Iterative design of a novel bionic CD storage shelf demonstrating an approach to validation of bionic industrial design engineering concepts

CARLOS A. M. VERSOS, DENIS A. COELHO
Technological Industrial Design Program, Department of Electromechanical Engineering
University of Beira Interior
Calçada da Fonte do Lameiro, 6201-001 Covilhã
PORTUGAL
carlos.versos@gmail.com denis@ubi.pt http://webx.ubi.pt/~denis/MDIT/index.htm

Abstract: - This paper demonstrates a validation process with tangled steps, encompassing verification actions of the achievement of five goals for design based on analogies with biological solutions. The approach was developed after scrutinizing a set of methods to support bionic design, which resulted in the finding that these do not prescribe any formal verification procedures regarding the level of attainment of the goals sought. Hence, in order to more fully support the use of bionic methodologies in design, within systematic approaches to design, a validation itinerary is proposed, encompassing five goals identified for bionic design endeavours. The paper demonstrates the deployment of the validation process proposed within an iterative design case, consisting of a novel CD shelf, which draws inspiration form nature, as its main solution principle is inspired on the spider-web. The process of validation reported in the paper makes use of surveys, conceptual-analytical arguments and standard engineering design procedures.

Key-Words: - design goals, design methodology, bionic design, systematic approach to design

1 Introduction

In order to be useful and of practical value to the generation of industrial design engineering concepts, bionic design methods should be able to fit into design endeavours that follow a systematic approach to design. Industrial design engineering endeavours may be enhanced by inherently structuring and supporting bionic design endeavours with methods set forth in the systematic design literature (e.g. [1], [2], [3], [4], [5]). The authors [6] presented an evaluation of three bionic design methods [7], [8], [9] which led to the consideration of the need to integrate validation procedures in industrial design engineering endeavours with a bionic character, outlined in Table 1. This set of validation procedures was developed in order to verify the achievement of five design goals considered to be encompassing and representative of the objectives set in bionic design projects. There use is demonstrated in the remaining sections of this paper in the iterative design case of a novel CD shelf drawing inspiration from nature, as its main solution principle is based on the development of an analogy with the spider-web .

Table 1. Specific procedures suggested for validation of goals sought by bionic design [6].

Goal	Validation procedures to evaluate goal accomplishment
Communication effectiveness	Validation is made according to the level of communication involved. • Passive communication (triggered by observation) - the effectiveness may be evaluated by assessing the degree of the overlap between the meaning intended to be incorporated into the product or system by the designer and the readings of signification made by users or observers (empirical verification). • Active communication (synchronous process between a sender and a receiver) - effectiveness evaluated from the assessment of the overlap between the messages from the sender and what is perceived by the receiver, which should conform to what is desired by the sender (empirical verification).
Form optimization	Validation based on a comparative approach with regard to a conventional product with functionality that is similar to the one intended for the bionic concept. Examples: • Reducing material and weight - analysis from solid modelling.

	• Stability - static analysis of mass centre (force vector modelling). • Resistance for maximum capacity - finite element method and prototype testing. • Object storage - capacity, maximum capacity; quantification.
Multiple requirements satisfaction	Validation based on objectively verifying, as much as possible, the level that has been reached for each property implicit in every requirement. This is followed by checking if the resolution of conflicts between non-compatible properties was made with compromises established on every side of the requirements concerned.
Organization effectiveness	Validation based on the comparison between two or more systems performing the same function (including the proposed system), but with different methods of organization. Collect measures of the levels of operation effectiveness from the (real or simulated) systems (including the proposed system), such as execution time, energy expended, material resources expended, or resources generated.
Paradigm innovation for improved functional performance	The evidence of paradigm change depends on the type of paradigm involved. Consider these examples of two kinds of paradigm change: • Paradigm change at the organizational level - could involve changing from a centralized model of decision making to a process of cooperative decision making distributed and performed by multiple system elements. • Paradigm change at the technical level – could involve fundamental changes in working principle, shape archetype, drive technology or kind of energy supplied. The verification of the attainment of this goal may centre on a conceptual-analytical argument distinguishing between the existing and the new paradigm, possibly illustrated by descriptive imagery and, or, technical schemes.

2 Validation procedures applied to a novel bionic design case

Three existing methods to support the generation of bionic design concepts for the solution of a given problem, retrieved from literature, were analysed by the authors [6]. These shared a common direction of analysis, which departs from a given problem and seeks the proposal of solutions by gathering insight and inspiration form natural systems. This approach begins with the identification of a problem or the needs of a project, which is followed by looking for inspiration from nature or seeking an analogy with a natural solution to foster the emergence of a solution to the problem (a bionic solution proposal).

A bionic design project was carried out, following an approach combining the methods reviewed ([7], [8], [9]). The problem considered was the storage and the physical display to enable browsing of personal music collections, focusing on CDs and DVDs. The conduction of the design process led to seek inspiration form nature, having selected the spider web as a natural example that was the basis for the analogy of working principle established. The requirements established for the project and their corresponding goals are listed in Table 2. Moreover, environmental concerns were expressed in terms of reduced environmental impact of materials, ease of maintenance and repair, as well as low weight of the product (and its package) for transportation. These requirements were dealt with in the design project, impinging on the selection of materials (selection of a bio-polymer and an organic elastomer) and on the design of the project (impinging on the goal of paradigm innovation for improved functional performance).

The validation processes carried out within the exemplified design case used are summarily described, and an overview of the evidence used and the results obtained is provided in the following sub-sections, considering the goals depicted in Table 6. In what concerns the goal of satisfaction of multiple requirements, a conflict was detected between the requirement of enhanced stability and lightness. This conflict was solved by means of an approach akin to TRIZ [10], with the contradiction solved by change of state, in the second iteration of the design. Bionic tower 2 hence encompasses a reservoir in the basis which may be filled with water or sand for added stability, while lightness is still guaranteed, for the sake of environmental concerns, especially focusing on the production and distribution phases of the product's life-cycle.

Table 2. Listing of requirements set for the bionic design case and their corresponding goals that were sought.

Requirements	Goals sought*
1. Nice and appealing shape, enabling the user to develop an aesthetic interest in product	Communication effectiveness

2. Sending a message of an avant-garde character, creative and youthful	
3. Enhanced stability against a dynamic disturbance compared with a conventional solution[†]	Form optimization
4. Increased lightness compared to conventional solution[†]	
5. Proper positioning of the title of the CDs, DVDs and books for enhanced readability	
6. Storage with versatility of CDs, DVDs or books	Organization effectiveness
7. Enhanced gripping of objects compared with a conventional solution	Paradigm innovation for improved functional performance

*- Satisfaction of multiple requirements is implicit in the consideration of the several requirements; [†] - Conflicting requirements, requiring a trade-off.

2.1 Design case validation of requirements contributing to the goal of communication effectiveness

The perception by the user of pleasantness and appeal, enabling the development of an aesthetic interest in the product (first requirement in Table 2) was validated through a questionnaire where, among other things, each of the two bionic CD towers was visually compared, with a conventional tower (Figure 1). The validation of this requirement is necessarily subjective, because the key issue that arises relates to the taste and sensitivity of each individual questioned. Respondents, answering by email, accounted to 85, aged between 18 and 60, both male and female, and with diverse professional and knowledge specialities.

Figure 1. Depiction of a conventional CD tower, and the two bionic CD towers developed: conventional tower(A), bionic tower 1 (B) and bionic tower 2 (C).

Each respondent indicated which of the towers was personally more aesthetically pleasing and appealing, from 3 paired comparisons presented. The paired comparisons approach applied to this case of three objects enables 8 possibilities of response, two of which are incongruent, since no ranking of preference can be established out of them. Three out of the 85 respondents reported incongruent paired comparisons. Thus, the analysis of results was carried out for 82 responses. The results were analysed on the basis of the procedure for calculating the Kendall coefficient of concordance [11]. The average ranking obtained was bionic tower 1 (first place), bionic tower 2 (second place) and conventional tower (third place). This result is considered significant to represent the overall opinion of respondents to a confidence level of 99%. These results support the validation of the first requirement depicted in Table 2. Both the first and second bionic towers received the preference of respondents over the conventional tower, which proves the validation of the gains in terms of pleasantness and aesthetic appeal, for both versions of the project.

In what concerns the second requirement that contributes to the goal of effective communication, validation was sought by means of a technique of anthropomorphizing products through the attribution of personality dimensions. In a first phase, a translation of the requirement into a product personality profile [12] was

ISBN: 978-960-474-265-3

proposed. In the second phase of the process, a sample of specialized public (eight undergraduate Industrial Design students) assessed the personality profile of the three objects shown in Figure 1. In such, whether or not the message intended by the designer was transmitted to the public could be verified.

The second requirement set in Table 2, was decomposed in a number of concepts to promote the matching process envisaged. This led to considering the attributes of modern, elegant, youthful, joyful, flexible and dynamic. Moreover the attributes consisting of lightweight and stable were also considered from the third and fourth requirements. The correspondence between product attributes intended by the designer to be perceived by the public and product personality dimensions [12] are shown in Table 3. The outcome of analysis on the respondents assessment of the personality profiles is also shown, based on evaluation of Kendall's coefficient of concordance [11].

For every personality pair, analysis was performed as exemplified for the pair energetic – non energetic energy, the average ranking of the panel of respondents (with a significance of 99%, given by the assessment of Kendall 's coefficient) resulted in the following rank order: 1st C, 2nd B, 3rd A. As a conclusion to this result, it is understandable that tower C (bionic tower 2) is considered more energetic than the tower B (bionic tower 1), and that tower C (conventional tower) is considered less energetic than tower B. This means that tower C is deemed the least energetic of the three towers and that C is the tower that emerges as the most dynamic and the less dynamic, thus validating this communication requirement.

Table 3: Analysis of the results of the survey on the personality profile of the towers for CDs and DVDs storage and verification of messages perceived from observation of the objects.

Designer's message	**Personality profile**	**Average ranking 1st- 2nd – 3rd**	**Significance level of Kendall's coefficient of concordance**	**Conclusion**
Modern	Bright – Dim	B – A – C	Not significant	Sample did not reveal agreement
Lightweight	Simple – Complex	A – B – C	99%	Tower A is considered most simple (lightweight)
Elegant	Gentle – Violent	B and C – A	Not significant	Sample did not reveal agreement
	Moderate - Excessive	A – B – C	Not significant	Sample did not reveal agreement
Youthful spirit	Liberal – Authoritarian	B and C - A	99%	Towers B and C are the most liberal (youthful)
	Rebel – Conformist	C – B – A	99%	Tower C is the most rebellious (youthful)
	Optimistic – Pessimistic	B – C – A	Not significant	Sample did not reveal agreement
Joyful	Light-hearted – Serious-minded	C – B – A	99%	Tower C is the most light-hearted (joyful)
	Kind – Unkind	B and C - A	95%	Towers B and C are the most kind (joyful)
Flexible	Flexible – Inflexible	C – B – A	Not significant	Sample did not reveal agreement
Dynamic	Energetic – Unenergetic	C – B – A	99%	Tower C is the most energetic (dynamic)
Stable	Stable - Unstable	B – A – C	Not significant	Sample did not reveal agreement

According to the findings obtained, the communication of a message of young spirit, dynamism and joyfulness were validated. Tower C (bionic tower 2) is the one which, according to the survey, more effectively conveys the desired messages, is considered the most dynamic, the most rebellious, most joyful and, together with tower B (bionic tower 1), most kind and most liberal. Regarding the transmission of the message of lightness, the personality profile related (simple - complex) did not translate so well the associated requirement. This might have led respondents to identify tower A (conventional) as the simplest, and therefore, according to the tenuous association, the lightest of the three. Interpretative meanings vary from person to person. The absence of actual trial of the towers on the part of respondents, who just exercised visual perception, may have also influenced and contributed to vagueness and lack of agreement among some of the responses.

2.2 Design case validation of requirements contributing to the goal of form optimization

The results concerning requirements contributing to the attainment of the goal of form optimization are shown in Table 4 (enhanced stability – according to force vector analysis), Table 5 (increased lightness – solid modelling analysis) and Figure 2 (enhanced readability of CD titles – graphical depiction). For the first of the three requirements concerned by this goal, bionic tower 2 ranks in first place, while for the second requirement, bionic tower 1 is clearly the lightest, while for the last of the three requirements both bionic towers achieve a tie ahead of the conventional tower. The results support validation of the achievement of the goal sought of form optimization, albeit both bionic towers are deemed equivalent in this respect.

Table 4: Comparison of results for the maximum lateral disturbance tolerated without loss of stability in the three concepts.

Maximum lateral disturbance to maintain stability	Conventional tower	Bionic tower 1	Bionic tower 2
At maximum capacity	49,96 N	49,59 N	74 N
At medium capacity	35,11 N	29,57 N	56,34 N

Table 5: Comparison of mass data among the three objects.

Total mass	Conventional tower	Bionic tower 1	Bionic tower 2
Transport mode	11,049 Kg	4,763 Kg	8,087 Kg
Use mode	11,049 Kg	4,763 Kg	17,087 Kg

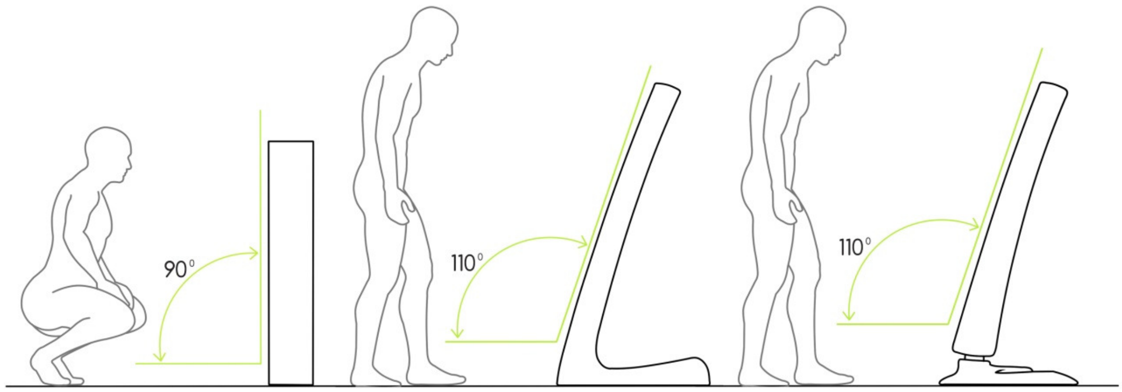

Figure 2: Graphical depiction of readability of content titles for the three objects (from left to right: conventional tower, bionic tower 1 and bionic tower 2).

2.3 Design case validation of requirements contributing to the goal of organization effectiveness

To validate the goal of organization effectiveness, the proof of achievement of the requirement of storage with versatility of CDs, DVDs or books was sought by means of a graphical depiction (Figure 3) which is deemed self-explanatory with regards to this requirement's attainment.

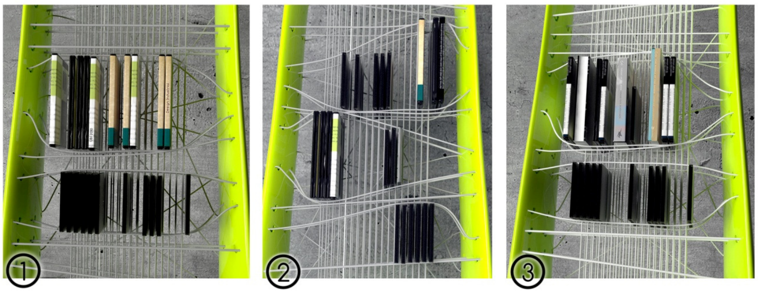

Figure 3: Depiction of three possibilities of dynamic storage of objects in the bionic towers.

2.4 Design case validation of requirements contributing to the goal of paradigm innovation for improved functional performance

To validate the achievement of the goal of paradigm innovation for improved functional performance, verification of the attainment of the requirement of enhanced gripping of objects in the bionic towers was sought. Calculations were established and performed analytically, resulting in an estimation of approximately 0,5 N of vertical compression force per CD. Finite element modelling was also pursued resulting in successful validation of the design for full capacity.

3 Conclusion

The approaches to validation proposed combine engineering approaches with social science approaches to validation, in accordance with the nature of each of the goal that is focused. Two variations of a novel bionic design for CD and DVD storage were analysed in terms of satisfaction of requirements and validation of attainment of goals sought in the project, in comparison to a conventional solution for the same problem. This design case hence demonstrated the deployment of the validation process proposed in this paper. This validation process may necessitate further refinement and improvement, which might be attained through its use in an expanded array of bionic design cases.

References:

1. Hales, C., 1991. Analysis of the Engineering Design Process in an Industrial Context, Eastleigh, UK: Gants Hill Publications.
2. Hubka, V., Eder, W.E., 1992. Enfürung in die Konstruktionswissenschaft – Übersicht, Modell, Anleitungen. Berlin: Springer Verlag.
3. Roozenburg, N.F.M., Eekels, J., 1995. Product Design: Fundamentals and Methods, Chichester: John Wiley & Sons.
4. Pahl, G., Beitz, W. 1996. Engineering Design – A systematic Approach, 2nd edition, London: Springer.
5. Ulrich, K.T., Eppinger, S.T., 2004. Product Design and Development, international edition, McGraw-Hill.
6. Coelho, D.A., Versos, C.A.M., 2010. An approach to validation of technological industrial design concepts with a bionic character. Proceedings of International Conference on Design and Product Development (ICDPD'10), Vouliagmeni, Athens, Greece, December 29-31, 2010.
7. Junior, W., Guanabara, A., Silva, E., Platcheck, E., 2002. Proposta de uma Metodologia para o Desenvolvimento de Produtos Baseados no Estudo da Biónica [in Portuguese – Proposal for a Product Development Methodology Based on the Study of Bionics], Brasília: P&D - Pesquisa e Design.
8. Biomimicry Institute, 2007. Biomimicry – a tool for innovation, URL: http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html (accessed June 20th, 2010).
9. Helms, M., Vattam, S.S., Goel, A., 2009. Biologically inspired design: process and products, Design Studies, Vol. 30, No. -, pp. 606-622.
10. Altshuller, H. , 1994. The Art of Inventing (and Suddenly the Inventor Appeared), Translated by Lev Shulyak, Worcester, MA: Technical Innovation Center.
11. Siegel, S., Castellan, N. J., 1988. Nonparametric Statistics for the Behavioural Sciences, New York: McGraw-Hill.
12. Jordan, P. W., 2002. The Personalities of Products. In William S. Green and Patrick W. Jordan (Editors) Pleasure with Products: Beyond Usability, London: Taylor & Francis, pp. 19-48.

ISBN: 978-960-474-265-3