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NATURAL ANALOGIES – CREATIVE PRINCIPLES OF THE NATURE AND THE PRODUCT DESIGNER

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Abstract. Present paper analyses the creative principles of the nature and the product designer, and describes a possible way of research. The study is restricted to the analogical solutions of machine elements, machines and products. The paper detailed deals with principles, evocation, articulation, proportion, etc., available in the nature and the design process.

Keywords: natural analogy, linguistic analogy, articulation, evocation, proportion, proportionality, balance, symmetry, asymmetry, order, rhythm, direction, contrast

1. INTRODUCTION

Josiah Wedgwood who was born in 1730, was an English ceramist, founder of the power pottery making, in other words the creator of power arts. Wedgwood produced cheap, simply producible, well usable, durable, easily storable, transportable earthenware pots made of locally mined clay and not least available for many people. Wedgwood created flagship products **adapted to the needs and opportunities of his age [**4]. **The essence of creatures are the adaptive work**, **too**, e.g. the tree implements its genetic program and grows upwards in undisturbed conditions. In unfavourable circumstances, however, extends towards the sky asymmetrically and diagonally. **The plant responds the environmental influences, adapts and modifies its structure within a certain limits, taking advantages of inherent opportunities**. Charles Darwin (1809–1882, grandson of Josiah Wedgwood) summarized the design principles of ecosystem as the theory of coordination of opportunities and adaptation, in the work of "On the Origin of Species by Means of Natural Selection, or the Preservation of favoured races in the struggle for life" [1], published in 1959. In this paper the authors study the relations between the respond of the living and inanimate nature giving to the environmental challenges, and the possible technical works. The relations are illustrated by previously known or analysed examples.

2. ELEMENTS

The scope of elements and forming principles of the living and inanimate nature is extremely wide, therefore this study is restricted to the field of our competence, as the machine elements, the machine design, the product design and the solutions of nature can be associated with them (*Figure 1*).

The machines are structures composed of elements, to solve a special problem. Their repetitive elements, in accordance with the task and design, are the machine elements. Beyond their tasks the machine elements can be classified on the basis of shape, design, load, material, production, etc. Among the machine elements there are fasteners, shafts, cou-

plings and clutches, bearings, seals and the drives. The research of direct relation between the machine elements and the living and inanimate nature is a rough simplification so **the correlations should be located by the similarity or identity of the problem**.

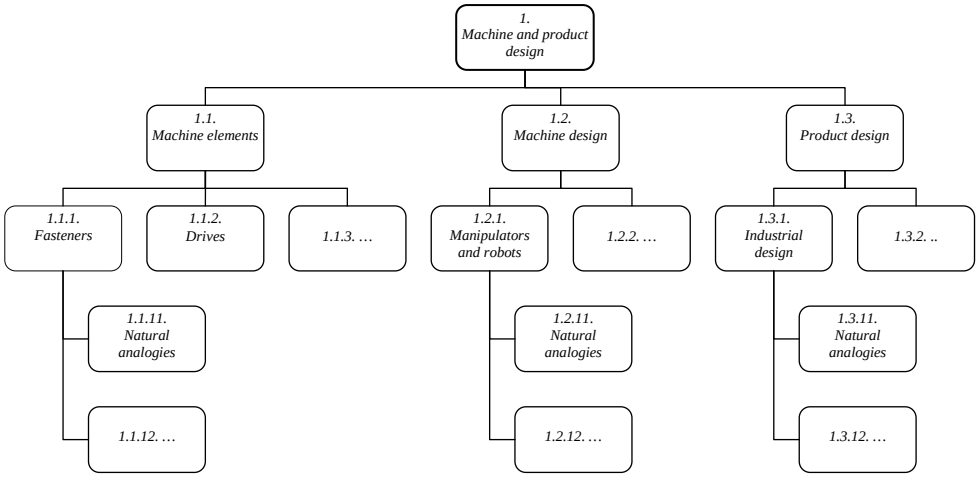


Figure 1. The studied areas of natural analogy

The frequently repeated elements of creatures and technical works are the fasteners assuring connection between the parts. The joints can be created by adding material, they can be force or shape closing, mixed shape and force closing, and elastic fasteners. The bonded joints are made by adding material, for example. Both nature and man use absorbing material, e.g. absorbing material covers the seeds of mistletoe (Viscum album), which stucking to birds and dropping of them assures the propagation of the plant. Shape closing joint is made e.g. between the cores of thistle (Carduus nutans) [*(Figure 2.a)*] and the fur of animal coming into contact with it.



a) *b)* *c)*

Figure 2. a) and b) Thistle and its hooked pins, c) Hook and loop fastener

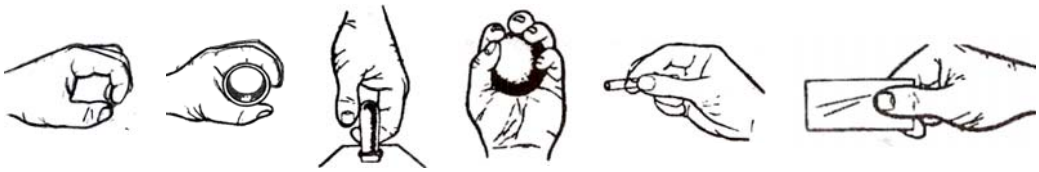
The hook ended pins [*(Figure 2. b)*] assures the spreading of thistle as a free rider in large territory. 21–25 piece of reflexed hooks assure the break of sting of a honey bee (Apis mellifera) into the stabbed human being or animal, and to get the poison from the detaching gland to the stabbed body. Similar hooks are used to close clothes and shoes [2], or to fix machine parts [*Figure 2. c)*]. The joint is shape closing between teeth of predator and the prey, or e.g. between the crocodile clip and the gripped electrical wiring. The joint is force

closing between the fingers of man and the gripped object [*Figure 3. a)–f)*] or e.g. between the sheet of paper and the fixing clip. The joint is both shape and force closing between the claws of predator and the prey. The joint is elastic between the skull bones of a newborn. Before the end of ossification the elastic parts assures the easier passage of the head through the birth canal, and the increment of volume of skull during the growing (the bones of skull, after the final formation are sutured and rigid join is developed. By similar manner the elastic joint assures the relative displacement and rotation of rigid parts in the machines. **The examples illustrate the natural approach of machine element education and the possible attract of audience (captatio benevolentiae).**

3. COMPLEX STRUCTURES

The nature of machine parts are material, e.g. the machine elements and immaterial, e.g. the software used to control. For example, the robots belong to the complex machines. Their main parts are the frame, the arms, the drive system, the energy supply system and the controller. Tools and/or grippers belong to the arms, similarly to the creatures of nature having arms and legs. The ideal gripper would be the copy of the human hand [*Figure 2. a)–f)*], so it is not surprising that the human hand is the starting point of making the versatile robotic gripper structures. In *Figure 3* there are characteristic types of gripping shown as a) with fingertip, b) cylindrical, c) with folded finger, d) spherical, e) rod end and f) gripping on side panel.

Since the shape, size and material of the object to grip is versatile, and similarly the operations and the environment have a wide range, too, the universal robotic gripper is usually large, heavy and expensive, relatively to the problem. To optimise the size, mass and costs, the robotic grippers are not universal, but task-qualified. Most frequently the relationship between the object and gripper is assured by shape closing or force closing. To the analogy of gripping with human hand, *Figure 3. g), h)* and *j)*, show grippers with fingertip, cylindrical and on side panel, respectively.



a) *b)* *c)* *d)* *e)* *f)*



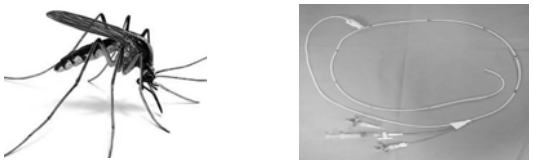
g) *h)* *j)* *k)* *l)*

Figure 3. a–f) Gripping with human hand, g)–k) robotic gripper, l) the sole of gecko

The *Figure 3. l)* shows the sole of a gecko, covered with millions of keratin hair having some micrometer. When the hairs get contact with some object, among the surface of object and each of hair fibre, a weak molecular attraction (van der Waals-type effect) occurs. These effects are tiny but the millions of fibres stick to the surface with a significant force. The *Figure 3. k)* shows a vacuum robotic gripper which joining effect is similar to the hair fibres but another one.

The product is, briefly and comprehensible saying, a work satisfying needs. Its content and interpretation are wider than that of the machine. Inherent parts of the product are, beyond the complex structure in which mechanical components interact, the effects on our visual, auditory, olfactory, or taste organs.

During the inquiry, to the analogy of machine elements, the part can be studied. Similarly, to the analogy of machine the complex creature and to the analogy of product the creature and its evoked effect can be studied.



a) *b)*

Figure 4. a) Blood-sucking female mosquito, b) medical catheter

For example, the piercing mouth organ of the mosquito can be inspected, the thin tube, which penetrates the skin causing no pain. Or that of the medical instrument similar to the sucker of mosquito can be studied, too, which is a catheter used to approach the inner parts of the body, to remove the undesirable parts, to widen any parts, etc. The parts of the mosquito as "a product" are the anticoagulant substance pressed into the pierced body, and also the "song" that evokes the presence and the sting of the mosquito.

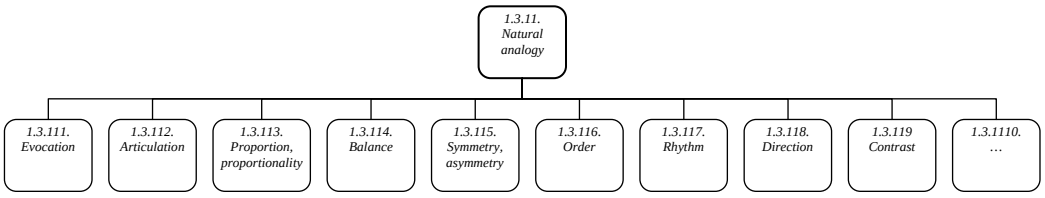


Figure 5. The components of the visual communication

4. LINGUISTIC ANALOGIES

When speaking one sounds the voices with the proper intensity to hear and to understand, creates words with **understandable length** from the voices and arranges the words into sentences with **comprehensible size**. The words obtain proper tone and emphasis in the sentences, according to their tasks, and **recall, tell something, following the rules of verbal communication.** The other creatures of the wildlife also communicate something with their sounds, they notify the demand over a territory, they search a partner of race or of op-

posite sex, they have their power felt, etc. **The animal sounds are also articulated, according to the essence of communication, those are emphasized and are diversified in accordance with the intention.**

The natural and artificial objects around us also let us know something, using the vision, the hearing, the touching, the taste and smell. The multitude of objects around us gives the most information about our environment**. The visual communication and understanding, based on the vision, have roles similar to the spoken language, which are learned by its users in cooperation with their environment during their development.** The visual perception is the active recording of things, which consist of a continuous consideration and comparison of the size, shape and colour of objects, and also the relationship among the parts, the whole product and the environment.

5. THE EVOCATION

The vision, hearing, touch, taste and smell of something produce the operation of their corresponding sensory organ. The sensory organ initiates a nerve process to the effect of stimulus, on the other hand it remains insensitive against the improper stimulus. If the intensity of the stimulus exceeds a certain threshold, it excites sensation. The notion is nothing more than the sum of sensations. **The evocation is interpreted as generating notions by seeing, hearing, tasting, touching, or smelling something.** The evocation is a valid category for both the human and the animal. **All carries a meaning, evokes something**. The man lives and socializes in a community and the decoding of sensations is based on the previously earned experiences, factual knowledge and the knowledge of the agreements within the community. For example the white cloth can be the sign of the purity or peace, but the evocation of death in other community. The evocation may be concrete and indirect. The sing of bird is concrete when it is recognised by the partners of species, and it is indirect when detecting the intensity of sound, the partners of species conclude on the physical condition of the singer. The meaning of a car logo in *Figure 6* is indirect; it evokes both the freedom of the wild horses galloping on the prairie and the sense of life of young people of the 1960's.



a) *b)*

Figure 6. a) Galloping wild horses, b) Car logo of the Ford Mustang

6. ARTICULATION

The first step of the visual communication is the division into parts, the articulation. Similarly to the words, the parts should be noticeable, visible and tangible. The articulated parts differ from each other in form, size, volume, colour, surface quality, etc. **The essence of**

articulation is the separation of the parts, the function based distinction, the separation of parts corresponding to their essence.

Figure 7.a) shows a rhinoceros beetle (Oryctes nasicornis), its soft parts and inner organs is guarded by chitin shell. The shell is not a monolithic unit but the chain of the hard, considerable as rigid parts and the flexible hinge dominant parts. The articulated shell is not the gift of nature, **the articulation is determined by the function of parts**. In the *Figure 7.b)* the Ford KA brand car was given a simple, reduced to essentials, rain drop shape body to degrease the aerodynamic drag. **Distinct curves separate the functionally detached parts to evocate the relation between the function and the parts.** Contrary to the chassis of the Ford KA car, the body similar to a bar of soap which had lost its edges is easily forgettable, because the lack of the definitely distinct parts. **The inarticulate spatial formation, similarly to the inarticulate speech, do not maintain the interest and live no trace in our memory.**



a) *b)*

Figure 7. a) Rhinoceros beetle and b) Ford KA brand car

There are creatures and man-made objects, which essence is the raising of no attention. The aim of the bird sitting on its eggs or the fawn crouching in the grass is the **hiding**. As a result of natural selection, they blend into their surroundings with then help of their feathers and fur, so **these animals constitute the inarticulate part of their surroundings**.



a) *b)*

Figure 8. a) Nestling, crouching in the nest, b) soldiers in camouflage suits

One of the essential elements of the articulation is visualized by *Figure 8. a)*. There are three nestling blended into their surroundings, the fourth one however is stretching for feed, and is distinct from its surroundings by its bright red throat. The behaviour of the nestling is determined by the hiding or the attention-raising, as aim. Similarly to the nestling, the cam-

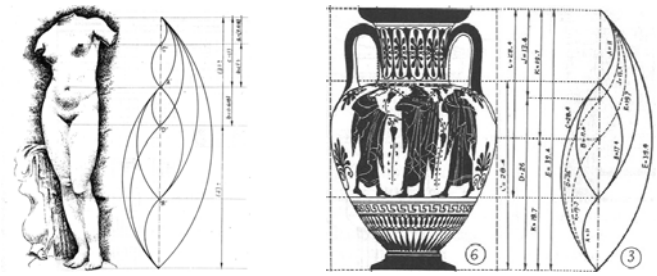
ouflage suits of the soldiers shown in *Figure 8. b)* are proper if they are inarticulate, undiscovered parts of the surrounding. If necessary, however, similarly to the nestling seeking feed, they sign their location to the friendly aircraft by a bright coloured sheathed. The examples illustrate that **the articulated or inarticulate being is determined by the aim and the task**.

7. PROPORTION AND PROPORTIONALITY

The scaling was developed from the counting, the appropriately chosen part of the numbered pattern, formation or mass, area are called unit mass, unit area, etc. For the shake of the visual communication the articulated parts are quantified, based on the unit, and the values can be compared to each other. **In a simple case the proportion is a comparison between two or among more values by the methods of the mathematics and the geometry.**

The designers have dealt with the proportion for a long time, e.g. the cause of beauty was searched by the scientists of antiquity, analysing the proportion of the human body [3], [5]. The cause of beauty was believed to be discovered, among others, in the golden section. Quantifying the lengths of the characteristic parts of the human body and comparing them, it was found that the ratio of the shorter and longer parts is equal to the ratio of the longer part and the whole.

The ratio of parts of the living and inanimate objects is independent of the observer, the relationship of the parts and its cause is searched by the man unintentionally. For example the crane bird lives in marshy, wooded countryside and eats sprouts of plants, rodents, fish and small mammals, standing on its tall legs it grabs the feed reaching far in advance and deeply by its neck, if necessary. Its long, slender legs and neck was adjusted to the way of life and the living environment by natural selection. The high, slender frame of a tower crane and the slender structure of the long extending jib are determined also by the problem. The load should be transmitted to a space domain, located far and occasionally deep from the tower. **In the case of creatures and the everyday objects the primary point of view is the expediency, the proportions are defined by the function.**



a) *b)*

Figure 9. The golden section [3,5]

One of the simplest tools is the hammer, however, its dimensions and the proportions show diversity. The mass, the ratio of the handle and head are different in case of the hammer of the dentist, carpenter, the mason or the blacksmith who flatten thick steel plates. The func-

tion of tool determines its proportion. The thickness of the handle, however, varies in a relatively narrow range, regardless of the task, as the thickness and shape of the gripped part of the handle is determined by the dimensions and shape of the human hand. In other words, **the proportion of the parts of the tool is formed by the function of the tool and the man – tool relationship.**

8. BALANCE

The equilibrium or balance is a used term in both the everyday speech and the language of professions. The equilibrium is the status of a system when the resultant of the effects is zero. For example a mechanical system is in equilibrium when the resultants of forces and moments substituting the effect of the left parts are equal to zero. The parts may be in balance on the basis of their dimension, shape, surface quality, colour, sound, taste, etc., too. The balance is a natural part of the world of creatures and inanimate objects, one involuntarily looks for the cause when recognise the lack of balance.

9. SYMMETRY AND ASYMMETRY

A spatial formation is symmetric when its adequate parts are mirror images of each other, for the axis or the plane of symmetry. The parts of the planar symmetric formations are mirror images of each other, for the axis of symmetry or for a point. **The symmetry is an easily recognizable element of the living and inanimate, artificial and natural organs and formations.** The symmetric architecture has numerous messages. The *Figure 10. a)* shows a symmetric face part and healthy teeth. In case of a living organ **the symmetry evokes the physical integrity and health**. Let us think about its contrast, the physical deformations caused by injuries or certain diseases. Based on our experience, the symmetric bodies, completed by other constraints, are in equilibrium and they remain in rest, e.g. the builders of pyramids created stable structure that has announced the remembrance of their builders for thousands of years shown in *Figure 10.b).* The dangerous machineries are formed symmetrical, e.g. the gas appliances shown in *Figure 10. c)*, too. **The symmetric form is the mediator of rest, timelessness and reliability.**

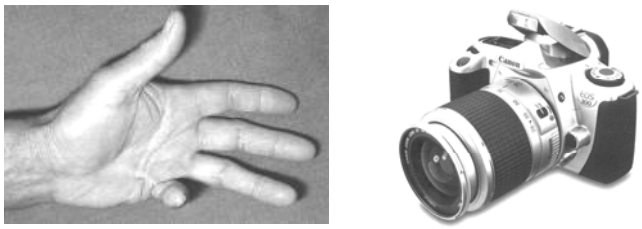
In our surroundings the most of the man-made objects are symmetric. The furnishings, equipment, books or the vehicles are usually symmetric, the symmetry is a generally used design principle. If you would like to focus attention onto something, it should be symmetrically prepared, e.g. the slot of a waste bin or the information desk is located in the middle to everyone can hit or find.



a) *b)* *c)*

Figure 10. a) Symmetric face, b) symmetrically built pyramids and c) gas appliance

It is an everyday experience, that creation of a symmetric object or drawing of a perfect circle can be made only with some talent and adequate experience. The establishment of a regular spherical body gives satisfaction to both the creator and the viewer. The objects formed to symmetrical reveal about the talent of the creator. The ancient Pythagoreans considered the circle as a perfect planar object and the sphere as a perfect spatial body. Aristotle ascribed spherical forms to the celestial bodies as he considered them perfect creatures [5]. The balls, used in the advertising films, suggest the excellence of the institutions. The advertising graphic designers form the logo into a circle consciously, for this **evokes the perfection** in the observer [6]. **The symmetry symbolizes the order, the peace, the possession of knowledge necessary to control the processes, and the reliability in technical meaning.** The bodies of creatures are symmetric when looking superficially, however, having examined carefully, differences can be found on it. The phantom drawing is symmetric, but the picture taken of a living person is asymmetric a little, e.g. the eye, the nose, the ear differs from the symmetric formation which make the face come alive. **In the nature the symmetry and asymmetry exist together, the asymmetry is the embodiment of the living thing or phenomenon.** The asymmetry is usually the counterbalance of the symmetry, the tool for making the object come alive. The objects however can be asymmetric not only in their details but entirely, too, **when the destination intends so**. For example the hand tools, the small arms the cameras are usually one-handed and asymmetric, the handle assure a sure grip, following the form of the hollow of the right hand, and the control elements adjusted to the thumb and index finger of the right hand can be managed with natural motions. **In this case the asymmetric structure is the marker of the function.**



a) *b)*

Figure 11. a) Asymmetric human hand, b) camera with asymmetrically arranged control elements

The asymmetric arrangement has a challenging effect, so the observer or user searches the cause asymmetry, e.g. at the control elements, **in the row of the same layout of buttons or keys, the asymmetrically located element calls the attention as visibly separated.** The balance of the asymmetrically arranged elements with each other has got the same effect as that of the symmetric design. **The destination decides between the symmetric and asymmetric design, the selection is always subject to the function.** The graphic designers can take advantage of the opportunity offered by the asymmetric arrangement of the shape; the asymmetrically located picture and text suggest vivid content. **The asymmetry is suggested by the content, and the varied content can be illustrated by asymmetric form**.



a) *b)*

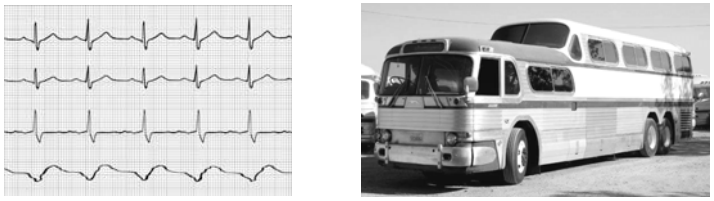
Figure 12. a) Order and b) disorder

10. ORDER

The message of the order is the same in both the nature and the man-made physical world, i.e. the conditions of existence, the growth and the enrichment are given, the things are going right and there are all the knowledge and skills available, which are necessary to the normal progress and control of the process. The disordered appearance speaks about the lack of conditions necessary to the normal being. In ordered condition, for the sake of good space utilisation the seeds are located along a logarithmic spiral in the plate of sunflower, as *Figure 12. a)* shows. In *Figure 12. b)* the disorder reveals the lack of order necessary to the cultured existence.

11. RHYTHM

The rhythm is a repeated articulation of any pattern. The rhythmical repetition is a basic human experience, such as the heartbeat, the healthy breathing and the return of the seasons. The modification or break in repetition may have a tragic consequence for both the individual and the community. **The rhythmic appearance of phenomena or patterns evokes that the process are going in order, as usual.**



a) *b)*

Figure 13. a) Heart rhythm graph b) Greyhound coach (Greyhound Corp., Pontiac, Michigan, 1954)

It is easy to recognise the rhythmic appearance, regardless of whether it is visual, auditory or touch based. **The rhythmic repetition amplifies the information.** The rhythmic articulation should be human scaled, i.e. the only repetition is understandable which is adapted to the sensitivity of our sense organ. The too high or too low frequency of appearance are felt no rhythmic repetition. The rhythmic appearance may have important role during the design

process. The side plates of coach shown in *Figure 13. b)* are corrugated, they evoke the orientation of progress of the vehicle. The corrugation of plates has got a point of view of strengthening, too. The flexural rigidity of the corrugated plate is higher by orders of magnitude than the flat plate having the same thickness. Further advantage of the corrugated plate is that the injuries and the repair do not cause as much as aesthetic error than that of on the flat plate. The operational temperature of prime movers, machines and electrical appliances are controllable by the help of radiator grilles, heat sinks and cooling fans. The rhythmic placement of the slots, the ribs or the blades of a fan is not a game with an end in itself, but the product function is converted into product design.

12. DIRECTION

Everyday experience is that the direction is in relation with the growth, enrichment or with the reduction, in other case with the displacement. The tree shown in *Figure 14. a)* well illustrates the spoken thoughts, its growth is not restricted by the surrounding and its shape points upwards. The essence of direction is illustrated by the logo of Lancaster University, shown in *Figure 14.b)*. **The university is universal but it does not unify and the limit of science is the starry sky. These are proclaimed by the four converging, similar but not identical bands which are pointing upwards** [6]. **The pyramid** shown in *Figure 10.b*) expands downwards, the resultant of the gravitational force acts inside the supporting surface, the structure is stable. **The form expanding downwards evokes the stability**. The *Figure 14. c)* shows the building of China Central Television in Peking. The visible part of the building **is not stable, the observer looks for the cause of the reason of staying standing up,** which lies in the design of the underground part of the building and the different distribution of mass of the standing and horizontal parts. **The purpose of amazing form is not the visualization of the stability but to attract the interest and the attention.**



a) *b)* *c)*

Figure 14. a) Tree growing upwards, b) The logo of Lancaster University, c) The headquarter of China Central Television (Rem Koolhaas and Ole Scheeren, The Office for Metropolitan Architecture)

The front panel or the windshield of the most vehicles is declined. The declined front panel is not a game with an end in itself, but there is less air resistance on it and it embodied a more favourable aerodynamic properties. **The declined front panel of the vehicles evokes**

the motion in both standing and moving conditions, the direction of progress and the advantageous design in the point of view of the losses of flow. Despite of this, a part of the chasses of the coaches are rectangular prism. **The standing front panel of these vehicles evokes not the direction of progress and speed but the intent of the designer that in a given volume the most number of passengers should be placed.**

13. CONTRAST

The terrestrial environment is created by natural a man-made object, which differ in dimension, mass, shape, proportion, colour, etc. The basis of contrast is the distinction, when the parts of the object and/or the environment are grouped on the basis of their evoking effect. The contrast is observable both in the worlds of creatures and man-made objects. In *Figure 15. a)* the bright feather dress of the male member of the pair of birds differs from its surroundings, contrarily to the simple feathers of the female blending into their surroundings. The contrast between the feather dresses is not an accidental phenomenon, the function is the raising awareness in the first case and that of the hiding on the other case.

The designer creates contrast with the shape, size, material and surface finish, pairing transparent and non-transparent materials, colours, patterns, etc., of the product. The baseline is not intention dependent, e.g. the tall is seen also tall and the small is seen also small when locating them next to each other. **In the contrast the difference makes the reception to be directed, e.g. the difference of two elements having the same form but differing sizes is recognized at once and the cause of difference is looked for, involuntarily.**



a) *b)*

Figure 15. a) A pair of pheasants b) Wolf brand pruning shears

The contrast is not a game with an end in itself; it is created always on the basis of destination among the parts or between the object and its surroundings. The elements correlating with the usage can be highlighted or subordinated in such way, e.g. on the pruning shears shown in *Figure 15.b)* it is made visible that the cutting edges are strong and which part of the arms should be acted to, or what are the associated locations of the lock and the cutting edges. **During the design process the contrast is applied in correlation with the destination and also the usability of the product is highlighted with the contrast.**

14. SUMMARY

Our environment consists of living and inanimate creatures, natural and man-made objects. The proportional, symmetric and/or asymmetric body composition of the living creatures the rhythmic appearance of the parts, the direction of their formation, the relations among the parts or between the whole and its surroundings are the result of the natural selection,

the embodiment of the struggle for existence. The wildlife and the product designer use similar constructional principles to design functional, viable and competitive living creatures or products, respectively.

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