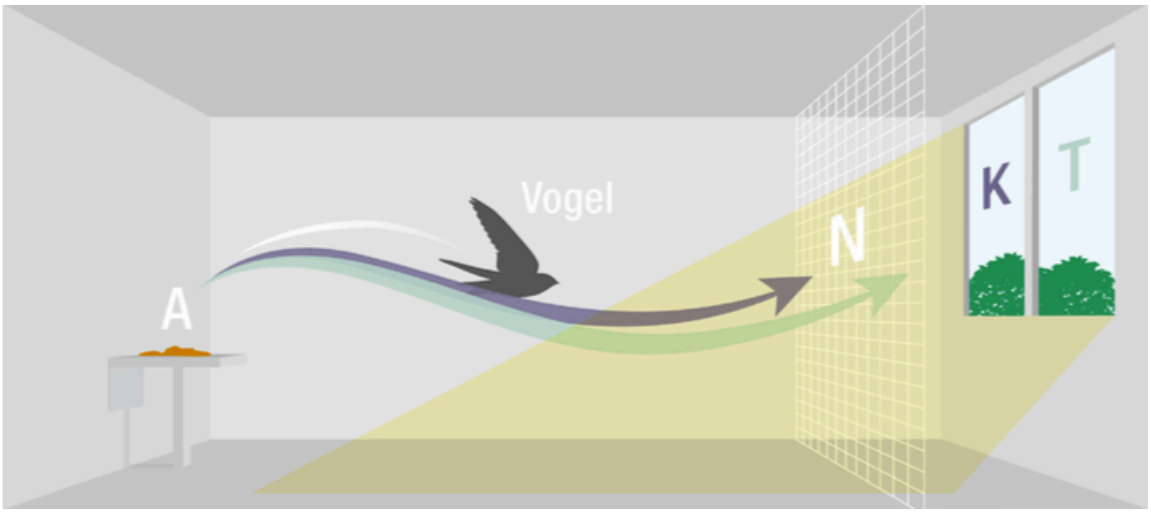
Appendix 19 | **American Bird Conservancy (ABC) Rating System**

Products listed as "tested" have been tested under controlled conditions or evaluated based on collisions numbers tabulated before and after installation (field trials). Data from testing have either been reviewed by ABC scientists or come from ABC's own testing program. ABC developed the concept of Material Threat Factor to assign scores to birds' ability to see and avoid patterned glass. Birds' collisions are tested in specific flight tunnels at various locations, whose testing is non-injurious. The Threat Factor of a product is based on testing at least 80 individual birds which are recorded whether they fly toward the conventional or to the patterned test glass. Consequently, the percentage of birds which avoid the patterned glass in registered and analysed. The following case serves as a clear example: if 80 birds fly down the tunnel, with 20 flying toward the test pattern and 60 toward the conventional, it means that the 25% (20/80) of the birds fly toward the test

pattern and it would therefore have TF=25. However, Threat Factors do not equal the exact percent reduction in collisions with real glass installations in buildings: products can perform differently depending on angle to the sun, habitat reflected, weather and so on. Nevertheless, monitoring programs confirmed that products with lower threat factors have yielded fewer collisions. ABC defines a "bird-friendly" glass if its threat factor is ≤ 30, corresponding to a reduction of collisions of at least 50%. The lower the TF, the more effective the test pattern will be at reducing collisions.

Source: American Bird Conservancy (2021b).

Appendix 20 | **ORNILUX Mikado – Prototype Flight Test**



Source: Biomimicry Business Intelligence (2016a).

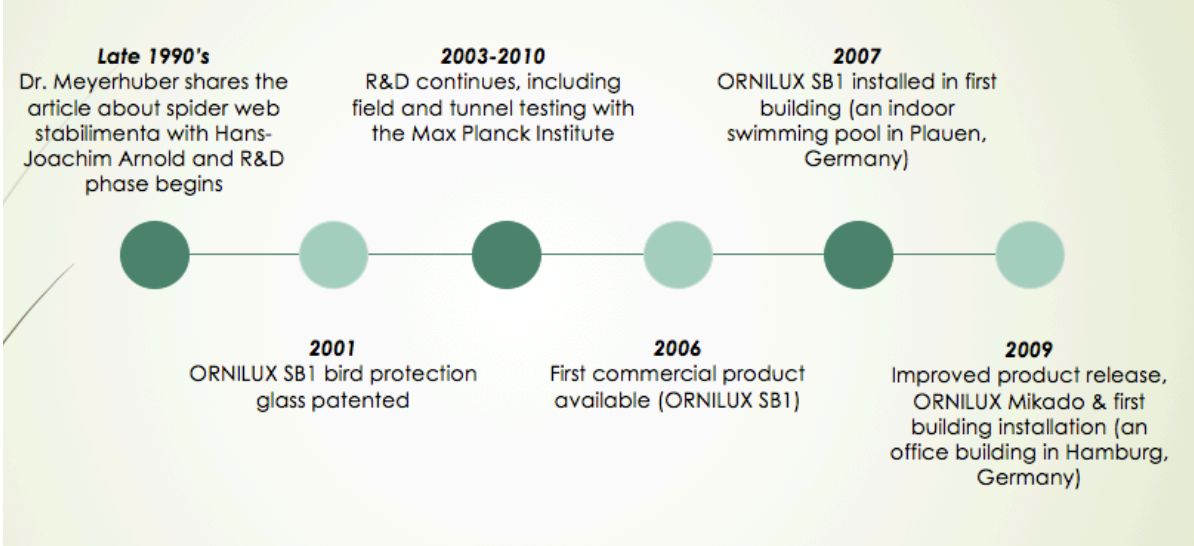
Appendix 21 | **Flight Test Conducted in Austria by American Bird Conservancy**

Figure 1: The Powdermill tunnel in operation. Birds are placed into the tunnel through a sleeve, at the right end, where video camera and computer are also located. The release door can be see at the left end of the facing side of the tunnel. Glass is mounted outside the right end of the tunnel.

Figure 2: A bird's view from inside ABC's Powdermill Test Tunnel, with clear glass on the left, glass with vertical stripes on the right. Note the net, which prevents birds from actually contacting the glass.

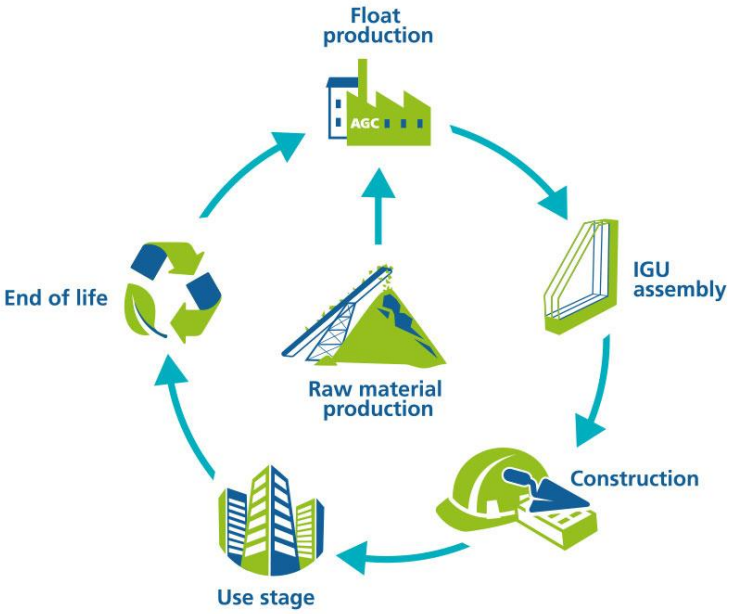
Source: https://abcbirds.org/glass-collisions/threat-factor-rating/.

Appendix 22 | **Products Development Timeline**



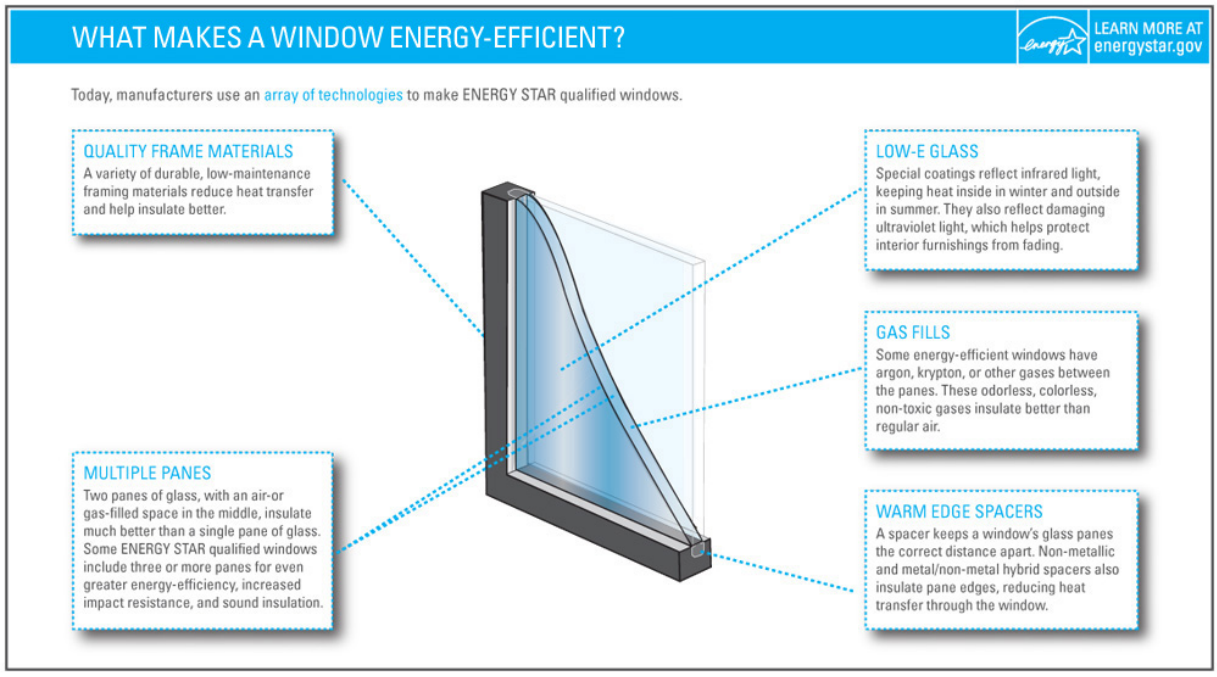
Source: Content adapted by author based on Biomimicry Toolbox (2013).

Appendix 23 | **Insulated Glass Environmental Impact**



Note: this image represents the insulated glass circular economy.

Source: https://www.agc-glass.eu/en/sustainability/environmental-footprint/epd-life-cycle-analysis.



Note: this image is a prototype of insulated glass of Energy Star company, which explains the reasons why this kind of product is energy-efficient.

Source:

https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/key_product_criteria.

Appendix 24 | **University Projects**

Arnold Glas successfully worked on two separate projects with the University of Utah and Vassar College, which accounted for about 66% of the company's total ORNILUX sales in the same year, underlining the importance of focusing on large-scale projects.

Source: Biomimicry Business Intelligence (2016a).

Appendix 25 | **Environmental Impact and Product Performance Overview**

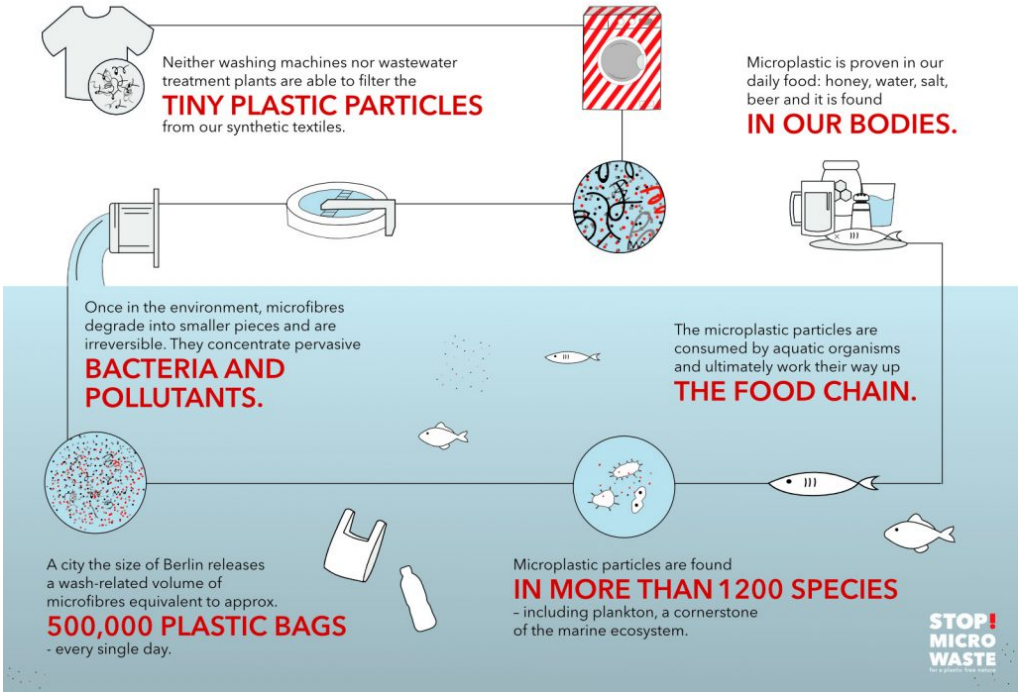
<table>
<tr><th colspan="2">ORNILUX MIKADO OUTCOMES</th></tr>
<tr><th>Environmental Benefits</th><th>Product Performance</th></tr>
<tr><td>76% reduction of birds' collisions</td><td rowspan="2">Huge product demand due to greater pressure from governmental institutions as well as non-profit organizations</td></tr>
<tr><td>Increased public awareness on the issue</td></tr>
<tr><td rowspan="2">Reduced energy consumption in manufacturing process</td><td rowspan="2">Lower production costs due to crisscrossed pattern</td></tr>
<tr><td>Use of eco-friendly materials</td></tr>
<tr><td>Improved recycling process</td><td>Effective transparency achieved</td></tr>
<tr><td rowspan="2">New local regulations born from stronger pressure from Arnold Glas and non-governmental organizations</td><td>ORNILUX Mikado best seller of the company</td></tr>
<tr><td rowspan="2">Most popular and effective bird-friendly glass on the market, in Europe and Americas</td></tr>
<tr><td rowspan="2">Biodiversity protected</td></tr>
<tr><td>Very well-rated aesthetics of the product from customers</td></tr>
</table>

Source: Author.

Appendix 26 | **Carpets' Landfill Waste**

Sources: https://www.treehugger.com/americas-carpet-industry-environmental-disaster-4856129; https://www.waste360.com/legislation-regulation/another-pending-decision-follow-california%E2%80%99s-newest-carpet-recycling-bill.

Appendix 27 | **Synthetic Fibers' Micro-Plastic Pollution**



Source: https://twitter.com/sfsfwi/status/1010464149040713728?lang=no.

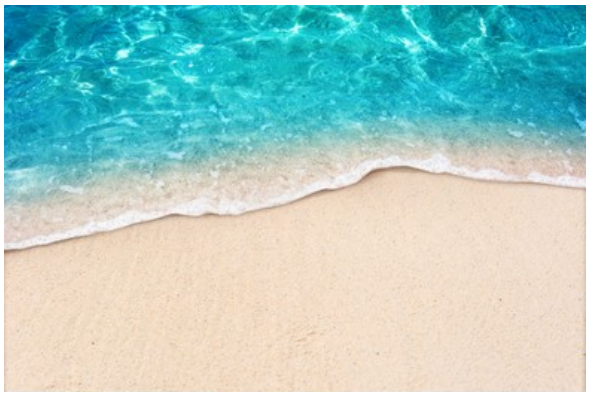
Appendix 28 | **Interface Organizational Tension**

INTERFACE ORGANIZATIONAL TENSION	
Environmental Impact to be Achieved	**Product Performance Goals**
Avoiding the use of petroleum-based fibers and improving recyclability by designing carpet tiles with natural materials	Maintaining the efficient product performance in terms of carpet tiles' technology and dealing with expensive material costs
Switching to greener technologies and renewable sources of energy	Being able to afford relevant investments in engineering and mechanical departments to connect the industry with greener practices
Modifying consumers' behaviour towards a greener shopping	Ensuring high sales with greener products, following the company's previous performance
Turning Interface into a restorative business	Preserving Interface profit margins

Source: Author.

Appendix 29 | **Nature Floors**



Sources: https://commons.wikimedia.org/wiki/File:Forest-floor-leaves_-_West_Virginia_-_ForestWander.jpg;

https://www.maxpixel.net/Kyoto-Forest-Floor-Nature-Moss-Forest-Trees-210093;

https://www.shutterstock.com/search/sea+floor;

https://www.shutterstock.com/it/search/shore.

Appendix 30 | **Entropy – Organized Chaos**

Sources: https://www.specifiedby.com/interface/entropy-ii;

https://labs.blogs.com/its_alive_in_the_lab/2009/10/technology-business-and-design.html;

https://www.pinterest.com/pin/114419646758603134/?d=t&mt=login;

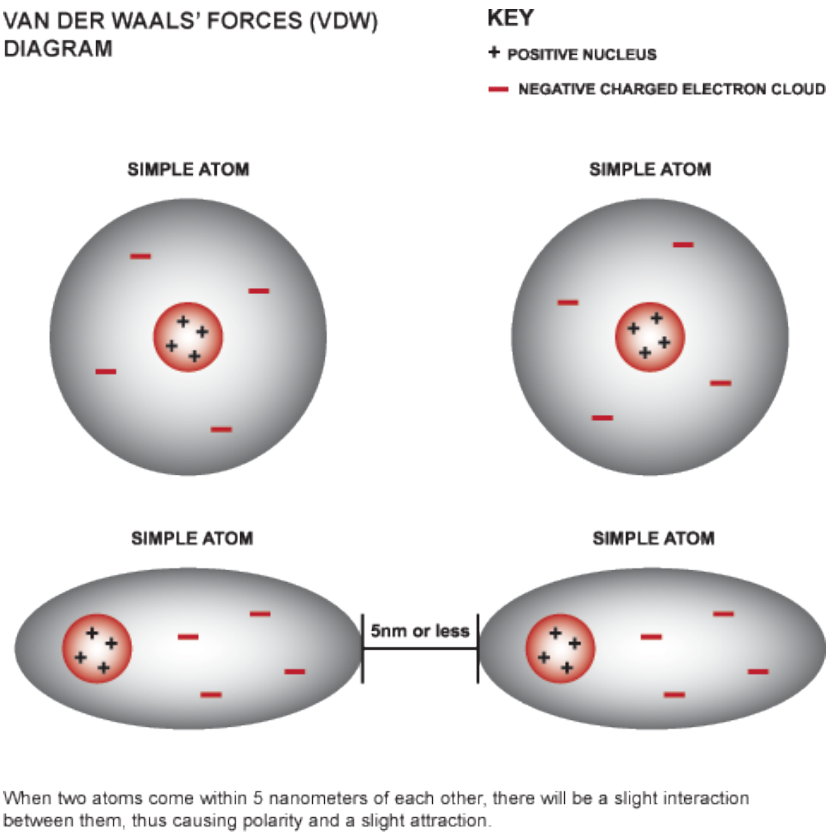
https://www.pinterest.co.uk/pin/91972017366559444/.

Appendix 31 | **TacTiles *vs* Previous Glue**

Note: the first image on the left is the TacTiles application on a carpet tile, while on the right the traditional toxic glue is used to allow carpets to adhere to the floor. Below, the TacTiles roll with an eco-friendly packaging.

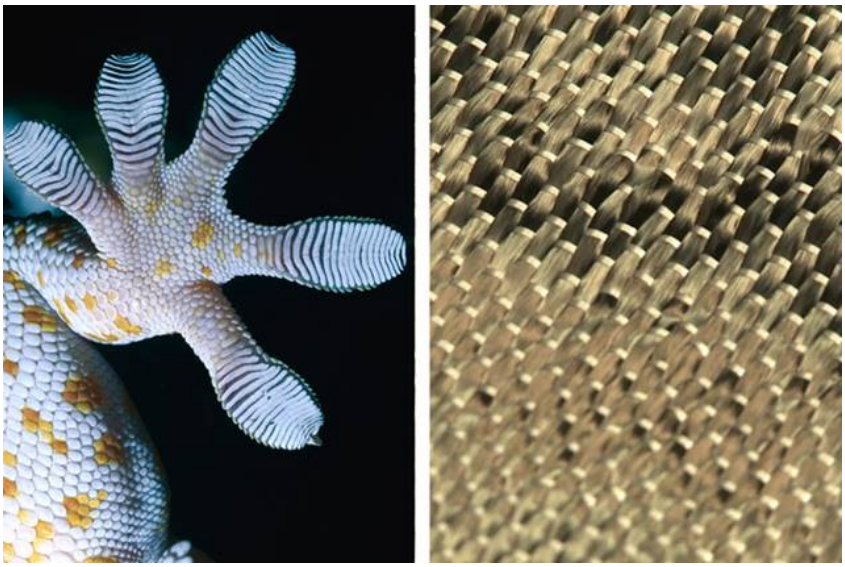
Sources: InterfaceFLOR (2012); https://www.interface.com/US/en-US/about/modular-system/TacTiles-and-Adhesives.

Appendix 32 | **Van der Waals Force**



Source: https://socratic.org/questions/how-can-van-der-waals-forces-be-either-attractive-or-repulsive.

Appendix 33 | **Gecko's Tiny Hairs that Follows Van der Waals Force**



Source: Biomimicry Business Intelligence (2016b).

Appendix 34 | **Main Biomass Sources of Biopolymer Fibers**

Biopolymers fibers are made of biologically derived polymers, which are a petroleum-free source of fibers for the textile industry and have a significant positive impact by reducing the dependence on fossil fuels as well as the carbon footprint. Additionally, biopolymers offer cost and durability benefits compared with synthetic textiles and they are easily recyclable.

Source: https://www.sciencedirect.com/science/article/abs/pii/S245221391930045;

Thangavelu & Subramani (2016).

Appendix 35 | **Comparison Between Natural Fiber and Synthetic Fiber**

Aspects	Natural fiber	Synthetic fiber
Density	Low	High
Cost	Low	Double
Renewability	Yes	No
Recyclability	Yes	No
Consumption of Energy	Low	High
Biodegradability	Yes	No
Carbon dioxide	No	Yes
Health risk	No	Yes
Eco-friendly	Yes	No

Source: https://www.researchgate.net/figure/Comparison-between-synthetic-fibers-and-natural-fibers-34_tbl1_335165275.

Appendix 36 | **Interface Biomimetic Solutions Overview**

INTERFACE BIOMIMETIC SOLUTIONS				
Name	***Source of inspiration***	***Function***	***What is it?***	***Benefits***
Entropy	Natural floors - every individual unit is unique, different in size and shape	To change the traditional concept of carpet tile which is highly wasteful	Carpet tiles different in colours and patterns	It can be placed randomly in any direction; reduction of waste caused by mis-matched dye lots; visually appealing; savings in installation costs as well as recycling and disposal ones
TacTiles	Intermolecular force that allows animals like the gecko to adhere to surfaces	To avoid the use of toxic chemicals in tiles installation and to improve recycling potentiality	Releasable adhesive squares that adhere tiles to each other, which once connected gravity keeps securely on the floor without be permanently attached	No use of toxic chemicals; no damage to the subfloor; no sticky mess during the installation; faster installation process; recycling potentiality highly improved
Bio-based fibers	Life-friendly chemistry principle of biomimicry as well as material use efficiency	To avoid the use of petroleum-based fibers, like nylon	Biopolymers fibers are made of biologically derived polymers, which are a petroleum-free source of fibers for the textile industry	Reduction of the fossil fuel dependence in manufacturing process; cost efficiency; high durability; high recyclability
Renewable energy	Energy efficiency principle of biomimicry	To avoid the use of non-renewable energy sources which are highly pollutant for the environment	Mostly solar energy	Huge reduction of Interface's carbon footprint (69% down per production unit)

Source: Author.

Appendix 37 | **Waste Cost Savings Chart – Different Product Lines**

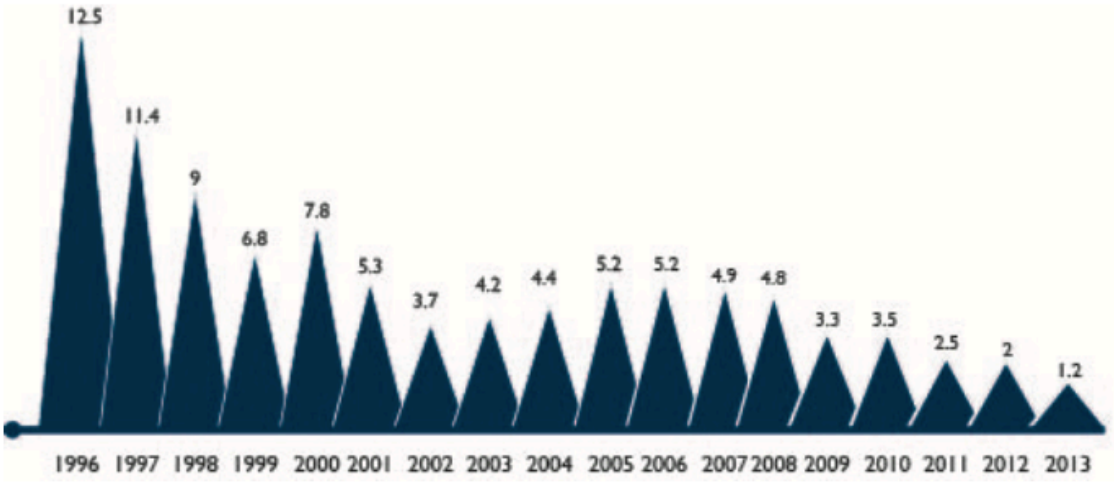
WASTE COST SAVINGS				
FACTORS	I2 NON DIRECTIONAL	MODULAR CARPET	I2 FT BROADLOOM	12 FT PATTERNED BROADLOOM
Size of facility (sq. ft.)	41,715	41,715	41,715	41,715
Carpeted area -70% (sq. ft.)	29,200	29,200	29,200	29,200
Installation waste (sq. ft.)	1.5%	4%	10.3%	18.2%
Total waste (sq. ft.)	438	1,168	3,008	5,314
Total waste (sq. yd.)	49	130	334	590
Total waste cost*	$980	$2,600	$6,680	$11,800
Total material cost savings with i2		$1,620	$5,700	$10,820

*Based upon estimated cost of $20 (USD) per sq. yd.

Note: the four categories analyzed are different products in i2 biomimetic product line. From the right side to the left one products are improved in terms of environmental impact and product performance, meaning less waste costs and material costs savings.

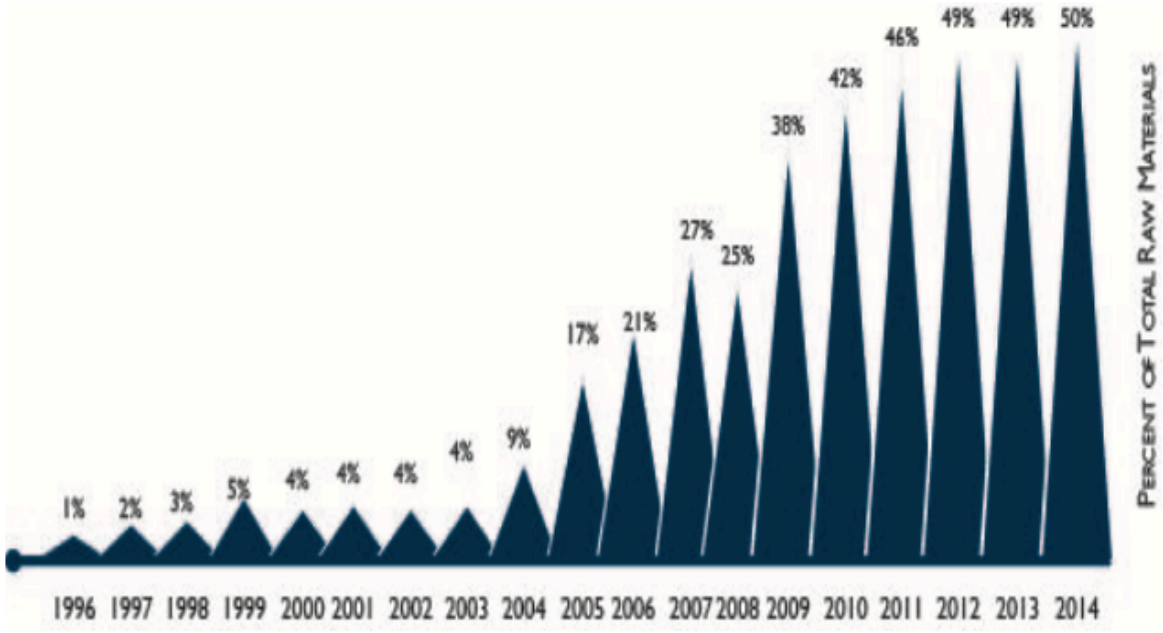
Source: InterfaceFLOR (2012).

Appendix 38 | **Waste to Landfill from Interface Carpet Factories**



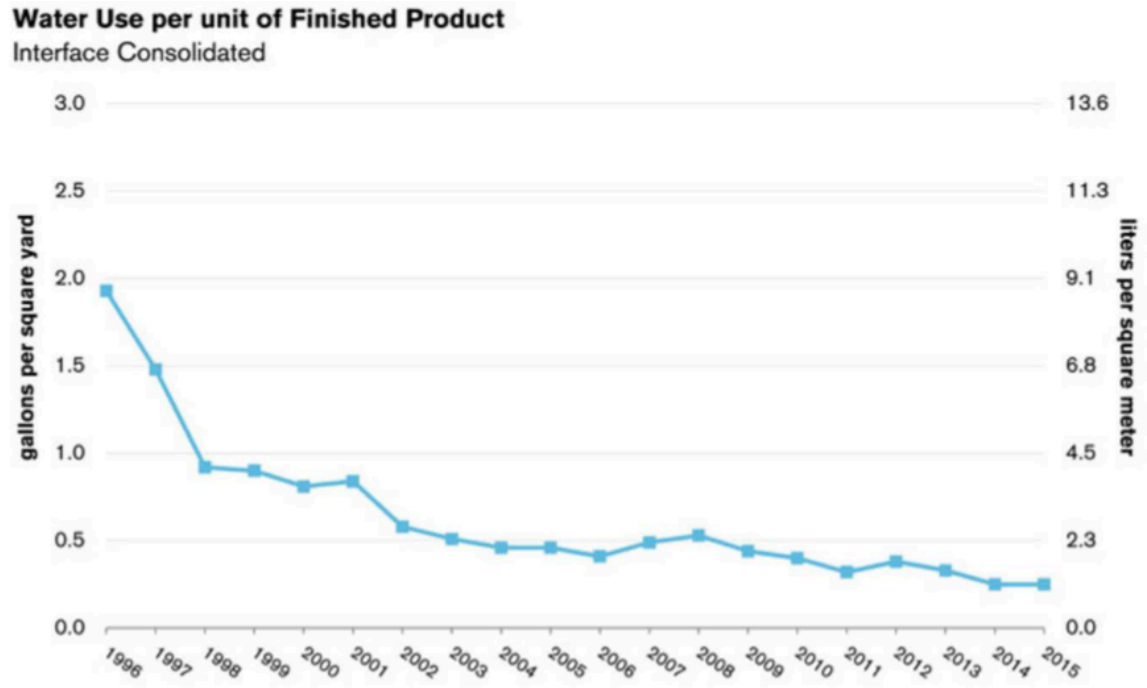
Source: Biomimicry Business Intelligence (2016b).

Appendix 39 | **Percentage of Recycled Bio-based Materials Used by Interface**



Source: Biomimicry Business Intelligence (2016b).

Appendix 40 | **Water Use per Unit of Finished Product**



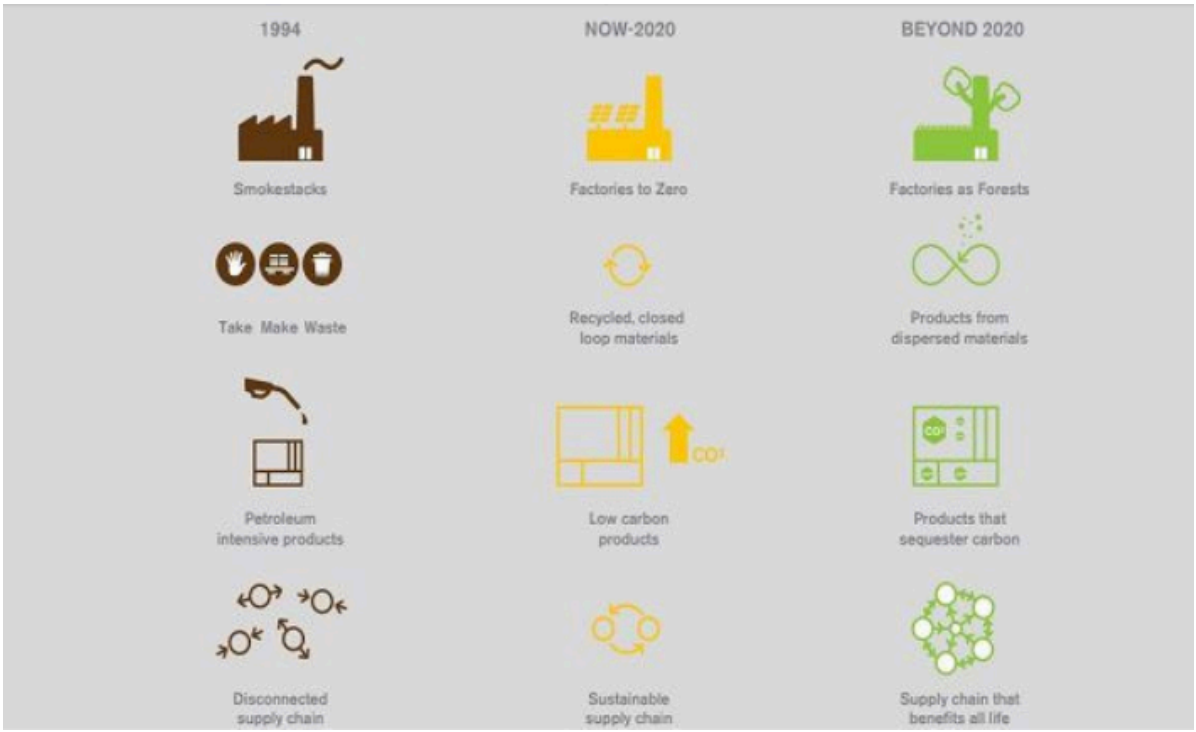
Source: Biomimicry Business Intelligence (2016b).

Appendix 41 | **Interface Biomimetic Environmental and Economic Benefits Overview**

BIOMIMETIC BENEFITS OVERVIEW	
Environmental Benefits	**Biomimetic Solutions' Economic Performance**
Total recycled carpet tiles equal to 74% (2018)	Recycling and disposal costs for raw materials widely decreased
Reduction of 92% in landfill waste (2018)	More carpet tiles passing quality check assurance
Waste from carpet production moved from 14% to 1.5% (2021)	Consumers could avoid installation costs as well as costs related to identical dye lots replacement
Renewable energy equal to 89% of all energy sources facilities used (2018)	Interface loyalty and popularity highly increased due to many benefits on customers' side
Percentage of recycled bio-based materials equal to 50% (2015)	Very well-rated carpet tiles aesthetics+ technical functions improved
Greenhouse gas emissions reduced by 96% (2018)	Huge growth in sales
Water intake reduced by 89% (2018)	Interface global top seller
Carbon footprint reduced by 69% per production unit (2018)	Entropy top selling product

Source: Author.

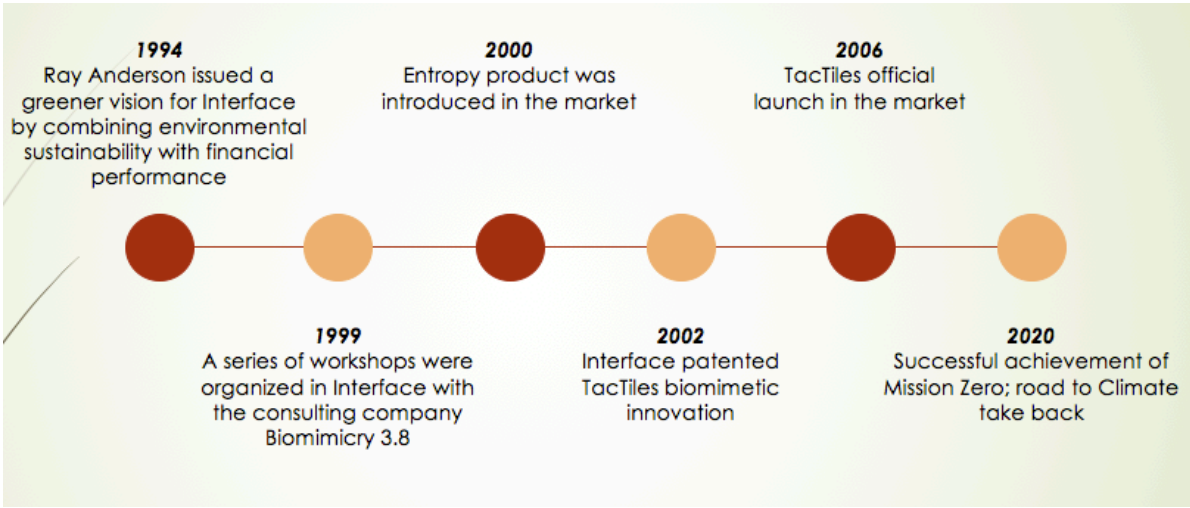
Appendix 42 | **Interface Roadmap**



Sources: United Nations Climate Change (2021);

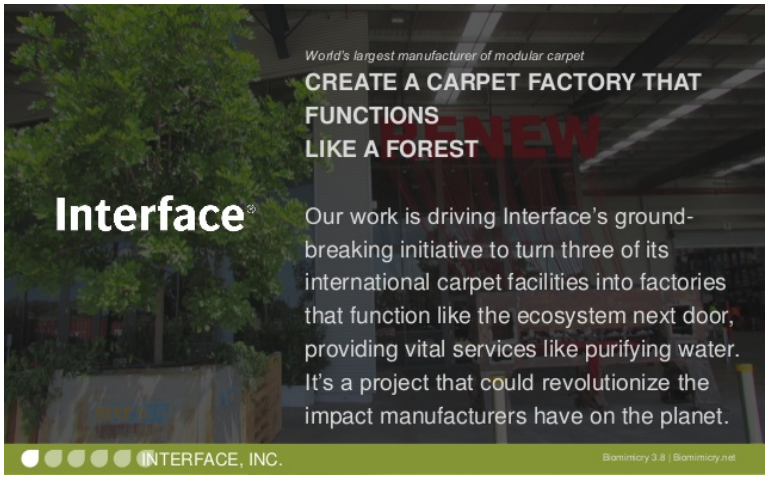
https://blog.interface.com/factory-forest-reimagining-facilities-ecosystems/.

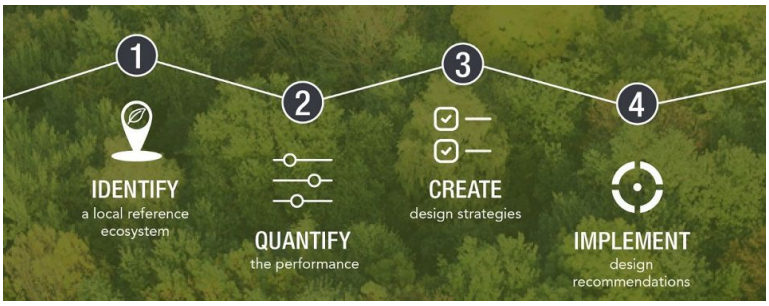
Appendix 43 | **Interface Biomimetic Timeline**



Source: Content adapted by author based on Biomimicry Toolbox (2010).

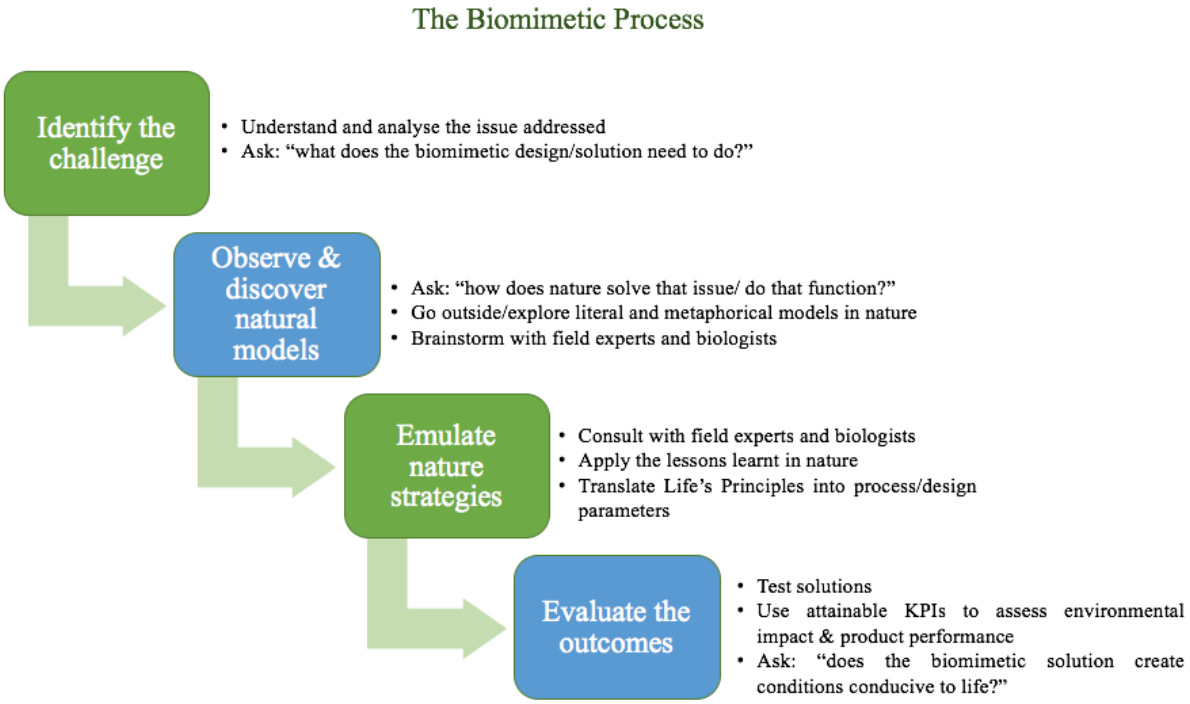
Appendix 44 | **Project Factory as A Forest**





Source: https://blog.interface.com/factory-forest-reimagining-facilities-ecosystems/.

Appendix 45 | **The Biomimetic Process**



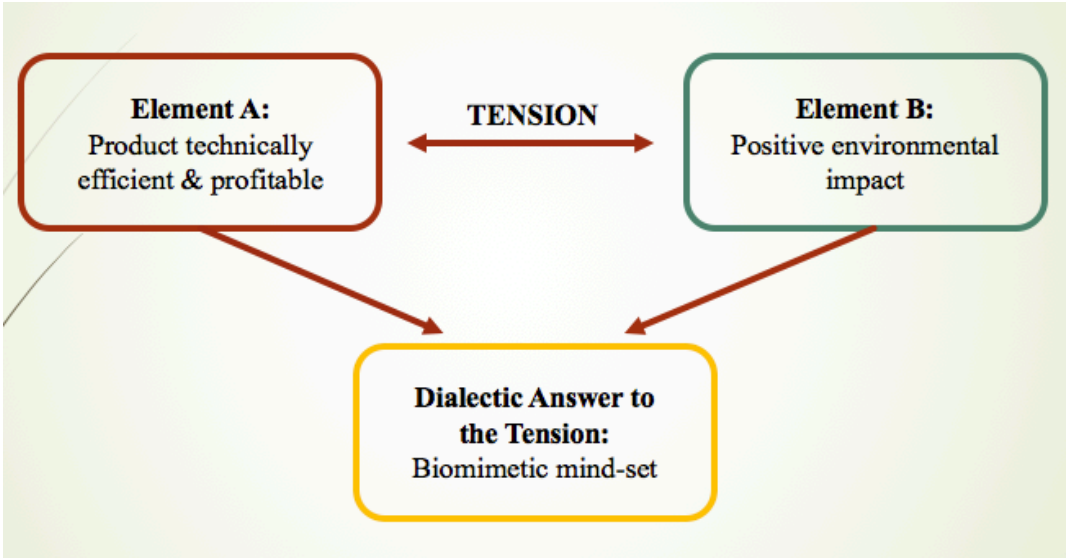
Source: Author.

Appendix 46 | **Differences & Similarities Between the Two Companies**

	ARNOLD GLAS	INTERFACE
Biomimetic overall process	Identification of the issue, nature observation, discovering models, emulating strategies, evaluating the outcomes	Identification of the issue, nature observation, discovering models, emulating strategies, evaluating the outcomes
Challenge addressed	Single and locally attuned negative direct effect on fauna (to be addressed then worldwide)	Total transformation of the highly polluting manufacturing process
Approach to the mimicry	Behavioural approach: imitation of processes and behaviours implemented by organisms	Ecosystem approach: imitation of a network operating in an ongoing cycle + form approach (TacTiles innovation)
Business philosophy	Further investments in research to improve current products ecologically and economically	Going beyond product development by spreading nature's principles in the organizational culture and strategy; deeper relationship with nature

Source: Author.

Appendix 47 | **Dialectic Approach to Solve the Tension**



Source: Author.