# APPLICATION SEARCH IN SOLUTION-DRIVEN BIOLOGICALLY INSPIRED DESIGN

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## ABSTRACT

In solution-driven BID (sol-BID) a challenge is to identify suited applications that will benefit from the solutions principles found in nature. A well-known example of sol-BID is the self-cleaning lotus plant, that has inspired lotus paint and other coating methods. However, sol-BID is often performed by biologists with insight into the biological strategy and organism and typically only little knowledge of technical applications and design methodology. Searching for applications is therefore a challenge to many. Sol-BID has many things in common with technical application search where new applications are sought for a specific production technology or another competence characterizing a company. Experiences from technical application search could therefore form a valuable input for how to perform sol-BID. The paper presents two case studies of application search and proposes a procedure to be used in solution driven BID.

**Keywords**: Biologically inspired design, Bio-inspired design / biomimetics, Creativity, Conceptual design

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# 1 INTRODUCTION

Biologically inspired design (BID) can basically be approached in two ways: problem-driven BID and solution-driven BID (Helms, Vattam and Goel, 2009; Lenau, Metze and Hesselberg, 2018). In solution-driven BID (sol-BID) a challenge is to identify suited applications that will benefit from the solutions principles found in nature. Helms *et al*. refer to the application search as the problem search (Helms, Vattam and Goel, 2009). Well-known examples of sol-BID are the cocklebur that inspired Velcro and the self-cleaning lotus plant, that inspired lotus paint and other coating methods. However, sol-BID is often performed by biologists with insight into the biological strategy and organism and typically only little knowledge of technical applications and design methodology. Searching for applications is therefore a challenge to many. Sol-BID has many things in common with technical application search where new applications are sought for a specific production technology or another competence characterizing a company. Experiences from technical application search could therefore form a valuable input for how to perform sol-BID.

Many companies are subcontractors specialising in a certain production technology such as reaction moulding in polyurethane (PUR) plastic. This type of company meets a challenge when they seek to expand their business into new areas. In contrast to companies that address end-users such as furniture or household appliances, subcontractors do not have a well-defined user group that can be explored in order to identify expansion potentials. They can off course improve their competence in the technology thus offering existing customers improved properties, but it is difficult to identify new markets. A limiting factor for such companies is that they are not trained in design thinking where they work with open problems and large solution spaces.

A possible design oriented approach to application search could be to identify the unique profiling properties of the technology and then search for end-user applications in order to identify candidates that will benefit from the technology. For the PUR-plastic example the profiling properties could be low tooling price enabling small scale production series and individualised products, large degree of freedom for free form geometry, light weight components with foamed core and insert moulding of metal, wood and textile items. For each of these profiling properties an open search for applications with this characteristic can be made. This can be done as brainstorming or as internet searches. This paper describes experiences from application search in two cases and proposes a procedure for how to apply it in sol-BID.

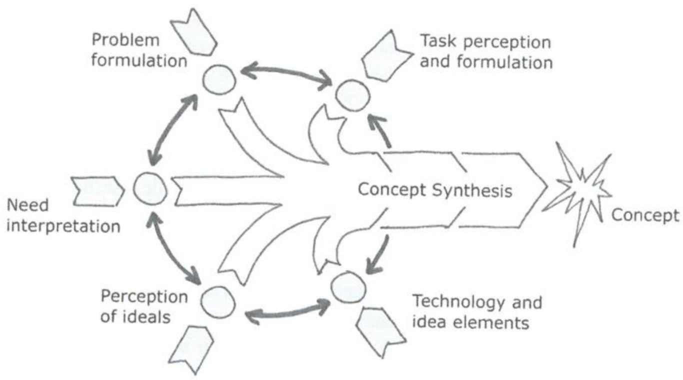


*Figure 1. Exploration model (Myrup Andreasen, Hansen and Cash, 2015)*

# 2 EXISTING APPROACHES TO APPLICATION SEARCH

Andreasen *et al* describe in their exploration model (Myrup Andreasen, Hansen and Cash, 2015) how the concept synthesis can be initiated through five feed chains: Need interpretation, perception of preferences, problem statement, task perception and technology & ideas (see figure 1). The first four feed chains all have in common that their starting point is a user need or application scenario. The fifth chain mentions technology as the starting point in combination with a need and gives the example of a certain motor gear system for focusing in surveillance cameras. The new technology made possible to completely redesign the camera series. The application search treated in this paper has similarities to this model but differ in not having an identified need but rather being open for many different possible needs.

Dorst & Cross describe how problem and solution spaces co-evolve, i.e. creativity do not only go from a specified problem to a solution but proposed solutions can affect and refine the problem definition (Dorst and Cross, 2001). The application search has similarities to the feedback from solutions to problem formulation in the co-evolvement model but misses the initial problem definition.

A technology-oriented model is the systematic theory of manufacturing described by Alting. This model describes how new technology can be developed by considering alternatives to the basic characteristics of a manufacturing process described in the morphological structure of material processes shown in figure 2: Material flow, Information flow and energy characteristics (Alting, 1978). The process morphology indicate how new manufacturing processes can be identified through the systematic variation of the characteristics without considering the need or requirements. The principles in the model are interesting for application search but the categories are specific to manufacturing processes and therefor not directly applicable to sol-BID.

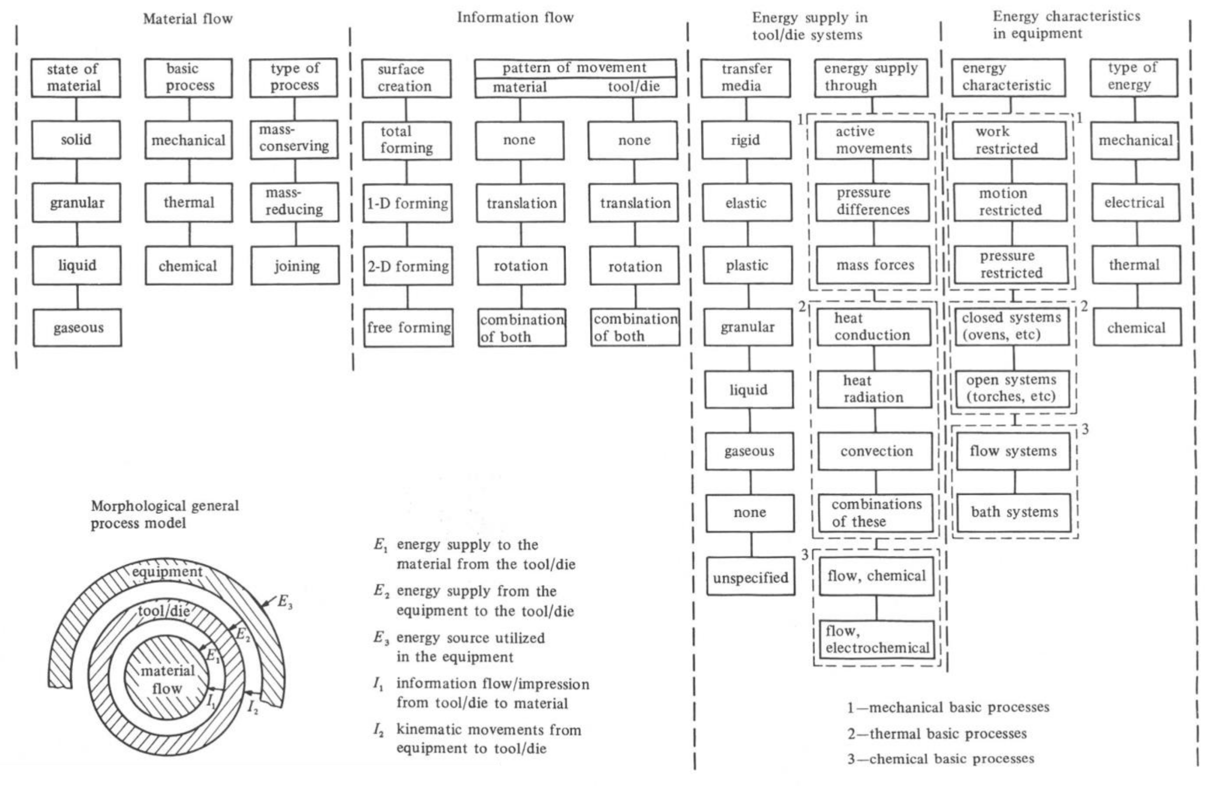


*Figure 2. The morphological structure of material processes (Alting, 1978)*

NASA Technology Transfer Program aims at finding applications for the many technologies invented and applied in the space programs. Apart from brochures and active participation in exhibition fairs they have an internet portal facilitating search for technologies (NASA, 2018). They provide help in finding relevant technologies to solve given problems but not in how to find applications of the technologies.

Subcontractors often attend industrial fair like the Hannover Messe when searching for new markets and applications that can benefit from their technology. The Hannover Messe also offer a search facility for finding relevant contacts and technologies (Deutsche Messe, 2018) but not how the subcontractors can identify new applications.

## 3 TWO CASES APPLYING APPLICATION SEARCH

In the following experiences from two cases of application search will be described. The first concern the pinart – a children toy that is transformed into the pin-type tool / flexform - a flexible manufacturing technology. The second relates to grow technology, where opportunities for using the shape producing mechanisms in plants for making artificial products are explored.

### 3.1 Pin-type tool

A pin-type tool is inspired by pinart, which is a children's toy where a large number of steel pins can move in the axial direction. By pressing an object into the tool the pins will form a pixelated image of the object (see figure 3). The idea was to make a flexible production tool such as a casting mould that could change shape between each casting. A number of pins would be individually adjusted, e.g. using small actuators) and an elastic membrane would be placed over the pins. Such a tool would enable casting of individual geometries without the need for a costly making of new tools.
At the beginning of the project the tool was no more than an idea. The application search was intended to be used for finding out if it was worthwhile pursuing further development and to identify promising applications. The works was done as part of two collaborating master projects and resulted in two very different applications: a casting tool for curved concrete façade elements and a tool for sequential marking of cast components (Pedersen, 2009; Vedel-Smith, 2009; Pedersen and Lenau, 2010; Vedel-Smith and Lenau, 2012).

*Figure 3. Pinart children toy*

The application search was done by specifying characteristics in the form of strengths and weaknesses for the technology as shown in table 1. The characteristics were found by the participating students by looking at the pinart toy while imaging it as a production tool. The characteristics were then used by the students to brainstorm on applications that shared the characteristics. For example, could the small tooling cost characteristic lead to 'individualised products' and further to 'personalised roller skate boots'.

*Table 1. Characteristics in the form of strengths and weaknesses for the pin type tool (Pedersen, 2009; Vedel-Smith, 2009)*

| **Strengths** | **Weaknesses** |
|---|---|
| Small cost difference between the making of flat, single curved and double curved parts. | More rough surfaces and less precision on tolerances. |
| Smaller tooling cost per part | Initial investment higher |
| Reduced storage cost for part moulds | Only one casting is possible at the same time |
| Can use input from a 3d-scan | Will be worn quicker |
| Shape can be changed and adjusted during the hardening/curing phase | |

A further refinement was to combine the technology characteristics with constraints. Such constrains could be the used material such as plastic, concrete, cast iron or chocolate. Other constraints could be the manufacturing process, e.g. casting or thermoforming, it could be the use context (what products do you have at home or different sports) or it could be a specific trade (what products does this type of shop sell). Another approach was to visit a place where many different items were on display, in this case the industrial design exhibition at the Danish Design Centre. At the exhibition items satisfying the initial characteristics could be identified (Pedersen, 2009; Vedel-Smith, 2009).

A third approach was search for key stakeholders for one of the already defined applications. For example, did the application ‘individually shaped sand casted gear houses’ lead to a dialogue with a foundry that came with the need for individually marked castings. The question is if the foundry would have identified the marking application if they had only been presented the initial pin-type tooling idea, or it was the more elaborate application where the pin-type tool was applied to gear housings that triggered the marking idea. We would argue that the more elaborate application forces the stakeholder to evaluate a very specific proposal which is easier than being creative and come up with ideas on how to apply the technology. In this case it worked.
The combination of identifying characteristics and constraints and involve stakeholders was used to make a search, which resulted in 136 possible applications. Applications covered very broadly from prosthetics, contact lenses, hearing aids, chocolate, cd-covers, jewellery, sailing boats propellers and concrete bridges. The list was prioritized by giving each application a score based on a number of criteria including economic potential. The top 5 candidates were rooted in either the architectural / construction area or the metal casting area. People involved within these 2 areas were therefore contacted and presented with the idea of using pin-type tool within their line of expertise. This stakeholder interaction confirmed one of the application areas, namely the fabrication of concrete façade elements. In another area (metal casting) the stakeholder dialogue moved the focus from individualised gear housings to a new not previously explored area namely the opportunity for making individual markings on castings thus enabling traceability in the production. The pin type tool could be made in a way so it could make individual markings in the sand mould in automatic sand casting machines meaning that the resulting castings would carry a unique identifier. The two applications were very different and addressed very different business areas and underline the importance of stakeholder involvement. The characteristics of the tool itself were also very different. The concrete pin-type tool would be fairly large and should be able to carry a heavy load from the concrete. The casting application on the other hand should be very small and be able to change shape quickly. The two tools are shown in figure 4.

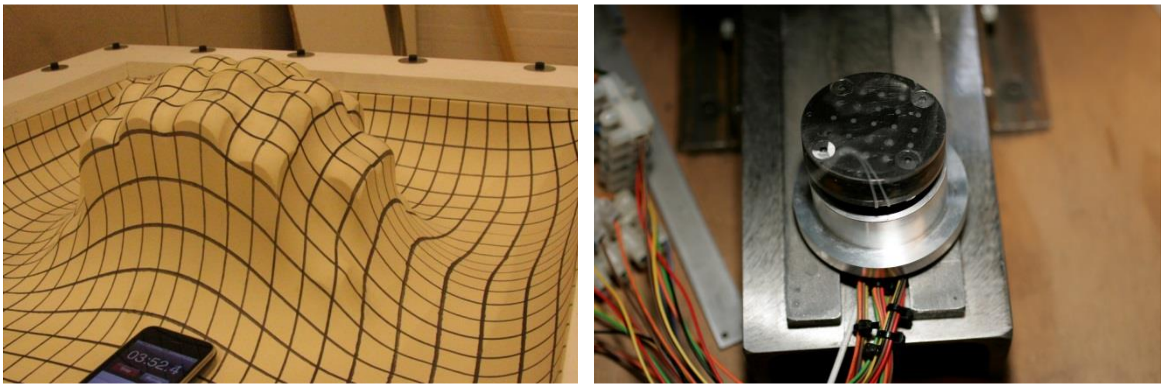

*Figure 4. Left: tool for façade element (Pedersen, 2009) and Right: individual marking of cast components (Vedel-Smith, 2009)*

### 3.2 Grow technology

The other case relate to growth technology. The basic idea is to utilize natures way of producing form, namely to grow into shape. The work was carried out by two students in collaboration in a bachelor project where the aim was to explore the opportunities in grow technology, propose suited applications and examine a selected application in more detail (Ørting and Thomsen, 2018). The assignment was broader in scope than the previous case on the pin-type tool since there was an extra degree of freedom where the specific type of grow technology was not yet selected. That selection was part of the assignment. The project therefore included two tasks: 1) map possible materials and types of grow technology and 2) propose suited applications. The project resulted in two booklets describing the outcome from the two tasks.
The procedure followed was as follows. For the first task specific organisms were listed from the categories plants, animals and other (which included fungus, bacteria and micro algae). For each of those relevant interesting growth principles were identified and described on inspirational cards using the same format (see figure 5) including known applications. 34 types of grow technology was identified.

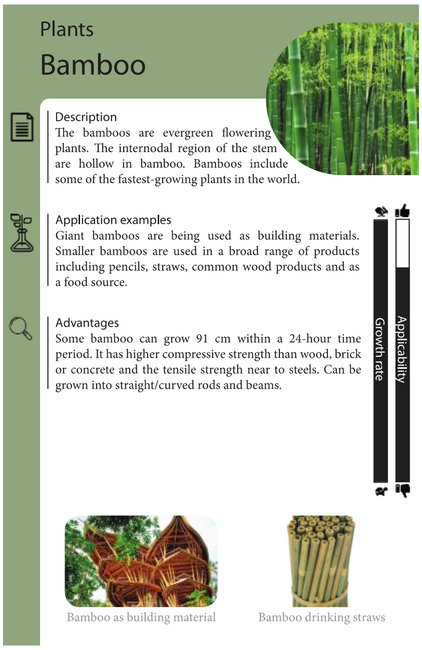


*Figure 5. Inspirational card describing a grow technology (bamboo) and its interesting properties (fast growth) (Ørting and Thomsen, 2018)*

*Table 2. Characteristics describing advantages for growth technology*

| **Characteristic** | **Explanation** |
|---|---|
| Renewable resource | Materials that grow are renewable as long as the basic ingredients are available in contrast to materials relying on fossil based fuels. |
| Biodegradable | Natural materials will often be biodegradable since microorganisms under the right environmental condition will brake down the material into basic substances that can be utilized elsewhere in nature. |
| Natural diversity | Not two natural organisms are identical and often are differences clearly visible in contrast to mass produced identical goods. |
| Sustainability branding | Using growth technology gives connotations to natures sustainable ecosystems. |
| CO2 absorption | Photosynthetic organisms consume CO2 |
| Minimal energy consumption | Nature uses a minimum of energy to produce form often at ambient temparatures. |
| Appearance | Objects in nature represent distinct and complex aesthetics often very different from man made objects. |
| Shape for strength | Many structures in nature exhibit high strength-stiffness to weight ratio. |

The second task was handled by defining 8 factors characterising possible advantages for growth technology. The 8 characteristics are described in table 2. The characteristics were used to carry out different types of brainstorm resulting 37 applications. For the more detailed exploration bamboo and furniture were chosen as grow technology and application. The following experiments examined opportunities for controlling the bamboo growth using physical barriers, directional light and gravity (orientation of the plant while growing).

The more open assignment where type of technology (within limits) and applications were sought simultaneously proved to be difficult and resulted in several time consuming iterations. Hindsight, it would probably have been more efficient to first identify the grow technologies and then for each selected grow technology perform the application search.

## 4 APPLICATION SEARCH IN SOLUTION-DRIVEN BID

Based on the learning from the two cases described in the previous sections the procedure described in table 3 for application search in solution-driven BID is proposed.

*Table 3. Procedure for searching for applications in sol-BID*

| **Activity** | **Comments** |
|---|---|
| 1. Define unique characteristics for the selected biological phenomena | Characteristics can be defined as desirable advantages and as unwanted consequences. |
| 2. Make a first open search for applications that will benefit from the found characteristics | Could be a brainstorm. |
| 3. Formulate constraints that will limit the width of the search but force a more deep exploration. | Constraints could be field of application (household, leisure, sports, hospital, professional tools,…), type of material, Daily activities (waking up, going to work, travelling,…) and others. |
| 4. Apply the constrains one by one together with the characteristics to make searches for applications | Could be made as a brainstorm |
| 5. For each found application the conceptual idea in applying the biological phenomena to the application should be described | Describe the conceptual ide as concrete as possible and include its intended behaviour in context. |
| 6. Confront selected stakeholders | Each of the constraints could be associated with certain groups of stakeholders, e.g. for sports it could be shops or producers within the area or it could be the athletes. Present the stakeholders with conceptual ideas instead of asking them about possible applications. |
| 7. Repeat 5. for new application identified in the discussion with stakeholders | |
| 8. The potential for each of the conceptual ideas can be evaluated based on a set of predefined criteria. | General evaluation criteria could include expected market volume and societal impact. |

### 4.1 The self-cleaning lotus plant

The use of the procedure can be illustrated with an example. One of the best known successful sol-BID cases it the one of the self-cleaning lotus plant *Nelumbo nucifera (figure 6)*. The Lotus plant grows in tropical areas and is famous for staying clean even when it growths in dirty environments. In some cultures it is considered a sacred plant for the same reason. The so-called lotus effect was described by the German biologists Neinhuis and Barthlott as how a combination of surface microstructures and epicuticular wax resulted in a surface being water-repellent and anti-adhesive to dust (Neinhuis and Barthlott, 1997). The observations led to the development of a range of products with lotus effect properties such as paints and surface coatings (Sto SEA Ptd Lte, 2014; Sto SEA Pte Ltd, 2018).

*Figure 6. The self cleaning effect seen on the leaf of a lotus plant Nelumbo nucifera (credit: Photo (c) 2007 Derek Ramsey (Ram-Man), Location credit: Chanticleer Garden. CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2241089)*

## 4.2 Application search applied on the self cleaning effect of the lotus plant

The following description of how the application search procedure could be used is an imaginary case made by the author in order to illustrate the application of the procedure. It does not reflect how the lotus-effect was actually developed or the viewpoints of the people involved in the discovery and development of the lotus-effect products. The following sections illustrate the type of considerations to be made during application search using the procedure described in table 3.

### *4.2.1 Define unique characteristics for the selected biological phenomena*

Desirable advantages of the lotus leaves are that they are water repellent and anti adhesive to dirt particles. When water is repelled it will easily transport the dust particles away. Unwanted consequences could be the matte velour-like surface appearance that would look very different to the glossy surfaces we normally associate with clean hygienic surfaces, e.g. tiles and sanitation ceramics. The microstructure and the wax crystals could also have refractive properties limiting transparency. An unwanted consequence could be that the self-cleaning effect does only work under running water, i.e. not in dry or just moist environments.

### *4.2.2 Make a first open search for applications that will benefit from the found characteristics*

One approach to search could be to identify areas where dirt on a surface represents a problem as listed in table 4.

*Table 4. Open search for places where dirt represent a problem*

| **Area** | **Example objects** |
|---|---|
| Clothes | Personal clothes, working clothes, baby clothes, shoes, glasses, jewellery. |
| Transport | Cars, busses, bicycles, airplanes, ships. |
| Houses | External walls, windowpanes, window frames, roofs, internal walls, doors, floors, bathrooms. |
| Food containers | Bottles for diary products, plates, cutlery. |
| Furniture | Tables, chairs, kitchen tables, kitchen zincs. |

### *4.2.3 Formulate constraints that will limit the width of the search but force a more deep exploration.*

Constrains could include the following: Frequency of cleaning (often, rarely), ease of cleaning (simple, complicated), type of liquid (water, milk, petrol, spirit), type of dirt (dry, sticky, powder), type of surface (smooth, rough) and degree of transparency (very clear, translucent).

### *4.2.4 Apply the constraints one by one together with the characteristics to make searches for applications.*

Combining the water repellent characteristic with the constraint ‘sticky dirt’ could for example add objects to the food container list like honey pots and ketchup bottles. If the water repellent characteristic is combined with the constraint ‘complicated cleaning’ the complicated geometry of car and motorcycle wheels could be thought of and added to the transport list. Water repellent and ‘rough surfaces’ could add graffiti removal from walls to the house list.

### *4.2.5 For each found application the conceptual idea in applying the biological phenomena to the application should be described*

When describing the conceptual idea the specific context should be selected and relevant details that could complicate the application should be investigated. For example for the graffiti removal application the context could be plaster walls that have a fairly rough surface texture. A challenge will be to find out a way to attach the repellent surface to the wall.

### *4.2.6 Confront selected stakeholders*

Relevant stakeholders for graffiti removal would off course be the cleaning companies that takes care of graffiti removal, but also masons, house caretakers, insurance agents and paint producers could be relevant stakeholders to contact. Apart from evaluating the idea they could highlight additional considerations like breathability of the wall but hopefully also additional ideas would emerge such as if the mason told about their problems in cleaning their equipment for plaster and concrete.

#### *4.2.7 Conceptual description of new applications identified in the discussion with stakeholders*

This could be to propose conceptual designs of mason's buckets or whisks so they will be easy clean with running water.

#### *4.2.8 The potential for each of the conceptual ideas can be evaluated based on a set of predefined criteria.*

Evaluation could be to estimate the realism in the proposed concepts and to estimate the size of the potential market.

## 5 DISCUSSION

In traditional problem driven product development good solutions normally require that a large solution space be ensured. This can be done by defining the required functions for a given problem and then search for many different ways of fulfilling the functions. Methods like brainstorming and analogy search can be applied. When engineers and designers are trained in design thinking the aim is to give them the mind set of demanding large solution spaces characterised by diversity. Good application search has similarities to the problem driven development in having the need for large diverse solution spaces. Since solution driven BID often is conducted by non-designers they need guidance in pursuing the search in a large diverse solution space. The proposed procedure will hopefully stimulate the broader and diverse search through the formulation of characteristics and constraints and in particular in the dialogue with stakeholders.
The proposed use of characteristics and constrains for facilitating the search for applications has similarities with the work done at Georgia Tech on the 4-box diagram and the T-chart shown in figure 7 (Helms and Goel, 2014). The Georgia Tech work is targeted towards problem-driven BID helping practitioners in specifying the problem and evaluating biological analogies. However, the tools could also be used for solution-driven BID if applied in a way similar to the application search procedure proposed in this paper. The functions in the 4 box/T-chart is equivalent to the characteristics used in step 1+2 in the application search while operational environment / specifications / performance criteria reminds of the constraints used in step 3 in the application search. While the basic categories are similar the Georgia Tech work do not provide support for how to perform the solution-driven BID search for suited applications.

| Design Problem | | Biological Analogue |
|---|---|---|
| Operational Environment | | Operational Environment |
| | Same | |
| | Similar | |
| | Different | |
| Functions | | Functions |
| | | |
| | | |
| Specifications | | Specifications |
| | | |
| | | |
| Performance Criteria | | Performance Criteria |
| | | |
| | | |

*Figure 7. The T-chart comparing design problems and biological analogies based on the four conceptual categories from the 4-box diagram (Helms and Goel, 2014)*


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## REFERENCES


Alting, L. (1978), “A Systematic Theory of Manufacturing”, *Environment and Planning B: Planning and Design*, Vol. 5 No. 2, pp. 131–156.

Deutsche M. (2018), *Hannover Messe*. Available at: https://www.hannovermesse.de.

Dorst, K. and Cross, N. (2001), “Creativity in the design process: co-evolution of problem–solution”, *Design Studies*, Vol. 22 No. 5, pp. 425–437. http://doi.org/10.1016/S0142-694X(01)00009-6.

Helms, M. and Goel, A. K. (2014), “The Four-Box Method: Problem Formulation and Analogy Evaluation in Biologically Inspired Design”, *Journal of Mechanical Design*, Vol. 136 No. 11, p. 111106. http://doi.org/10.1115/1.4028172.

Helms, M., Vattam, S. S. and Goel, A. K. (2009), “Biologically inspired design: process and products”, *Design Studies*, Vol. 30 No. 5, pp. 606–622. http://doi.org/10.1016/j.destud.2009.04.003.

Lenau, T. A., Metze, A.-L. and Hesselberg, T. (2018) ,“Paradigms for biologically inspired design’, in. Denver, USA: Proc. SPIE, Bioinspiration”, *Biomimetics, and Bioreplication* Vol. 10593.

Myrup Andreasen, M., Hansen, C. T. and Cash, P. (2015), *Conceptual Design - Interpretations, Mindset and Models, Conceptual Design*. Springer International Publishing. http://doi.org/10.1007/978-3-319-19839-2_1.

NASA (2018), *NASA Technology Transfer Portal (T2P)*. Available at: https://technology.nasa.gov/ (Accessed: 16 December 2018).

Neinhuis, C. and Barthlott, W. (1997), “Characterization and distribution of water-repellent, self- cleaning plant surfaces”, *Annals of Botany*, Vol. 79 No. 6, pp. 667–677. Available at: <Go to ISI>: http://doi.org/1997XG01500011.

Pedersen, T. H. (2009), *Værktøj til Facilitering af Fleksibel Formgivning - af Beton*. DTU Master Thesis, Kgs, Lyngby.

Pedersen, T. H. and Lenau, T. A. (2010), “Variable geometry casting of concrete elements using pin-type tooling”, *Journal of Manufacturing Science and Engineering*, 132, p. 061015 1–10. http://doi.org/10.1115/1.4003122.

Sto SEA Ptd Lte (2014), “StoColor Lotusan - Intelligent paints with lotus-effect technology”.

Sto SEA Pte Ltd (2018), *StoColor Lotusan self-cleaning facade paint.* Available at: http://www.sto-sea.com/en/company/innovations/sto-lotusan-/sto-color-lotusan.html (Accessed: 15 December 2018).

Vedel-Smith, N. K. (2009), *Tool to Facilitate Versatile Shaping - Sequential Marking of Cast Components*. DTU Master Thesis, Kgs, Lyngby.

Vedel-Smith, N. K. and Lenau, T. A. (2012), “Casting traceability with direct part marking using reconfigurable pin-type tooling based on paraffin-graphite actuators”, *Journal of Manufacturing Systems*, Vol. 31 No. 2, pp. 113–120. http://doi.org/10.1016/j.jmsy.2011.12.001.

Ørting, M. C. and Thomsen, C. E. (2018), *Grow technology - a new manufacturing method*. DTU Bachelor thesis, Kgs. Lyngby. Available at: https://findit.dtu.dk/en/catalog/2436261440?single_revert=%2Fen%2Fcatalog%3Fq%3DMads%2BChristoffer%2B%25C3%2598rting%2BChristoffer%2BEgelund%2BThomsen%26show_single%3Doff%26utf8%3D%25E2%259C%2593 (Accessed: 15 December 2018).