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BIO-INSPIRED PRODUCT DESIGN BRIEF MODULE

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ABSTRACT
The principal objective of this paper is to demonstrate the capability of biomimetic inspiration as a useful thinking module while relating to product design brief concerns in design education. This bottom-up approach module is based on the mechanical principle of Salsola Tragus, an annual weed that begins life as a typical multiple branched bush but takes on a spherical form when blown by the wind, spreading thousands of seeds. The research aim was to bridge between the abstraction stage and transfer of knowledge, utilizing a two-step module that links the stages. By applying the module, the organisms and the design are summarized via checklist guide questions, resulting in a clear flowchart which constructs the brief concept. While empathic thinking has detected the wow effect in children's games, analogue thinking exposed the essence of the application of a ball. This combination of thinking methods contributes greatly to the ideation process. Although the WHAT was initially known as a ball attribute, the wide biological investigation via the module operation led to a creative mindset of the HOW: hence, the module principle can be used to formulate a bio-inspired designer brief.

Keywords: Biomimetic design education, formulating, scoping, ideation, brief

1 INTRODUCTION

Nature has always served as an inspiration for problem-solving approaches; its systems operate within restricted conditions, minimizing waste and irreversible damage to the ecosystem [1]. The biomimetic approach is part of nature's design strategy, emulating its solutions, processes, and strategy from a holistic, sustainable perspective [2]. Its aims are to abstract biological principles and apply them to design solutions as, philosophically, endless time-tested solutions can be found in nature [1]. Biomimetics acts mainly in the preliminary stage by expanding the range of possibilities through observing nature. Its application during the ideation stage leads to a search for similar sustainable patterns of biological systems [3], focused on using nature's benchmark to improve man's artificial creations [1]. The approach involves knowledge transfer from biological system to design solution. The first starting point is a bottom-up, solution-based direction, while the second is top-down and problem-based. To support designer access to nature's vast database, varied methods offer a systematic framework for finding relevant biological systems, abstracting their design solutions [4]. These methods differ in operation needs, investigation levels and emulation quality, however, during the transfer stage, most cannot address all design objectives [5,6]. Biomimetic search methods identify appropriate biological systems via biological databases, using keywords such as the AskNature search engine [2]. Abstraction methods focus on understanding biological principles to extract them by design principles such as form follows function approach (FFF) [10] and structure-function patterns (SFP) based on the core components of a functional system [7]. Transfer methods focus on supportive guidelines during transfer development, by comparing biological and functional models, for example [8]. Life principles are nature's survival strategies by adjusting structure to function, functioning in symbiosis with the environment as a sustainable benchmark [1]. Tumbleweed, with its unique structure and function, is a distribution vehicle for plant seeds. NASA redeveloped this structural concept, using spherical rolling objects based on tumbleweed type strategy. Besides innovation, the core of design is establishing rational connections between discourse types emerging throughout the development process, resulting in new insights. Designers often use analogies when examining function or behaviour. Analogies also link fundamental structures with design challenges, serving as a domain for possible solutions. Thus, design thinking aims to control and ensure accuracy by using a checklist which sharpens the objectives, segments the problem into sub-problems, and clarifies goals hierarchically. The gap between the problem space and the solution space is the ideation stage, which emerges from the WHAT and HOW stages, acting as a creative bridge to form new ideas [09], prior to their selection and evaluation. The ideation role assembles knowledge, continuously reiterated by examination, synthesis, and experiment processes, to develop innovative solutions [10]. During the product design (PD) process, creative solutions are formed to meet user requirements. Design solution is based on the designer's individual brief, aiming to address expectations, utilize attributes from the WHAT stage, and implement methods in the HOW stage. Using multidisciplinary means, tumbleweed's natural mechanism was explored through biological investigations. The research applied biomimetic steps to map gaps, focusing on PD briefs, and produced a solution to facilitate access to biomimetic design education (BDE) through hands-on experience.

2 METHODOLOGY

Methodology derived from mixed biomimetic methods adapted to BDE, with a framework modified to suit that terminology (Table 1-3). The method comprised three stages: Search, Abstraction and Transfer. The stages were a series of research events, divided into steps (Table 1-3, step 1-6), then subdivided into goals, tasks, and research questions. These step divisions formed the research framework. A trial run employing a bottom-up approach was analysed through qualitative research. The research process was synectically-based to optimize collaborative brainstorming by specialists from biology, engineering, and PD, to innovate from direct and indirect analogies. The WHAT lies in the information mapping process and in the abstraction end stage, involved with attribute definition. The HOW is created in the formulating process in developing a bio-inspired design concept. During the design process a two-step module facilitated the research objective (Table 2).

2.1 Module functions and structure

The module enables definition and key data transfer from a biological source of inspiration to establish product brief using a design thinking approach. The module serves as a new filter, conducting information between abstraction and knowledge transfer stages during biomimetic process. The abstraction stage objective is to abstract, identify and consider the biological solution aspects to define the context via mechanism performance. The transfer stage provides guidelines for concept implementation, through multidisciplinary knowledge translation from biology to design. The module consists of two linear matrices of qualitative and quantitative data assessment with independent knowledge spaces. It engages mainly attributes and environment contexts required for success. The first step maps information, the second formulates concepts, while the design checklist organizes important information on task execution.

2.2 Formulating step structure

The first step is a mid-stage validation of the entire process, logically mapping search, and abstraction stages. This step is applied after the abstraction stage and aims to summarize the knowledge concisely. The structures derived from the FFF are extended to the attribute: form follows function approach (AFFF), referring to the linear, logical correlation between form and function. The structure consists of five nature checklist principles. Its linear hierarchy clarifies biological system uniqueness. Aims are to apply strategy, define context, explore functionalist attributes and environment. The checklist steps are attribute (strength or weakness, dependency on functionality, process, and strategy); form (structure with external appearance of function); function (reasons why procedure or action occur naturally); environment (factors affecting organism survival) and similarity (identify similarly functioning systems in different contexts). The main step-guiding question is: What are nature design principles' guidelines? A flowchart summarizes the step based on SFP [7].

2.3 Scoping step structure

The second step concerns implementing solutions. It examines biological system data with a particular objective for idea creation and emphasizes how nature design principles influence solutions through analogue thinking. This ideation process, applied at the start of the translating and implementing stage, enhances solutions through empathic thinking. Aims are to define context and explore required attributes through user needs. The checklist includes keyword function (defining the action), context descriptors (affinity that gives significance), clarifying process and physical attributes (contextual), constraints (limitations affecting concept implementation) and performance (describing the desired operation qualitatively and quantitively). The main question is: Where can the guiding idea be applied as a successful, sustainable conceptual solution? A summary was performed through a flowchart based on the WHAT brief checklist [11].

3 CASE STUDY AND RESULTS

Table 1. Pre-design mapping process (search and abstract stages)

Process		Guiding Questions
Step 1	**Discovering**	1.Which natural models to select in databases and habitats? 2.Which strategies support survival?
1.Objectives	Discover	
Tasks	Find and research an organism	
2.Objectives	Abstract	1.Which essential attribute mechanisms promote successful strategies? 2.Which actions and principles enable system operation?
Tasks	Summaries: biological strategies mechanisms and process	
Step 2	**Biologize**	1.What is the biological function definition? 2.What are the keyword definitions (search method)?
1.Objectives	Identify	
Tasks	Identify biological function and match structure to function	
2.Objectives	Define	1.How does the solution work? 2.What are the mechanism parts? 3.Define functional morphology and anatomy.
Tasks	Define biological solution	

First, multidisciplinary professionals planned the work process, examining and modifying natural structures. After several flora and fauna were explored, biomimetics directed them to the Salsola tragus species of tumbleweed. Tumbleweeds are dried-out parts of various plants which detach from their root systems and roll with the wind. The plant has the evolutionary advantage of dispersing seeds over dry open terrain. The carefully orchestrated formation and synchronization of programmed cell death after

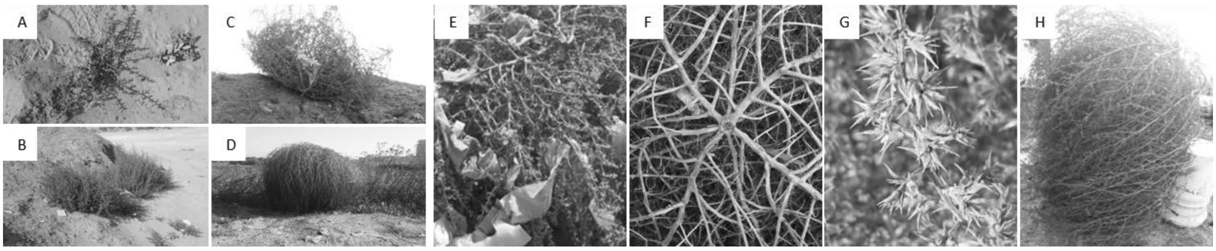

Figure 1. Tumbleweed plant's growing stages (A-D) and findings (E-H)

the seed development is complete, and adequate drying of the plant body allows ideal movement using wind power and effective seed distribution [12]. After locating a biological system, the team performed the abstraction, including system analysis, and defined biological process mechanisms. Comparative investigation diagnosed plant strategies. The biologist and designer reached the step-wise process enabling emulation. Information formation included flow sketches of plant performance, describing the relationship between forces and functions creating the phenomenon. Abstraction involves physical and conceptual disassembly, to reveal structural complexity. Figure 1A-D shows plant growth stages, from seedling to ball structure, prior to their tumbling journey. Early-stage research shows the plant alive and green, with, upright stems a strong footprint, and steady roots. The plant structure with erect stems usually bends inwards when dry, transforming it into a ball form. Removing its lowermost part reveals spiral stem development with fractal dimension. Patterns can be identical or repetitive and detailed.
(Figure 1F). With imagination, one notices a chaotic thorny entanglement with individual order in its lower section, evident in its structure, dimensional placement, and range. The circular, repetitive element in the stem's fleshy root and seed-laden thorns is significant, considering unusual mathematical qualities when calculating fractal structure equations, and translating structure principles into geometrical shapes.

Table 2. Pre-design and design process (module location)

BIO-INSPIRED PRODUCT DESIGN BRIEF MODULE			
Abstract stage		**Transfer stage**	
		Step 3	**Creating**
Objectives	Formulate	Objectives	Scope

Tasks	Summarize	Tasks	Create bio-inspired ideas and find relationships between strategies
Organism checklist guiding questions		Design checklist guiding questions	
What are nature design principles' guidelines?		Where to apply guiding idea as conceptual solution?	
Attribute	Which are the attributes? Keyword search?	Keyword Function	What principle and function would I like to emulate?
Form	What are the structure and system sub-components?	Context Descriptors	Who needs the attribute?
Function	What does the mechanism do?	Process attributes	Where is the attribute needed?
Environment	How does the mechanism work?	Physical attributes	Why and when is it required?
Similarity	Where in nature are similar mechanisms?	Constraints	How can the attribute be transmitted?
		Performance	Which parameters will be valued?
System flowchart - Organism context		System flowchart - Concept context	

3.1 Discovery of form and function

Salsola tragus, with its winged distribution units has an airy appearance and ball-like volume, with segments repeated in intricate crisscrossing layers (Figure 1D). Its minuscule sails act as a resisting force to the wind that enables their movement. These flexible elastic segments disperse seeds gradually over distances. The observed structure repositions the ball as it moves in space (Figure 1G). Identification of the density, size, and diameter of branches, hollow or not, can guide gravity centre placement. Its thorns too have varying parameters of size, flexibility, adherence, and function – recurring protrusions benefitting movement mechanism, encouraging ground grip while rolling (Figure 1E). Although the research process halted due to funding and time issues, data sufficed for new revelations. Other Salsola tragus structures such as cylinders, streamlined and twisted structures went unexplored. After initial abstraction, a biological investigation summary and related information were mapped in a flowchart based on checklist questions (Figure 2A). The transfer stage led to solution-focused ideation on relationship between strategy, form, and structure, using mechanical definitions of spheres in Salsola tragus to analyse the game concept systematically. Through checklist where and how questions the guiding idea can be implemented as a conceptual solution; the thought process focused on the game

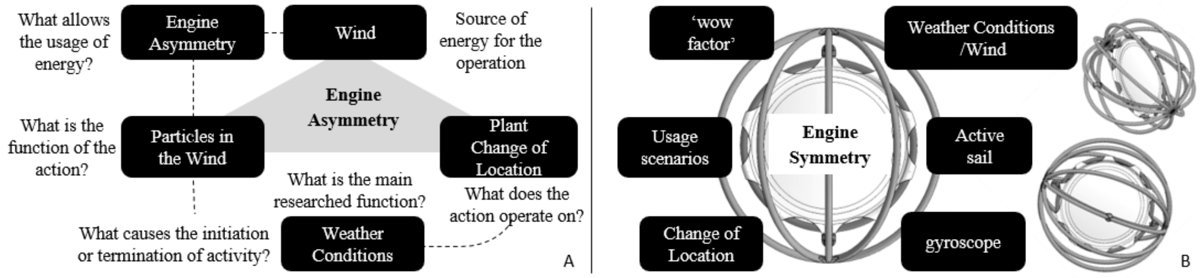

Figure 2. Organism and concept system flowchart

experience, influencing formulation and scoping factors. Defining and transferring attributes from biology to design space led the creation process. During transfer stage, biological investigation integrated nature design principles into the solution approach and analysed them through sustainable benchmarks from the life principles tool. After module step implementation, a flowchart-based design checklist organized implementation principles. Additionally, fast sketches aided alternative design concepts. At advanced information-transfer stages, research findings were integrated into the process. An asymmetrical sphere-shaped structure was chosen, incorporating endless mobility (Figure 2B).

3.2 Implementation: derived from design concept

The research outcome was a dynamic ball game inspired by the tumbleweed and its spatial movements. The ball concept has an independent active sail as inner structure, which enables maximum resistance, utilizing wind energy and gyroscopically-based inertia principles. Additionally, the ball structure acts as an airy shield and outer support for the inner sail. This ball concept is designed for outdoors, with natural wind flow, whose intensity and direction are significant, as in kite flying. The flexible sail propels ball forward by trapping circulating air, which creates natural motion.

Table 3. Design formulating process (transfer stage)

<table>
<tr><td>Step 4</td><td>Biologize</td><td rowspan="3">1.How to improve nature design principle and implement mechanism?
2.How to improve concept via sustainable benchmarks (life's principles)?</td></tr>
<tr><td>Objectives</td><td>Integrate</td></tr>
<tr><td>Tasks</td><td>Principles' integration</td></tr>
<tr><td>Step 5</td><td>Creating</td><td rowspan="3">1.How to optimize application by system strategies?
2.How to measure designs via sustainable benchmarks (life's principles)?</td></tr>
<tr><td>Objectives</td><td>Emulate</td></tr>
<tr><td>Tasks</td><td>Copy and apply principle in a conceptual mechanical application</td></tr>
<tr><td>Step 6</td><td>Measure</td><td rowspan="3">1.Did solution meet goal? (life's principles, quality assessment, criteria, and testing)</td></tr>
<tr><td>Objectives</td><td>Evaluate</td></tr>
<tr><td>Tasks</td><td>Verify</td></tr>
</table>

Wind currents, using lift and drag forces, move the sail forward spatially. Optimally, lift exceeds drag, establishing an ultimate driving force. The sails' structural design has a tremendous impact on their aerodynamic efficiency. Important sail functions are height-to-width ratio and concavity degree. Their design also utilizes wind airflow motion: when the ball structure follows the wind, its power pushes them forward; but when the structure faces the wind, air flows from its sides and redirects it, causing acceleration. Sail propulsion is achieved by wind force and kinetic energy. When air flows by the sail's curved object, it is faced with an 'angle of attack': wind moving along its upper and lower parts takes the longer path, causing acceleration. Sails accurately situated to the wind produce pressure and forward motion. The ball is inspired by a gyroscopic wheel-type device, with disc and rings that rapidly turn inside a structure, enabling it to form various angles, or rotate freely while preserving its position. The flat disc is situated on a centred, fixed, vertical pole, while the other axes rotate freely. When the wheel is spun, rotating axes retain their original direction, despite disc direction. Their movement coordinates with the wheel and fixed pole, resisting changes in spin angle. The structure allows the device to balance and is responsible for gyroscope inertia attempts to forcefully change rotation angle cause resistance.

4 DISCUSSION

The validation was directed towards the design objective; quality information was mapped based on overall plant structure, spatial behaviour, and presumed functionality. The information provided the foundation for developing a creative designer brief resulting in a primary concept for a solution proposal. However, a full design process is required for a working prototype that analyses performance using play ball criteria. Topic and sub-topic division provided analysis that led to clues from subsequent steps. Updated checklist questions were useful. By insights of sub-events, flowcharts and module information, knowledge was transferred between biology and design domains, with mapping collaboration at the abstraction stage. The transfer stage used creative brainstorming. Designers focused on benefits derived from the analogous system, with problem-solving followed by engineering integration. Failures between stages were mainly due to objective and terminological gaps. Nevertheless, expert involvement reduced these: biologists clarified bio-mechanisms, while designers bridged biological and engineering spaces. The main gap lay between abstraction and information-transfer stages. The module assisted the design domain to formulate an accessible scope by locating operational attributes. Analogical thinking concentrated on plant phenomena, and empathic thinking on imparting the wow factor to a child's toy. When the module was applied to both formulation and scoping steps, a creative mindset enhanced communication; design synthesis and conceptual maps were expressed by flowcharts and quick sketches. The steps' design outcome linked stages, enabling linear user focus on the WHAT, and afterwards on the HOW. Diverse quantitative data from the abstract stage were not examined. While data analysis could explain tumbleweed seed dispersal dynamics, resources were insufficient. Bottom-up biomimetics examined how nature's mechanisms successfully utilize design elements. A careful morphological study from biological and engineering viewpoints could explain which components most contribute to tumbleweed dispersal and examine their functional properties. Inspiration derived from observed phenomena and designs, including asymmetrical spherical structures, are biomimetically significant. Moreover, expert multidisciplinary knowledge is critical for BDE. Knowledge accumulated during the abstraction stage was extracted from online databases after nature observation. Biologizing led to analogous thinking that affected design synthesis and concept. The concept mimics the movement of a kite in flight: unexpected motion and dynamics provide a surprise element that maintains the wow factor. The concept requires navigation, intuition, and coordination – enabling physical and cognitive development. The predictable behaviour of a traditional ball due to perfect symmetry is a component eliminated from the design. This altered form offers an unexpected new function. Though potential for natural solutions is limitless, it is currently restricted by lack of pre-knowledge resources and ability to identify, abstract and utilize nature's progress within a defined period.

5 CONCLUSIONS

Biomimetic abstraction is a complex expensive process. The module is bio-inspired, serves as the starting point for defining a designer brief, and leads to a creative mindset that resolves design challenges. During module operation, the main obstacles in mapping information from Salsola tragus enabled the formation of a reliable understanding assimilated in the ball brief. Using the flowchart methods chronologically (first based on SFP, and second on the WHAT brief checklist) distilled information into knowledge through productive design synthesis. The principles outlined in the flowcharts clarify plant insights, focusing on a dynamic sail whose function may offer surprise movements. These parameters made it possible to formulate the idea based on ball brief and validate the module functionality. The module reduced the gaps between the abstraction and the knowledge formation stage, guided by an analogue and empathic design thinking approach. The module improves information accessibility between pre-design mapping and transfer design process via AFFF. Multidisciplinary integration is essential for workflow and high-quality design outputs. Module integration in the main biomimetic method can be applied in BDE without physical contact with inspiration sources. However, such prolonged contact plus module application aid design concept development. Additional structures and functionalities in tumbleweed require analysis. A multidisciplinary approach and connecting function and structure will enable more creative solutions. PD students and professionals may benefit from this module.

6 SUGGESTIONS FOR CONTINUED RESEARCH

Further exploration of the module is needed to address design objectives. This research should also evaluate and expand the module taking inspiration from fauna and flora in online sessions.

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