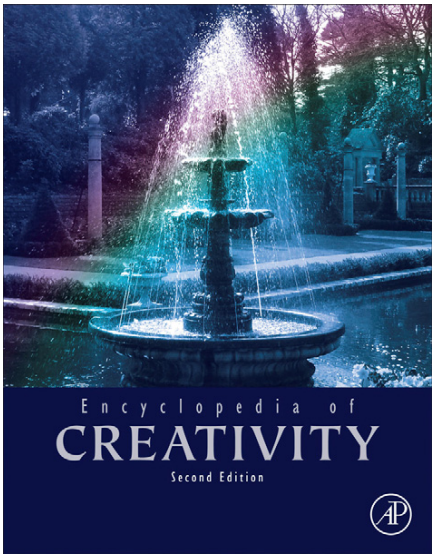

Gero J.S. and Kannengiesser U. (2011) Design. In: Runco MA, and Pritzker SR (eds.) Encyclopedia of Creativity, Second Edition, vol. 1, pp. 369-375 San Diego: Academic Press.

Design

J S Gero, George Mason University, Fairfax, VA, USA
U Kannengiesser, NICTA, Alexandria, NSW, Australia

Glossary

Behavior The attributes that can be derived from the structure of an artifact. Informally, behavior can be described as 'what the artifact does.'
Design The outcome of the process of designing.
Designing The process that transforms requirements into designs. It creates new worlds by reformulating some of the requirements based on the designer's situation. This provides opportunities for producing designs that were not possible or not obvious in the previous world.
Design world The set of expected design alternatives produced by the designer's current situation. A design world consists of three subspaces: function subspace, behavior subspace, and structure subspace.
Emergence The process of making implicit properties of a design explicit.
Function The teleology or purpose of an artifact. Informally, function can be described as 'what the artifact is for.'
Situated creativity (or s-creativity) A type of creativity in which novelty is defined relative to a current situation. It is the result of a change of the world of possible designs.
Situation The process that directs what concepts are produced during designing, based on the designer's experience and interactions.
Structure The components of an artifact and their relationships. Informally, structure can be described as 'what the artifact consists of.'

What Is Design Creativity?

Designing

Everything around us with the exception of natural things is designed, and even an increasing number of what appear to be natural things are designed. We will use the word 'designing' as the verb and the word 'design' as the noun to distinguish between the process (designing) and the outcome of designing. Designing is the process by which we posit changes to the physical and virtual worlds in which we live through intentional acts. Designed physical objects include architectural, mechanical, industrial, textile, electronic, graphical, and chemical objects, amongst the many physical objects designed. Designed virtual objects include those that exist in virtual environments (e.g., computer games) as well as plans and strategies, processes and conceptual models, representations and systems, and hypotheses and theories. Designing is not a unitary activity and as a consequence cannot be simply explained from a single perspective. The distinguishing feature of designing is that it creates new worlds within which it operates. These worlds can be thought of as new ways in which design requirements are viewed. They provide opportunities for coming up with designs that were either not possible or not obvious in the previous world. This feature of designing is most apparent when designs are required to meet conflicting constraints. For example, aircraft fuselages are designed to exhibit high strength but low weight, and digital cameras are designed to provide sufficient image resolution at affordable prices. Some of the conflicts can be resolved through simple tradeoffs that do not require new worlds to be created. However, in many cases of designing there are hard constraints (such as physical or legal constraints) that cannot or must not be violated. As an example, let us assume that an engineering design problem requires the length of a physical part to be at least 10 cm. However, during designing adjacent parts it turns out that this length must be restricted to a maximum of 5 cm. This conflict is depicted graphically in Figure 1, where x is a variable that represents length. Using this representation, it would not be possible to find a solution.

The conflict can be shifted into a different space by introducing a new design variable y that represents a new geometric dimension (e.g., width), as shown in Figure 2. The constraints now become $x \leq y + 5$ and $x \geq 10 - y$, which leads to the feasible solution space as depicted.

New worlds can be created at all levels of a design. At a low level, they lead to changed elements of the same overall design. At the highest level, they lead to changed needs and actions of users of the design. As the architect Denys Lasdun put it:

> our job is to give the client [...] not what he wants, but what he never dreamed he wanted; and when he gets it, he recognizes it as something he wanted all the time.

This may even require violating some of the constraints that initially appear mandatory. A famous example is the Sydney Opera House; its architect, Jorn Utzon, broke all of the original design constraints and yet won the design competition. He even broke the constraint that required the 'building to lie wholly within the site.' His design required a larger site than the one specified. In this case since the site had water along three of its four sides it was possible for the client (here the state government) to expand the site to fit the proposed building. The resulting building is considered to be highly creative and is one of the architectural icons of the twentieth century.

Designing involves activities that range in a continuum from selection to routine through to the nonroutine activities. Selection typically occurs at the level of individual elements. For example, materials, springs and bearings can be selected from standard design catalogues. Selected elements do not need to be assessed. Routine design activities involve the generation and testing of alternatives within existing worlds of designs.

Encyclopedia of Creativity, Second Edition (2011), vol. 1, pp. 369-375

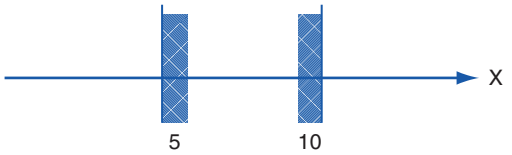

Figure 1 The constraints $x \leq 5$ and $x \geq 10$ lead to no feasible solution.

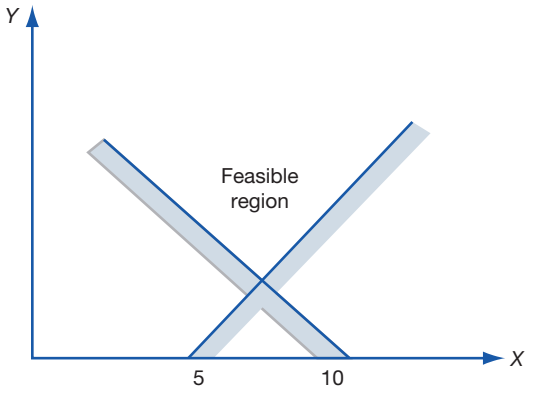

Figure 2 Introducing a new variable changes the constraints to $x \leq y + 5$ and $x \geq 10 - y$ that now lead to a feasible solution space.

They are often carried out iteratively. The criteria for testing alternatives are known and fixed, making designing resemble a process of search within an existing world of designs. Nonroutine design activities are those that create new worlds that allow searching in areas that were not available before. As a result, novel designs can be generated that are potentially creative.

Nonroutine design activities account for the common observation that designs tend to be unique even though they have been produced using the same initial requirements. This means that different designers create different worlds within which they operate. And the same designer often creates different worlds at different times during the process of designing. The notion that accounts for these changes is called the 'situation.' When designers reason about and act upon a design problem, they do so within a unique situation that directs what concepts the designer brings together based on experience and how the designer interacts with the design, the design process and other designers.

Design Creativity

For designs to be creative, three necessary conditions must be fulfilled: (1) The design needs to be novel; (2) the design needs to be useful; and (3) the design needs to be surprising. The first condition allows separating creative designs from routine designs. The second condition is often used for delineating design creativity from purely aesthetic creativity (although 'usefulness' can be understood in a broad sense that may include aesthetic value). The third condition describes the unexpectedness of creativity, providing the potential to change people's expectations.

Creativity in design draws three distinctions: the common distinction between historical creativity (or h-creativity) and psychological creativity (or p-creativity), plus a third distinction that is situated creativity (or s-creativity). h-Creativity is the strongest form of creativity, where novelty is assessed in relation to the history of humankind. For example, the first steam engine was an h-creative design. p-Creativity implies novelty with respect to the history of an individual. An architect designing a high-rise building using, for his or her first time, reflecting glass can be viewed as producing a p-creative design. h-Creative designs must also involve p-creativity. s-Creativity is defined relative to the situation that pertains during the process of designing. A design or design feature is s-creative if it is the result of a change of the world within which designing operates. p-Creativity must involve s-creativity.

It is important to distinguish design creativity from design innovation. Design innovation turns the outcomes of design creativity into practice by realizing (implementing, manufacturing, assembling) or using them. Therefore, design innovation needs design creativity as a precursor. On the other hand, design creativity also needs design innovation, because outcomes of designing must be realized to be useful. Consequently, the study of design creativity must consider both the producers and the adopters of creative designs.

Design creativity can be located in designs, in the process of designing, in designers, and in users.

An Ontology for Locating Design Creativity

Identifying and characterizing the loci of creativity in design requires a systematic framework for describing the knowledge of the design domain in terms of all the concepts in this domain and their relationships. The notion of an ontology provides such a framework. The function–behavior–structure (FBS) ontology is a design ontology that describes all designed things, or artifacts, irrespective of the specific discipline of designing.

Structure (S) of an artifact is defined as its components and their relationships ('what the artifact consists of'). Table 1 shows some examples of the structure of various artifacts.

Behavior (B) of an artifact is defined as the attributes that can be derived from its structure ('what the artifact does'). Behavior provides measurable performance criteria for comparing different artifacts. The examples of behavior in Table 1 show that most instances of behavior relate to notions of quality, time, and cost.

Function (F) of an artifact is its teleology ('what the artifact is for'). It is ascribed to the artifact by establishing a connection between one's goals and the artifact's measurable effects. Table 1 shows some examples of function.

Relationships between function, behavior and structure are formed by humans through experience and between behavior and structure through the development of causal models based on interactions with the artifact.

Locations of Design Creativity

Design creativity can be located in designs, the process of designing, designers, and users.

Creativity in Designs

There are three locations of creativity in a design: function, behavior, and structure.

Table 1 Examples of function, behavior, and structure of different artifacts

	Building	*Text editing software*	*Manufacturing process*	*Team*
Structure(S)	Geometrically interconnected walls, floors, roof, windows, doors, pipes, electrical systems	Computationally interconnected program components	Logically and physically interconnected operations and flows of material and information	Socially interconnected individuals
Behavior(B)	Strength, weight, heat absorption, cost	Response times, cost	Throughput, accuracy, speed, waste rate, cost	Working speed, success rate, cost
Function(F)	Provide safety, provide comfort, provide affordability	Be time efficient, provide affordability	Be safe, be time efficient, provide sustainability, provide affordability	Be time efficient, provide affordability

Creativity in function

Creativity in function is the result of ascribing novel and surprising purposes to the artifact. An example is the 'pet rock' conceived and marketed in the 1970s. Pet rocks were simple grey stones to which a new function was ascribed – 'be a low-maintenance pet,' because unlike living pets they did not require feeding. Although pet rocks seem like a bizarre idea, they were very successful in the market.

Creativity in function may or may not require changes of behavior or structure. In the pet rock example, no further behaviors needed to be added to the stones' existing ones, and no changes had to be made to their structure (although some pet rocks had 'eyes' attached). The new function was just a changed interpretation of the stone.

Other instances of creativity in function do require changes in behavior and structure. For example, changing the function of a chair from that of an artifact for sitting to a multifunctional artifact that includes both sitting and being used as a ladder would involve changing its behavior to allow for 'ladderly' behavior by having more than one step and hence changing its structure such that the chair's back could be rotated to produce an additional step or two.

Creativity in behavior

Creativity in behavior is the result of deriving novel and surprising attributes of an artifact. These attributes are often new mechanisms, techniques, or physical principles that may support existing or new functions. For example, replacing a car's existing behavior 'petrol consumption' with the new behavior 'rapeseed oil consumption' may not change the existing function 'move people from A to B' but is likely to introduce the new function 'operate ecologically responsible.'

Creativity in behavior may or may not require changes of structure. The new behavior 'rapeseed oil consumption' of the car is likely to require changes of the structure of the engine and other parts. No structure changes are required when the new behavior can be brought about by modifying the interactions between the artifact and its environment. For example, holding a large piece of hardboard and shaking it in a lateral direction produces sounds without changing the hardboard's structure. This novel and surprising behavior was used by the Australian musician Rolf Harris to create a new musical instrument, known as the 'wobble board.'

Creativity in structure

Creativity in structure is the result of introducing novel and surprising components or relationships between components in an artifact that may support existing or new behaviors. Studies of designers indicate that this is the most common form of design creativity. For example, the first suspension bridges introduced novel components, component configurations, and materials with respect to the earlier arch bridges. Suspension bridges have left most behaviors unchanged, except for replacing compression strength with tensile strength.

It is more common to replace some element or relationship in the structure than to replace an entire structure by another. For example, replacing a large petrol engine with an electric motor and a smaller petrol engine, along with the elements needed to capture energy in the battery that runs the electric motor, produced the novel, useful, and unexpected design of the hybrid system in many cars today. The rest of the car remains unchanged.

Some creative designs involve a subtractive change in structure followed by the addition of a new structure element. An archetypal example of this is the design of the Sony Walkman. Prior to the Walkman all portable electronic music players had speakers and as a consequence were large and heavy. They were difficult to carry around. The Walkman eliminated the speakers and shrank the player dramatically so it could fit into a pocket. The speakers were replaced by earpieces. Earpieces themselves had never been used with music players previously. This change in structure resulted in a change in behaviors of the design (sound from earpieces) and a change in the function of the design. Previously, music listening via portable players was a group, social experience (hence their nickname 'ghetto blaster'), however, the Walkman changed listening to music from a public to a private experience. This social dislocation was an emergent function (see 'emergence' later in this entry). It took the recent introduction of the design of digital file sharing applied to music to turn music listening into a social experience again, albeit a new kind of social experience.

Creativity in Designing

Creativity in designing is located in the activities that produce new worlds in which new designs can be found. A world can be thought of as a set of possible design alternatives based on expectations produced by the designer's current situation. Design worlds are partitioned into three subspaces: function subspace, behavior subspace, and structure subspace, as shown conceptually in Figure 3. The subspaces are interconnected through the designer's knowledge of qualitative and quantitative relationships between function, behavior, and structure.

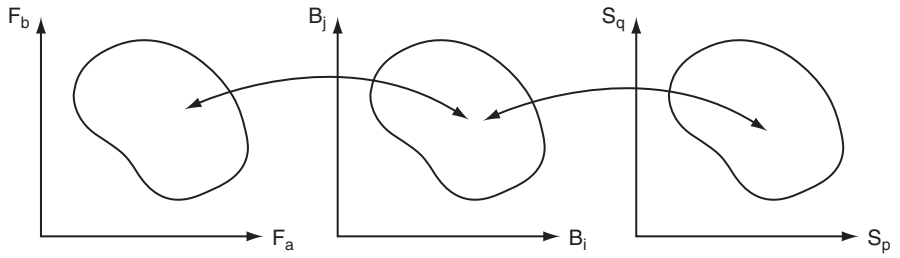

Figure 3 Function, behavior, and structure subspaces, and their interconnections.

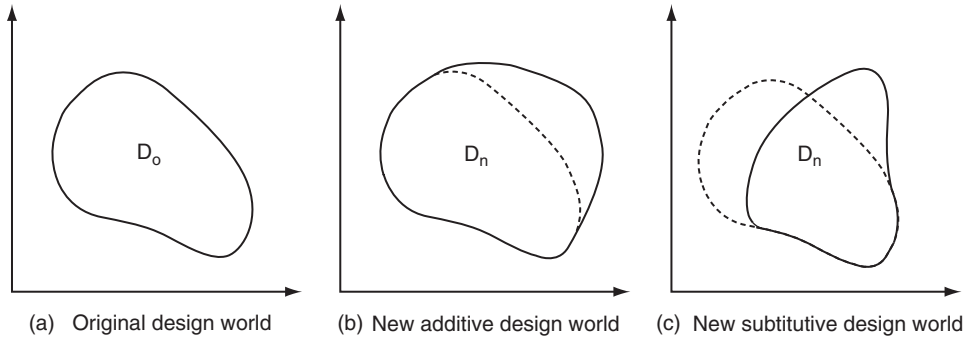

Figure 4 Possible changes of a design world. (a) The original design world, (b) additive change, (c) substitutive change.

The notion of a design world allows distinguishing two fundamental classes of design activities:

- Activities that use a situation to create new design worlds: They are described as shifts of an existing design world through changes in the designer's interpretations and expectations. The changes may be additive or substitutive, as depicted in Figure 4. The example shown in Figure 2 is of an additive change produced by introducing a new design variable. Figure 5 illustrates a substitutive change where one set of variables (the two squares) is replaced by a different set of variables (the two L-shapes and the smaller square). It is in these activities where creativity in designing is located.
- Activities that operate within a design world produced by a situation: They are described as moves through an existing design world to search for the most appropriate design alternative. Most commonly, the moves occur within the structure subspace and involve mapping their effects on behavior, as depicted in Figure 6. A good example is design optimization that searches for the 'best' design by generating and then testing variants of the same type of structure. Figure 7 shows different variants of the same cross-section of a beam and their effects on two behaviors: section modulus (related to the strength of the beam), and moment of inertia (related to the stiffness of the beam). As the moves do not cross the boundaries of the design world, no creativity is involved. All creativity in designing is in the activities that operate on, rather than operate within, the design world.

Creativity methods for designers are concerned with changing existing design worlds or producing novel design worlds within which the designer then continues to operate until they change that world. Some creativity methods are formal and others informal, in the sense that they are used unconsciously. Typical creativity methods employed by designers include: brainstorming, morphological analysis, synectics, back to first principles, analogy, mutation, inversion, and TRIZ (the acronym for a formalized method, developed in Russia, for invoking physical principles that can be used to produce creative solutions). All these methods are concerned with introducing new variables and hence changing the design world within which the designer is designing.

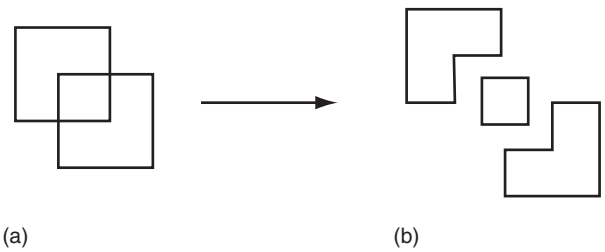

Figure 5 Example of a substitutive change: two overlapping squares (a) are replaced by two L-shapes and a smaller square (b).

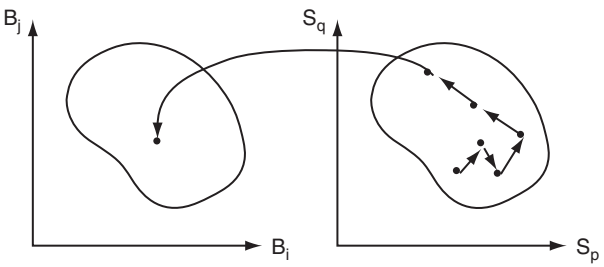

Figure 6 Search within a design world.

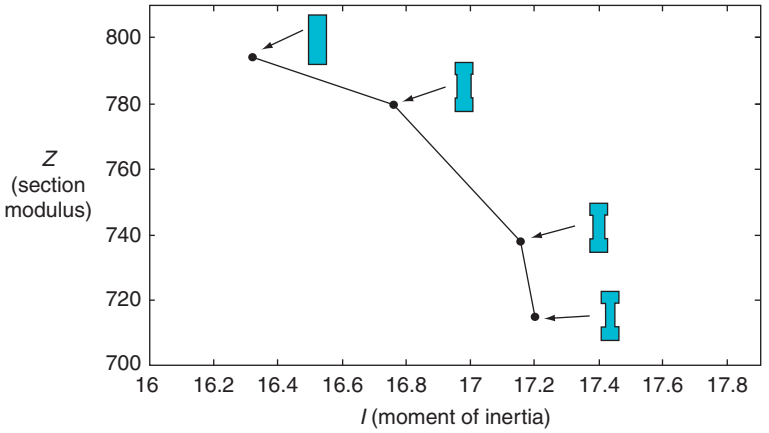

Figure 7 Example of search within a design world: optimizing the cross-section of a beam.

Creativity in Designers

Creativity can be located in individual designers or teams of designers, whose creative designs have led to innovations that have been exceptionally successful. In many cases, these designs spawn new classes of artifacts. For example, the first ballpoint pen spawned a whole new class of ballpoint pens that vary in form but use the same underlying design concepts. The creativity in this design certainly reflects back onto its original designer, Laszlo Biro. In fact, his surname has been used in many countries as a generic term for all ballpoint pens.

Once designers have gained a reputation of being creative, any subsequent design from the same designers is likely to be seen as creative even though its degree of novelty is relatively low. This is because the designers' names suffice to produce expectations of creativity without the need for objective assessment. Many examples can be found in the world of fashion design, where expectations of designers' creativity are based more on the designers' (or brands') names than on the actual designs. These names can be thought of as representative for certain styles of design creativity.

The close connection between a designer's reputation and successful design innovation is one of the reasons why most designers strive to be creative all the time. It also underpins the widely held view that designers belong to the 'creative professions.'

Creativity in Users

Creativity can be located in individual users or groups of users that discover new ways of using existing artifacts for new purposes. There are often adoption effects among users with similar needs and goals, leading to wider spread of the new use of a design. The pioneers of this process may then gain a reputation of being creative, depending on their visibility among peers. The 'wobble board' mentioned earlier in this article is an example of a new way of using an existing design, and many people would agree that its inventor, a popular musician, was creative.

Similar to the creativity in designers, the reputation of being a creative user often lasts for a long time, even when no more creative use is demonstrated by that user. However, these users are often accepted as opinion leaders for assessing creativity or adopting creative designs, as their own choices of using designs influences their peers' choices.

Many creative users may never gain such a widespread reputation. For example, the skateboard was reportedly invented by children that experimented with different uses of a scooter whose handles had fallen off. This is a form of serendipitous design creativity.

Interactions in Design Creativity

There are three primary interactions in design creativity; they are in the sociotechnical environment of designers, designs, and users, as shown in Figure 8:

1. Interactions between designers and their designs
2. Interactions between users and designs
3. Interactions between designers and users.

Interactions Between Designers and Their Designs

Designing is an activity during which designers perform actions to change their current designs. By observing and interpreting the results of their actions, they then decide on new actions to be executed on the design. The designers' situations may change according to what they are 'seeing,' which itself is a function of what they have done. The design researcher Donald Schön has coined the phrase 'interaction of making and seeing' to describe this phenomenon. The interaction between designers and their designs is one of the fundamental acts that can lead to creativity because it can lead to the generation of new design worlds. Because of this interaction design creativity is not predictable.

One of the processes that result from this interaction is emergence, a process that makes implicit properties of a design explicit. Implicit properties are those that are not intentional. An example of this process is shown in Figure 5. Emergent properties often include visual forms and their potential consequences. They are based on the fact that producing designs, by means of sketching or modeling, necessarily imposes organization and detail on the design, not all of which are specifically intended by the designer. For example, sketching components of a design on a piece of paper produces a set of lines that compose shapes with intended spatial relations.

Other spatial relations emerge when the designer inspects the sketch at a later point in time.

Take the layout of a set of buildings produced by an urban designer, shown in Figure 9(a). At the initial time of drawing the layout, the designer attends to the four buildings individually. Upon inspection of the layout, the designer becomes aware of a horizontal axis and an urban space between two buildings, as shown in Figure 9(b). These features are spatial relations that were implicit in the initial design but are now made explicit. Figure 9(c) shows how the designer subsequently changes the design of an individual building to more directly produce an urban space.

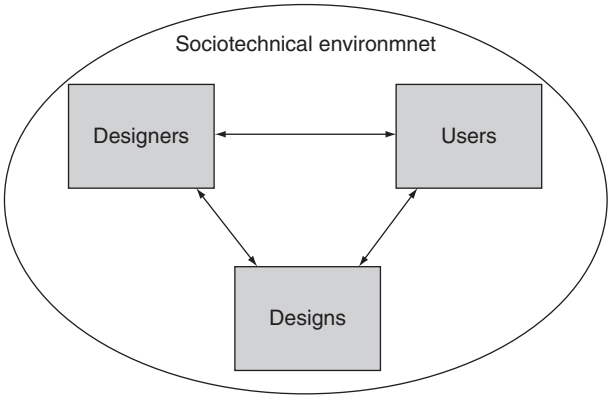

Figure 8 Interactions in the sociotechnical environment formed by designers, designs, and users.

Emergence is well known in the art world, as is its role of driving creativity. For example, in his description of Leonardo da Vinci's creative process, the art historian Ernst Gombrich stated that "in searching for a new solution Leonardo projected new meanings into the forms he saw in his old discarded sketches."

Interactions Between Users and Designs

Users interact with designs in various ways based on their current situation. These interactions are visible mostly as the users' actions aimed at using the design. Similar to designers' interaction with their designs, users observe and interpret the results of their actions, to decide on subsequent actions. This changes their situation that can affect their view of the design and consequently any further interactions. A creative use can be the result of these changes.

Most creativity driven by the interaction between users and designs is related to function and behavior.

New function can arise as a result of changes in a user's goals and needs. Some of these goals and needs arise dynamically from the unique circumstances of an individual user. For example, using a screwdriver as a weapon introduces the new function 'injure someone.' This function may arise from a user's sudden need for self defense.

New behaviors can arise as a result of changes of the artifact's environment that were either accidental or intended for different purposes. For example, a user may accidentally drop a timber slab into water. By observing it floating on the water's surface, the user realizes a new behavior, 'buoyancy.' The user

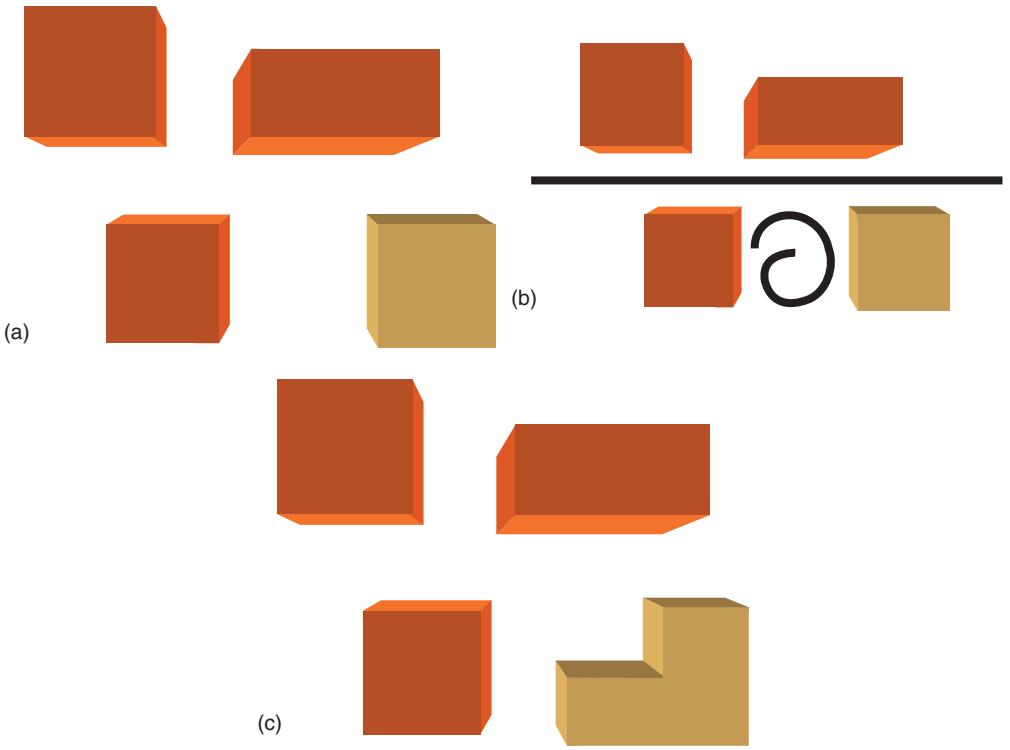

Figure 9 A sequence of sketches of a town layout: (a) the initial layout, (b) the same layout highlighting an emergent urban space and horizontal axis, and (c) subsequent change of the design as a consequence of the emergent urban space.

may explore further possible behaviors by grasping, pushing, or pulling it. This produces a new 'floating' behavior, which the user may find useful for activities such as transporting objects.

New structure can arise as a result of changes of the artifact itself, occurring either accidentally or for different purposes. The skateboard mentioned earlier was an instance of an accidental change of structure. The children found this changed structure useful after they explored new ways of interacting with it.

Interactions Between Designers and Users

Designers and users interact in two ways: directly, and indirectly via the market.

- Direct interaction includes all forms of design-related communication between designers and users. The communication from designers to users includes the designs, instructions of use, and marketing campaigns. The communication from users to designers is via studies of focus groups and general customer feedback.
- Indirect interaction via the market includes all other forms of communication and the interpretation and analysis of market data. The most common form of indirect interaction is the influence of indicators of market success on both designers and users. These indicators may be market share, sales figures or other metrics. Creative designs that are successful on the market will affect expectations of what future creative designs are produced by designers and adopted by users.

Both direct and indirect interactions between designers and users generate new situations that can lead to novel designs. Situations can change in designers and users. Their interconnection allows propagating changes from one individual to another.

Conclusions

Just as designing is multifaceted, so too design creativity has multiple facets. The creativity can be in the design or artifact, in the designer or in the user. Equally it can be in the interactions of the designer with their developing design, in the interaction of the user with the design or with the user with the designer. Most commonly it is in the interactions between the designer and the developing design. It is here where most design creativity support tools are targeted.

The examples in this entry have been mainly about physical artifacts, however, virtual artifacts are no different and much of design creativity is increasingly focused on them as designing is applied to manufacturing processes, business processes, government processes, and research processes.

Creative designs can be thought of as Lamarckian evolution rather than Darwinian evolution in that the attributes of a creative design change all the designs that follow it. It matches Schumpeter's notion of 'creative destruction' as a descriptor of innovation.

Creative designs change our expectations of future designs by changing our perceptions through changing our value systems.

See also: Architecture; Creative Products.

Further Reading

Corne DW and Bentley PJ (eds.) (2001) *Creative Evolutionary Systems*. San Mateo, CA: Morgan Kaufmann.
Dasgupta S (2008) *Creativity in Invention and Design*. Cambridge: Cambridge University Press.
Eastman C, Newsletter W, and McCracken M (eds.) (2001) *Design Knowing and Learning: Cognition in Design Education*. New York: Elsevier.
Fischer G, Scharff E, and Ye Y (2004) Fostering social creativity by increasing social capital. In: Huysman M and Wulf V (eds.) *Social Capital and Information Technology*, pp. 355–399. Cambridge: MIT.
Gero JS (2000) Computational models of innovative and creative design processes. *Technological Forecasting and Social Change* 64: 183–196.
Gero JS (ed.) (2010) *Studying Design Creativity*. Dordrecht: Springer.
Gero JS and Kannengiesser U (2004) The situated function–behaviour–structure framework. *Design Studies* 25(4): 373–391.
Goldschmidt G and Tatsa D (2005) How good are good ideas? Correlates of design creativity. *Design Studies* 26(6): 593–611.
Gupta MS (2003) *Psychology of Engineering Creativity*. Miami: Osmo Publishing.
Leon-Rovira N (ed.) (2007) *Trends in Computer-Aided Innovation*. Berlin: Springer.
Marzano S (ed.) (2005) *Past Tense, Future Sense: Competing with Creativity: 80 Years of Design at Philips*. Amsterdam: BIS.
Sosa R and Gero JS (2005) A computational study of creativity in design. *AIEDAM* 19(4): 229–244.
Stiny G (2006) *Shape: Talking About Seeing and Doing*. Cambridge: MIT.

Relevant Website

http://www.jaist.ac.jp/ks/labs/nagai/DesignCreativity/index.html – Special Interest Group - Design Creativity.