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changing connections

the role of connections in products between traditional and new technologies

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Abstract

It is the connections between parts and elements that form the products and product systems that surround us. Despite the more common attention towards the parts, it is increasingly the way in which all these parts are connected, the modality and characteristics of these links that determines to a large extent the overall quality of a product. In fact, looking closely, there is an extraordinarily rich variety of ways in which parts and objects can be joined and which have reached high degrees of maturity.

Now, how do recent technological innovations, in fields such as digital technologies, sensor systems, wireless data transmission or nanotechnologies, open up new perspectives for the design of connections that compose products? How can industrial design make the best use of these technologies in connecting parts and products to form meaningful wholes for today's requirements?

This research investigates how the analysis of traditional product connections can contribute to the design of new forms of joining in which the potential of new technologies can be best harnessed. A first methodological step has been to single out factors which assume relevance both in traditional connections as well as novel typologies that are viable on the basis of recent technology developments. This approach has proven a fruitful strategy to reveal and understand change, describing the role each of six factors plays in traditional and existing connection types and subsequently developing them into thematic chapters of this thesis which thus relate to: *responsiveness*, *compatibility*, *articulation*, *seamlessness*, *reversibility* and *scale*.

The aspects of connections related to these factors are then analyzed, in reference to the range of product connections contained within four classes of joining typologies that have been established around increasing levels of interaction between material and immaterial elements such as digital information and which are *physical connections*, *connecting digital information to objects*, *connecting objects through digital information exchange*, and *patterns of connections*.

Having identified these basic and fundamental factors and classes of reference it is shown how the role of these factors changes in light of new technologies linked to how parts and objects are joined.

Furthermore it is through the analysis of traditional connections that weaknesses of new ways of joining are identified and approaches to address these are formulated, disclosing at best the potential of new technologies and suggesting new horizons for the design of connections.

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1. Industrial design, innovation and connections

1.1 Why connect?

Following Charles Eames in claiming “The connections, the connections, the connections […]. It will in the end be these details that give the product its life” (Eames, Eames, & Caplan, 1976), the objective of this research is to better understand the relevance of connections between parts in determining the overall quality of products and their changing role in the light of technological innovation.

Observing the artifacts that surround us it is difficult to spot an object that does not consist in at least one connection. Most products are formed by multiple, connected parts that consist in components which in turn are made up of different materials composed by their molecular structure.

Shaping these objects, the designer chooses how to subdivide an object into its constituting elements and how to characterize the connections at different scales, determining by this to a significant degree the quality of the whole. Choosing how to connect the elements, join components and parts, materials and information and modalities of usage in designing them are amongst the most important decisions a designer is involved in. Even more so since they imply further consequences and repercussions within the design process and determine the dynamics in which a product can enter at a later point.

During all of history, man has generated an enormous amount and richness of different modalities of joining parts, each with very distinct characteristics and behaviors, beneficial to specific requirements of making parts meet. Some of these connections are linked to the materials they join, others are based on the motion of parts they allow while others still emerged in specific use scenarios and contexts of application.

The prehistoric wedge consisted in one single element but "ever since early man first figured out how to attach a spearhead to a tree limb, assembly has been one of mankind's principal endeavors. Quality became an issue the first time a spearhead came off a hunter's shaft in the middle of a struggle" (Rotheiser, 2004, p. XXXVIII).

Industrial design lies at the intersection between social dynamics into which products, that result from its activity, are introduced on one side, and technical or technological innovations on the other side. Today we find ourselves confronted with a panorama of highly complex products for both the competences that contribute to their formation as well as the multitude of parts and connections they are composed of. Recent innovations such as those in the field of digital technologies, sensor systems, wireless transmission of digital data or nanotechnologies do not only determine the form of products as a whole but do also impact the way parts of the product, its components or different products relate to each other, the user and their environment.

The growing possibility of integrating these technologies into an increasing number of product typologies and the subsequent fusion between material and immaterial elements within one single product, together with technologies that allow for the transmission of data without requiring physical contact between parts, have altered basic assumptions of what we call *connections*.

New fabrication methods enable both the creation of complex shapes not possible before and capsize a past truth according to which producing many identical parts would be in any case advantageous compared to multiple unique components. Finally, in an increasing number of cases technological and material innovation reaches the domain of industrial design directly from scientific research. Take for instance nanotechnology: it is in the laboratories that fundamental characteristics of the generated material's qualities are determined by means of manipulation on the nanometric scale for which it is already at this stage that the collaboration with design needs to take place.

A characteristic these developments have in common is the rapidness with which they occur. At the center of attention are not anymore individual inventions that lead to a changed but temporarily stable context. Today it is an accelerating flow of innovative passages that occur in parallel and in distinct fields, and the transversal dynamics between them, that connotate the circumstance into which products to be designed are introduced and, through social interactions, disclose their potential.

In this context, the research question of this thesis is how the role of connections in products changes with the introduction of new technologies and, if and how the analysis of the wealth of traditional methods of joining elements and objects can contribute to the development of new types of connections. Understanding fully the way in which the role of connections changes with the introduction of new technologies will enable the designer to design innovative products that harness in all respects the potential of these innovations and to make effective use of the parts that form the products which surround us.

To reveal and understand change, elements connotated by a higher degree of permanence and stability are required to relate to. A first methodological step in this research has thus been to single out factors which assume relevance both in traditional connections and novel typologies that are viable on the basis of recent technology developments.

For this purpose, starting the selection of the collected material for this research and devising a method for accurate analysis, I have cross-related critical aspects of connections with core concerns of the design discipline such as the interaction between user, product and environmental aspects; the composition, making and interplay of product parts; a comprehensive view on the design process and the actors involved; dynamics of innovation; and handling of the life cycle of products. This has lead me to extrapolate the following principal factors:

- *Responsiveness*

  or the ways in which connections communicate to the user or to other parts of a product system aspects about their character, their state or the process that involves them.

- *Compatibility*

  or all aspects linked to what determines a good fit between parts and in what ways this might be beneficial or not.

- *Articulation*

  or the schematic structure which makes of a connection in terms of what parts are involved and what are their roles in connecting elements.

- *Seamlessness*

  or the fascination with making connections that are less perceivable and apparent.

- *Reversibility*

  or the time related dynamics that involve parts to connect and disconnect in specific intervals and occasions.

- *Scale*

  or the different magnitudes and measures that are involved in connecting parts, be it at levels of size or number of elements.

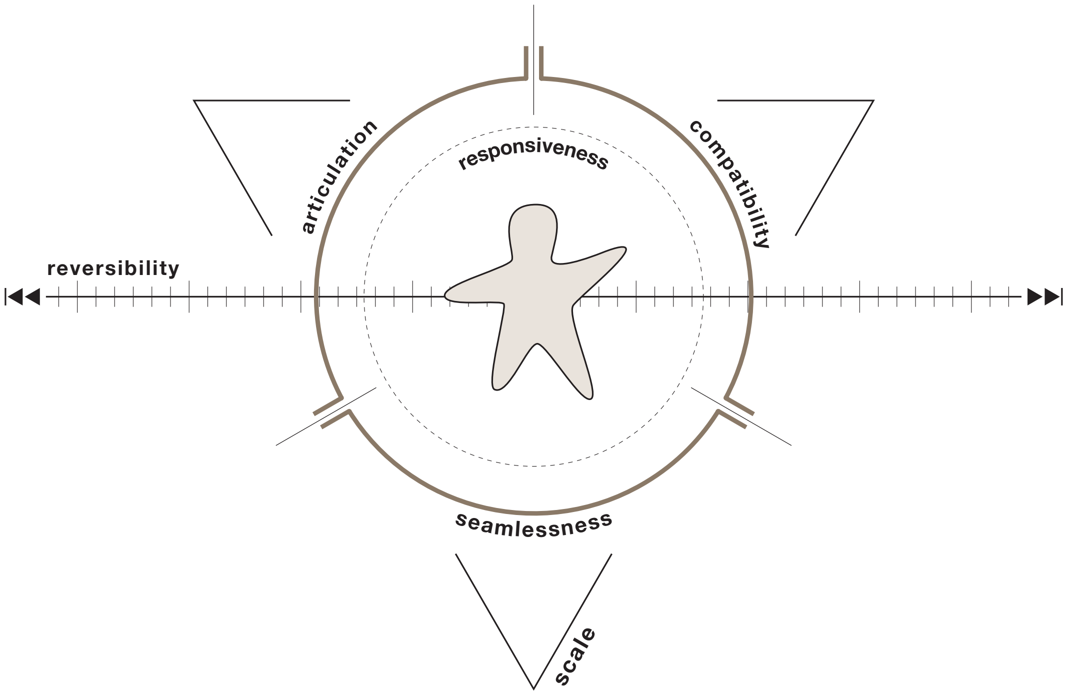


Figure 1.1: Six factors, identified as the basis of a methodological approach to the analysis of the changing roles of connections in products and new contributions from the design process

These factors have each been subsequently developed into a thematic part of this thesis. In this way they become analytical and critical tools with which to examine existing connections of different kinds. Furthermore, I have employed these six factors as filters to reflect change, to understand and describe the role which each of them plays in traditional and existing connection types and to decipher in what way this role remains intact, adapts or disappears when specific technologies are introduced in connecting modalities and how, on that basis, new design approaches can be formulated.

1.2 What to connect?

Connecting has a manifold relevance to industrial design: the discipline's objective of generating ideas to solve new problems involves "connecting previously unrelated dimensions of experience [...]" (Koestler, 1971) in a creative process. Planning and conceiving products implies the assembly of parts and components while design's role as a communicator and translator between different contexts such as manufacture and product use attributes it a mediating position in the process of product development.

On the basis of this variety of ways in which the act of connecting plays a role for industrial design three distinct realms of connections can be distinguished:

1. The actual connection between elements, both of material and immaterial nature
2. The creative thought process in terms of establishing novel connections between existing knowledge to generate a new idea
3. Metaphoric connections in the process of designing objects and as part of product semantics

Out of these three realms, the first one can be seen as a core of the design discipline since it regards the foremost outcome of the design activity, the conception of artifacts, for which it is given particular attention.

In considering the design of connections between parts and products in association with technological innovation, in recent years particularly relevant developments have occurred in those technologies involved in the generation, processing and transmission of data and information.

> "It is becoming increasingly obvious that information is, in important ways, material, and matter is informational. From this expanded point of view, neither information nor materiality is what it seems to be when it is interpreted in simple oppositional terms. Thus, the movement into the Information Age should not be conceived in terms of growing abstraction and increasing dematerialization, but as the complication of the relation between information and the so-called material conditions of life." (Taylor, 2001)

In the case of connections of physical contact, a link is established by means of a mechanism or a manual intervention and in any case by way of material interaction. As however this domain has been widened, also an inquiry wanting to address the topic of connections ought to broaden its view and consider at an equal level such new forms of immaterial connectivity within products.

What then are the kinds of connections one needs to consider in tackling a question such as this research poses? The connections considered throughout the following chapters and in light of the six factors introduced in the previous section can be structured in four classes according to the presence and exchange of material and immaterial matter:

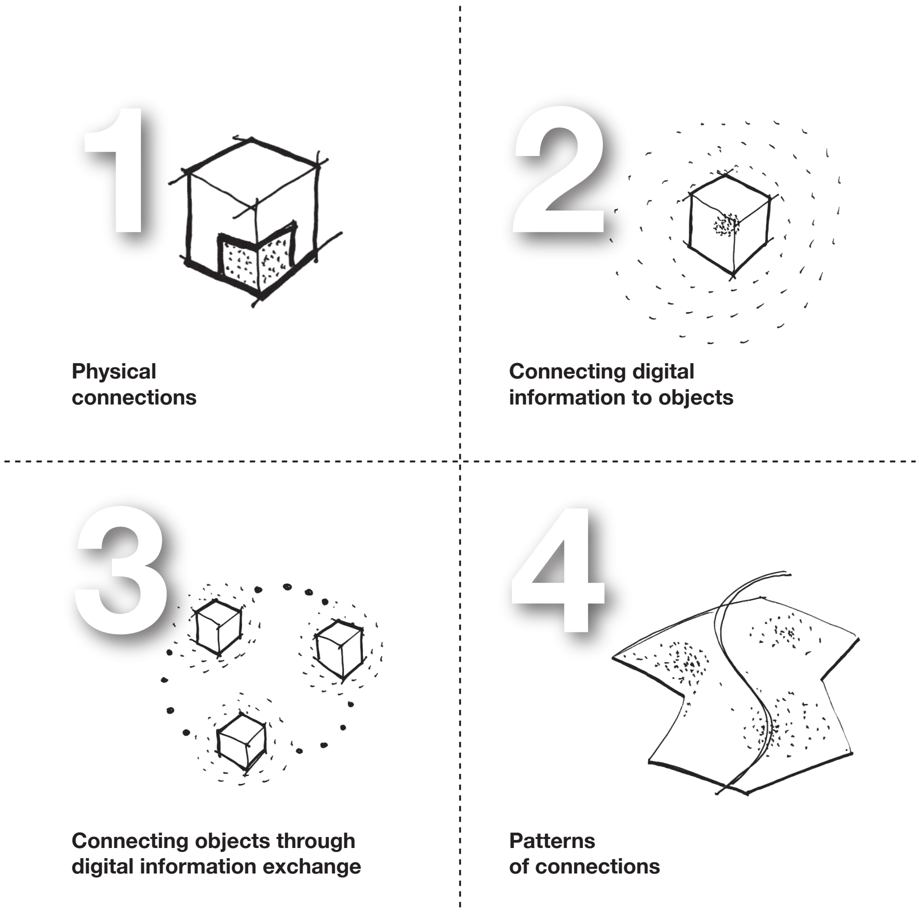


Figure 1.2: Division of product connections into four classes, addressed in this research regarding their changing dynamic in view of technological innovation

1. *Physical connections*

   This class comprises the wealth of traditional physical connections. Links between parts of different materials joined by connectors that attribute different qualities to the whole in terms of degrees of freedom, movement and endurance.

   There are different ways to distinguish connections of this class, some of which are based on the type of joining method in terms of mechanical, chemical or physical processes. Another approach subdivides physical connections according to the materials involved such as wood, metal, plastics or ceramics.

   Traditional connections are the starting point for this research. Their analysis investigates both their potential contribution to the design of new modalities of joining and opportunities for applications of recent technological innovations in their composition and functioning.

2. *Connecting digital information to objects*

   This second class of connections considers product connections between physical parts and elements of digital information. With the development of the microprocessor in the early 1970's a whole new perspective opened up of products that have digital components embedded. Sensors are capable of perceiving a multitude of parameters regarding the context in which a product is used and the way it is maneuvered by the user while microprocessors can process this data to trigger outputs in the form of modified product behavior or appearance in front of the user, both creating effectively dynamic links between the user, the product and the environment whose effectiveness depends much on the design of these links.

3. *Connecting objects through digital information exchange*

   The generation of digital data and its association with a multitude of objects opens up possibilities of interfacing these objects and parts by way of exchanging that data and information.

   The opening up of the telecommunications standards in the US in the 1970's and 1980's in conjunction with developments of digital computing capabilities have radically transformed the landscape of material culture and more recently lead to the development of wide area networks. Internet is one of these networks which obtained its public face in the form of the world wide web created by then CERN's Tim Berners-Lee in 1989 (before being publicized in 1991).

   This third class of connections embraces product connections in the form of data and information exchange through either physical contact or contactless modalities.

4. *Patterns of connections*

   Ever more typologies of objects are being connected through digital data exchange over large distances between each other and with large networks, and the connections and connective patterns they generate have recently become subject of study in different disciplines. Sensors integrated in an object can give information regarding its specific use and moreover, if all those objects are networked, patterns of connectivity regarding all objects of its kind can be generated.

   After concentrating such efforts within fields of research, the attention has recently shifted to consider patterns connectivity as relevant information for users of products and systems. The ambition is to enable use modalities that are more synchronous with overall system dynamics.

In the following chapters, the aspects of connections related to the six factors previously discussed: responsiveness, compatibility, articulation, seamlessness, reversibility and scale, will be analyzed while keeping as a reference the range of product connections contained within the four classes relating to *physical connections*, *connecting digital information to objects*, *connecting objects through digital information exchange*, and *patterns of connections*.

Having identified these basic and fundamental factors and classes of reference forms the backbone for the study of dynamics involved in traditional connections from different angles and facilitates understanding as to how and in what ways design can tackle the development of novel types of connections disclosing at best the potential of new technologies.

2. Responsiveness

2.1 Recognizing connections

2.1.1 Connections and Gestalt theory

A prime interest to the designer in giving shape to the connections of his products is that these are recognized by the user as such. How does a user understand, that a plug can be fit into a socket, that a screw can be twisted into an appropriate hole or that a zipper may be closed by pulling up the lead? How, in one word, does he become aware that two or more parts he finds in front of him can be put together in a way that produces a combination that makes sense and is of benefit to him.

In studying aspects of human perception, one field of study offers itself particularly to the context of this research: Gestalt theory. When founded by Max Wertheimer in the wake of the 20th century, this theory focuses on how we perceive figures, shapes and generally wholes within an environment that consists of many distinct elements. It is concerned with how parts relate to each other to form larger entities and how these larger entities, or the potential of forming them, is perceived by a person. Furthermore, it has identified shape characteristics in parts that we perceive as fitting together while others that we perceive as odd or wrong if combined together.

Unlike the cognitive sciences[1], Gestalt theory attributes this type of perception of the visual field to the organization of shapes and objects themselves as opposed to cognitive processes such as learning and memory. "La forma è una caratteristica che le esperienze hanno o non hanno. È irriducibile ad altri attributi"[2] (Köhler, 1983).

[1] Cognitive sciences are concerned with the study of thought, learning, and mental organization. One essential questions of this discipline is the reflection concerning: What is intelligence?, and, How is it possible to model it computationally?
The cognitive processes of learning and memorizing related to the recognition of product connections plays an important role in the distinction between expert and non-expert users. In this regard, an increased familiarity with connection configurations consisting in learning and memorizing patterns does certainly influence the way a user recognizes possibilities of connections in a product. However, in following the reasoning of Gestaltists, also such learning experience and subsequent knowledge of a connection is based at first on the phenomenological aspect linked to how a user perceives parts in his environment. Even if a connection is recognized on the basis of a past experience, in that past experience or at least in one past experience, an original perception must have given rise to cognitive processes thereafter. Since such an original experience is thus linked to a direct confrontation with a product's parts involved in a connection, it is this type of interaction which has a particular significance for the industrial designer, since he is involved in giving shape to these parts.
For this reason, I have decided to focus on the Gestalt theory's approach for this part of my study even if recognizing that cognitive processes do certainly play a role in the recognition of connections as well.

[2] Translation: "Form is a characteristic that experiences have or do not have. It is not reducible to other attributes".

Gestalt theory concentrates on the phenomenological aspects of perception, that is how objects manifest themselves in front of a person more than how cognitive processes elaborate sensorial stimuli.

> […] despite substantial advances in our understanding of the structural, functional, and computational properties of the brain, the study of perceptual phenomena remains the most solid basis for sensory physiology and for the understanding of why we see the way we do. (Spillmann, 2006, p. VII)

The way shapes are perceived in our environment depends on the inner organization of the factors that make up these shapes. This inner organization of the visual field happens by large without the involvement of the observer and it is described by Gestalt theory with the German term "Prägnanz" which can be translated in terms of expressing in concise ways a high degree of content and meaning. Metzger describes forms that represent *Prägnanz* as those containing a certain lawfulness, autonomy, integrity and simplicity and in various examples Gestalt theory illustrates specific laws that can be identified in the presence of perceivable forms in different contexts.

> [Wolfgang Metzger] states that the factors governing visual perception are inherent in the visual system. Although his book contains several examples of the influence of experience on vision, the majority demonstrate that the organization of the visual field occurs essentially without our involvement. Metzger therefore calls the Gestalt laws *natural laws*. (Ibid.)

For all these aspects, Gestalt theory is of particular interest when trying to understand how a user can recognize the possibility of connecting parts to form a meaningful combination. Following are some of these laws which are of particular interest to this study and which I elaborated as examples for the recognition of connections in our environment.

2.1.2 Shape complementarity and law of closure

An observation that suggests to a user that a connection is present in his environment, and that can be linked to Gestalt laws, is that when two parts complement each other in their shape geometry. Wertheim's "wo es fehlt und paßt"[3] summarizes in a concise way the situation in which something is missing so that we want to add it to complete the shape and suggests to make the user fit one object to another in a way that fits well.

Now, how to create a satisfying whole? Being presented a situation where "das 'Überschießende' wegzunehmen und es dorthin zu bringen, wo es 'fehle' und 'paßt', so daß im Hinblick auf die Herstellung eines 'einheitlichen' Aufbaues zwei Fliegen mit einer Klappe gescschla-

[3] Translation: "where it is missing and where it fits".

gen werden"[4] (Metzger, 1975, p. 214), children in exercises and also most of us feel tempted and motivated to "putt it right" and to complete a whole that makes sense in a "proper" way.

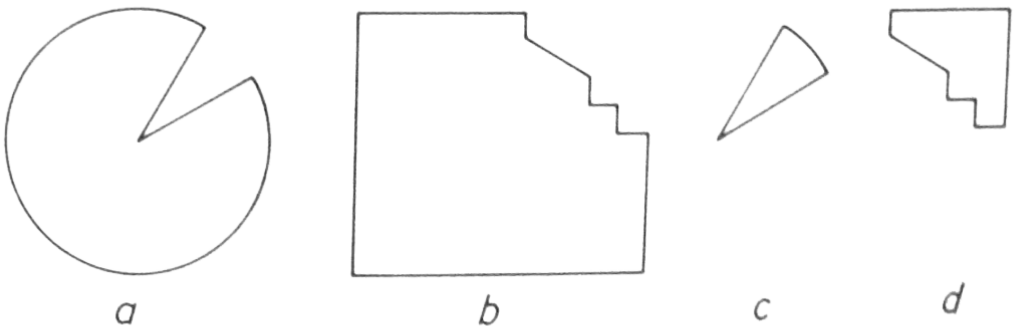


Figure 2.1: Exercises reproduced in (Metzger, 1975, p. 213) concerning the tendency to put things right when seeing two parts that fit well together. These exercises were carried out by children

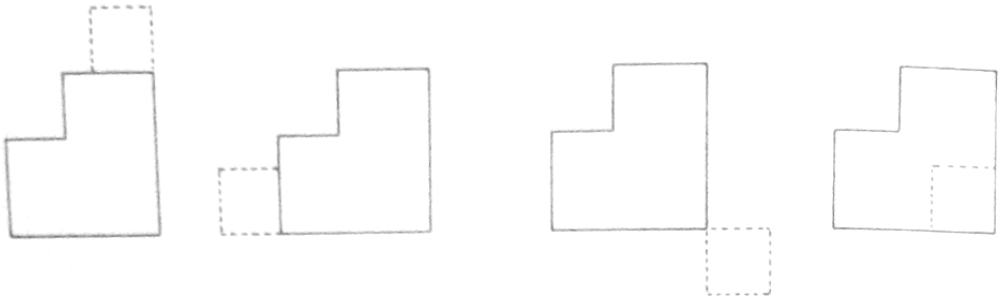


Figure 2.2: Exercises reproduced in (Metzger, 1975, p. 214) regarding the tendency to put parts into "proper" positions of a whole. These exercises were carried out by children

Not only is it the geometrical correspondence of the zones of connecting elements directly at contact with each other that suggest that they fit together. It is also the coherence of the overall form character of the elements that influences our tendency to combine them as is illustrated in Figure 2.3.

[4] Translation: "taking away the redundant and putting it there where it lacks and fits so that, in the consideration of creating a unified structure, two goals are reached in one move"

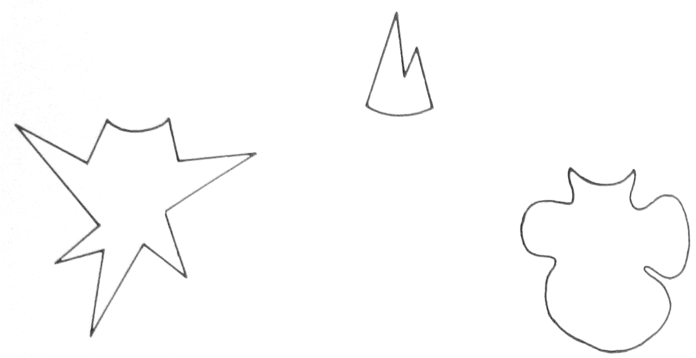


Figure 2.3: Coherence of Gestalt character in choosing which of the two side parts fit to the central part. Illustration from (Metzger, 1975, p. 216)

A classic example for such shape complementarity that suggests a user involvement in bringing parts together is the geometric puzzle game. By the careful structuring of the different puzzle parts the designer in one way facilitates the player in understanding that parts go together while communicating clearly impossible situations (edge pieces, corner pieces, central pieces). At the same time he introduces difficulty by making connections appear congruent which in fact are only similar and by this inducing the player towards a playful trial and error approach.

Figure 2.4: A classic example for shape complementarity that suggests to a user that parts can be brought together to form a meaningful combination is the geometric puzzle game

Further examples of connections that, in terms of user feedback, work by shape complementarity are found in two ways of closing bottles of water or other beverages.

The circumstance, that many people try closing a screw cap by turning it the wrong way around might suggest, that while the possibility of connection is easily perceived, the shape does in fact not express sufficiently well the way in which this connection works. Or better, the twisting process is clear but the critical distinction of direction is not evident in the product itself. Situations that see users in difficulty when trying to understand the direction in which to turn the screw cap can be commonly observed when the cap is either completely stuck or when it does not seem to attach to the thread. The tendency in such situations, trying to twist the cap in the opposite direction, indicates clearly that the process follows rather a trial and error approach than a clearly perceived connecting modality that is inherent in the object.

Figure 2.5: Different screw caps as an example of a connection that works and is perceived by the user for its shape complementarity. However the direction of twisting is often misunderstood.

The second way of closing bottles is that which makes use of the crown cap. The crown cork or crown cap is said to have been the first disposable product in history, invented by William Painter in 1891 and inspiring as such King C. Gillette in inventing the disposable razor while he was working as a salesman for the Crown Cork Company (McKibben, 1997, p. 8). The story of this invention is intriguing and I will refer to the subsequent dynamics between Painter and Gillette that lead to the development of the safety razor blade on page 60 in the context of compatibility of connections.

The way that the crown cork serves as an example case at this point is in the form of its most recent modification. Recently, a version of this disposable product has been released in the United States which changes, without apparent traces, its very core characteristic: the one way disposability. Instead, and not recognizable when attached, it contains a screw thread inside and is in fact more of a screw cap than a traditional crown cap and can as such be resealed for multiple usage. The fact, that by experience we know how to open a crown cap by bending it open, not perceiving the characteristic of this new version in being a screw cap, leads the users to ruining just that very innovative addition. Bending open the screw thread in fact destroys its ability to be resealed.

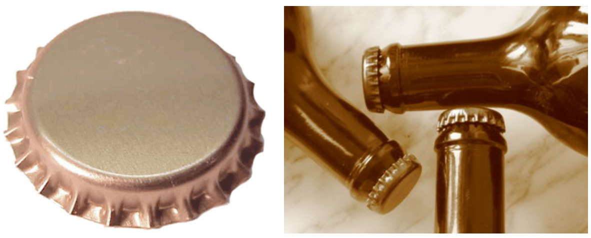


Figure 2.6: Examples of William Painter's crown cap on the left and its latest modification containing a re-sealable screw mechanism inside which would allow to reseal a bottle. Not recognizing this new capability, a user tends to bend open the cap as with traditional crown caps, effectively ruining the screw mechanism.

A last example concerning how shape complementarity contributes to the recognition of connections in our environment I want to analyze in detail the user interaction with the following more complex product system.

As illustrated in figure 2.7, the connection process between the ticket and the ticket stamper works on the basis of a ticket of specific size that fits into an equally sized slot on the ticket stamper. The meaningfulness of this correspondence, or the *Prägnanz*, of this system's *Gestalt* becomes apparent when observing a modification in this product system's characteristics that has occurred in Italian railway stations several years ago and which I will outline in a moment.

Figure 2.7: Image showing a connection that is being established between a ticket and a ticket stamper in the process of stamping

First however, in order to better understand this, I want to analyze in its entirety the *Gestalt* of the interaction process between a user that wants to stamp his ticket, the ticket and the ticket stamper:

1. Holding a ticket in his hand, a user becomes aware of the ticket stamper in most cases because of its signal color (orange or red in many cases) that stands out in its surrounding environment.
2. Having arrived in front of the stamper itself, the user perceives a correspondence of the ticket and the slot of the stamper which is emphasized by a wedge like opening that widens towards the stampers surface so as to facilitate the introduction of the paper ticket.
3. Attracted in this way, as soon as the ticket is being introduced, the well-fitting slot functions as a mechanical guide communicating back to the user that in fact, the connection he is about to establish is a correct one signaling he is on a promising

way in terms of his goal of stamping the ticket (consider how the case in which a ticket is too large or gets blocked when inserted in the slot would suggest that I am attempting to insert a wrong ticket into the ticket stamper).

4. Proceeding with the introduction of the ticket, a moment later the user feels that the ticket can be no further inserted which indicates that the ticket has reached its final position.
5. A fraction later the user hears the sound of the stamp that prints a code onto the paper ticket which also signals that it is now possible to extract the ticket.
6. While extracting the ticket, even without controlling the code itself, a change of its graphical surface structure inflicted by the printed code tells that the stamping of the ticket has worked successfully.

A few years ago, this product system comprised of the paper ticket and the ticket stamper has been modified only by one small change which however altered the above process to a great extend as shall be seen. What happened was that besides the adequately sized large tickets, the new ticket stampers, in their same slot, accommodated also a much smaller ticket type used for regional transport distances only. Users approaching these ticket stampers with narrow tickets have an immediate doubt whether to insert or not the ticket because of the absent shape complementarity between ticket and slot.

Uncertainty arises over the side of the slot where to insert the ticket in order for the stamp to hit the ticket properly. Perceiving a non-correspondence in one dimension, a doubt about the second dimension arises instinctively as to how deep to insert the ticket and whether there too will be a perceivable stop in that direction. Lastly, even when hearing the ticket stamp, the user cannot be sure whether the stamp has hit the ticket due to the above doubt concerning the ticket's position in the slot in the first place.

Figure 2.8: Ticket stampers at Italian railway stations enabled to handle tickets of different sizes. Difficulty in user feedback arises as to what side of the larger slot to insert some of the smaller sized tickets. At a later point, adhesives were applied to the machines trying to help users to position the ticket properly in order for it to be stamped.

What I want to show with this example is how many physical elements and interactions are involved in connecting one object (the ticket) with another one (the ticket stamper) and moreover how critical they are in determining an overall sequence of mostly not considered user feedback during the connecting process. That these feedback clues remain unnoticed can be deduced from how easily they are missed out in product modifications as the one outline above and also in those triggered by technological innovation.

One such case of technology innovation linked to our example case of the ticket stamper consists in the transition towards the use of contactless RFID technology in ticketing systems.

Figure 2.9: imob ticket stamper, smart card ticket readers

In many cities recently RFID enabled smart cards have substituted the traditional paper ticket, doing away with shape constraints such as those present in the paper ticket stamper (slot, stamp, stamp sound and vibration). Together with these restraints, also the subtle feedback elements of user guidance, which I have outlined above, have been lost.

The liberty of not being constraint to shape complementarity in physical terms has also lead to a break in terms of user guidance, causing that even though the physical gesture might be simpler, it is now part of a cognitive process that requires learning and remembering as to how the process of connecting ticket and ticket reader works in order to understand and executing this now virtual process of stamping the ticket.

2.1.3 Similarity and proximity

A second Gestalt law of interest to the analysis of how to recognize elements that can be joined relates to the similarity and proximity of parts that form a whole.

In (Köhler, 1983) we find the description of a number of experiments undertaken with birds following attempts to understand how in a group of congruent objects one object can be marked as "special" or "odd one out" by positioning it in a way that breaks with the regularity of spaces between the other objects or which sets it at an odd position in relation to a larger shape (a circle or oval in this case) created by the other objects (see figure 2.10). These experiments underline how meaning is contained within the organization of elements in that they create larger wholes that can be perceived even without or prior to cognitive processes such as learning or memory.

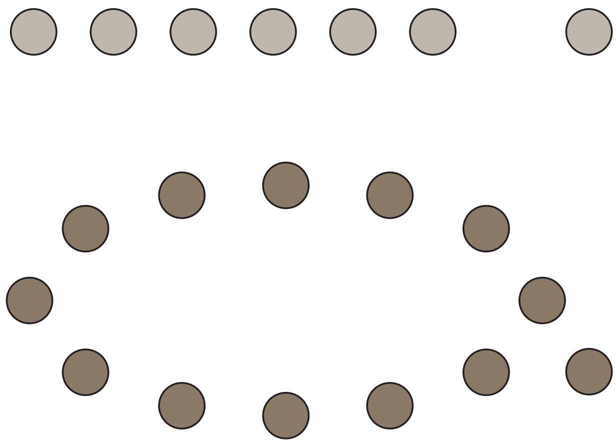


Figure 2.10: "Odd one out" shapes, circles in line and in oval shape, Köhler

This circumstance can be used to emphasize elements of an object that the user can interact with to connect or disconnect parts. It can also be used in the opposite way in terms of concealing connecting elements from the user that he ought not interact with by integrating them within what will be perceived as a larger *Gestalt*.

As an example, we can imagine a ring of recessed circles in a product of which only some contain mounting screws while the others serve the purpose of concealing the screws' location within the larger shape of a hole-circle.

Such a design technique con prove beneficial in situations in which connections need to be protected from inappropriate usage by users, in contexts where such disconnection would put the user's safety or the product's integrity at risk.

Another possible application of such a situation can be assumed when user interactions at different levels of expertise, such as in the case of beginners or professionals, are to be integrated within the same product. Connecting parts can be arranged in a way so that they are not perceived as such by the beginner since they dissolve within a larger form like the circles in the oval in figure 2.10. A professional user instead would know about the presence of connections within that larger figure by way of a learning processes and thus be able to operate them appropriately.

2.1.4 Affordance and connecting

Gestaltists put their focus on the fact that the value of objects and elements is intrinsic to them and that it is perceived directly in terms of organization of the elements rather than through a cognitive process. On this basis and specifically on Koffka's elaboration of it, James J. Gibson elaborated what he referred to as the *ecology of perception*, emphasizing the coupling between the human or animal and the environment as a mutual relation within which perception occurs. The perspective Gibson developed in the context of this study is a precious link that leads us from looking at the recognition of the connection towards the emphasize on the process of connecting instead.

Koffka described with the term "demand character"[5] a postbox that "invites the mailing of a letter" and the handle that "wants to be grasped, emphasizing how things tell us what to do with them" (Gibson, 1986, p. 138).

Taking up the "demand character" of Koffka, Gibson elaborated his theory of *affordances* which are present in the environment but which exist as such in relation to the observer. For example, a platform or board at knee height has the *affordance* of a seat only on the basis that the knee height is naturally linked to the body size of the observer or user. Gestaltists did in some aspects consider objects in their environment, when Köhler considers the organization of elements on his working desk (Köhler, 1983, p. 95) or in considering the way that objects are circumscribed by continuity of material or color and therefore perceived as wholes within their context of a natural environment (Ibid., p. 108). However it was Gibson that emphasized how "animal and environment form an inseparable couple" (Gibson, 1999, p. 42).

While Koffka's "demand character" of an object is present at the moment that a person manifests a need, Gibson's *affordances* are an integral part of the environment. *Affordances* of something do not change with altered needs of the observer (Ibid., p. 222), "the object offers what it offers, it is what it is", in the words of Gibson.

Affordances can be understood as action possibilities that are physically possible. The example of the postbox describes how Gestaltists understand the value of posting a letter being recognized when seeing a postbox only under the condition that I want to actually post a letter while Gibson prefers attributing to the postbox the *affordance* of inserting a letter that I want to post in the context of finding myself in a community that has a postal system. *Affordances*, for Gibson, are part of a more persistent and stringent relation between people or animals and the environment.

While orthodox psychology describes objects being perceived by way of their properties and qualities, Gibson insists on them being perceived by their *affordances* and therefore as action possibilities instead. In the context of connections, this perspective not only results relevant but does in fact support Gibson's claim in the sense that recognizing the presence of a potential connection means recognizing how this connection works. It is the process of connecting and its modality or, its *affordance*, that is being recognized.

[5] Koffka in this further developed the term *Aufforderungscharakter* or *invitation character* earlier coined by Kurt Lewin.

2.1.5 Designing recognizable connections

By considering together Gestalt theory's elaborations and Gibson's *affordances* as well as cognitive processes such as learning and memorizing, I suggest to identify three distinct circumstances for the recognition of connections that seem significant to how industrial design contributes in conceiving connecting elements.

1. Connecting elements which contain the *affordance* of being connected can be said as containing implicit instructions perceivable to the user under their presence. Two puzzle pieces are clearly "to be joined" even without any knowledge or further instruction and even independently whether a user does want to join them or not.

2. Connections can be not apparent or intelligible to the user but he possesses knowledge derived from a cognitive process such as learning, that joining two elements generates a whole that is beneficial to his goals.

3. In a third case, the possibility of connection is neither present in the parts as perceivable affordance, neither as user knowledge but comes from a third external source such as a user manual, an instructor or any other element that instructs the user under the presence of multiple elements in how to join them and create a combined entity.

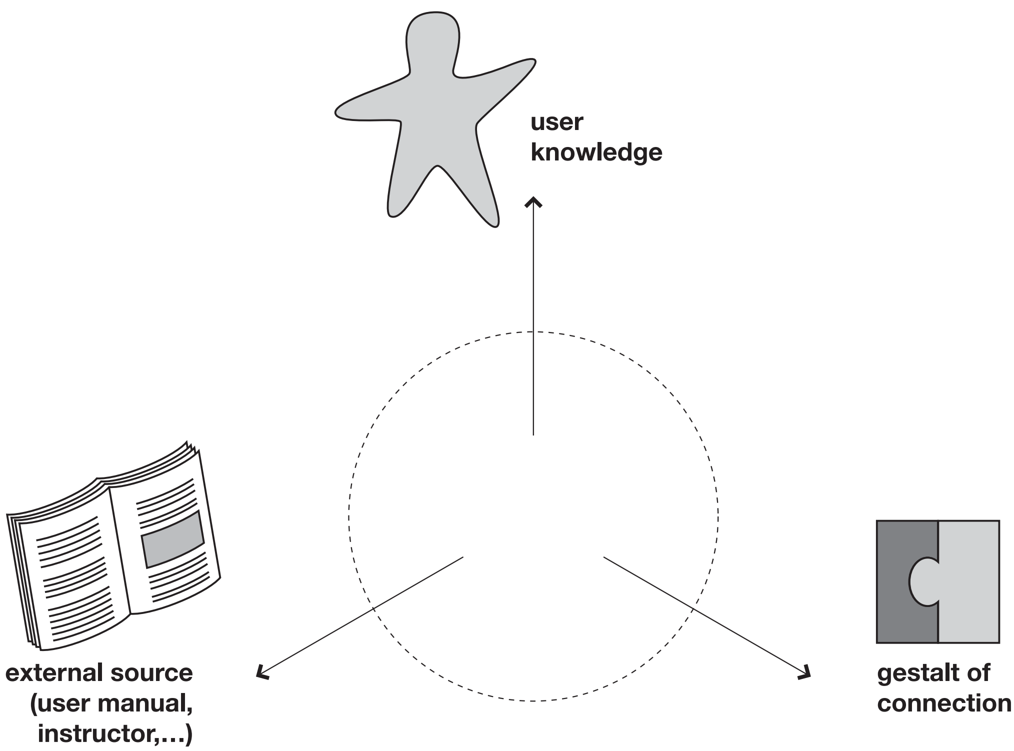


Figure 2.11: Diagram indicating how information about the possibility of joining parts can be present implicitly in the object in terms of affordances, in the form of knowledge obtained by the user through

cognitive processes such as learning and memory or it can be present in an external source such as user manuals or an instructor consulted by the user under the presence of elements to join.

This distinction is useful to consider for an industrial designer when making use of traditional connections but also when designing new types of linkages. Being aware in what ways connecting parts should be recognized in specific contexts and by specific user groups during the interaction with the product, the responsiveness of the parts involved can be emphasized on one or more of these three distinct layers of recognition accordingly.

Linked to this consideration is also the aspect of designing connections that contain implicit use instructions. If the recognition of the modality of linking is part of the involved parts itself, this can effectively substitute for the need of having separate use instructions in the form of a printed manual, online help or the presence of an instructor. This is an important field for design research since it potentially enhances by large extents the effectiveness of connections by avoiding the need for complementary services and products for its function functioning.

In 1988 Donald Norman, who has himself worked together with Gibson, in *The Design of everyday things* introduced the term *affordance* to the design community. While Gibson's interpretation of the term was independent of a user perceiving an *affordance* present in his environment, Norman's way of making use of it was instead linked closely to that aspect. In fact, in, he illustrates:

> When you first see something you have never seen before, how do you know what to do? The answer, I decided, was that the required information was in the world: the appearance of the device could provide the critical clues required for its proper operation (Norman, 1999).

However, he continues to specify that "The designer cares more about what actions the user perceives to be possible than what is true" (Ibid.).

The question of recognizing connections is interesting for the design of objects where connectivity is given by material configuration but it shall be even more interesting to see how this understanding of potential connections in a user's environment can be approached in the context of new material characteristics such as those enabled by molecular manipulation on the nanoscale or new technologies such as digital contactless connections.

In this regard, an author that I want to consider in this context and that based his studies on the work of Gestalt theorists is David Katz. In *The world of touch* he focuses on the aspects of touch and color of objects and identifies *Gestalten* that emerge from these object qualities.

Especially considering the recent developments in products with touch-sensitive surfaces, considering the design of such touch *Gestalten* could be a challenging horizon for industrial design. Certainly, the attention to touch qualities has for long been an aspect of interest to the discipline and in physical objects, touch qualities are always present in some way even if not considered in the product's design. However, new digital technologies do not come with implicit touch characteristics and so they need careful design from scratch in order to be present in novel types of product-user interaction.

2.2 Connecting as a process

2.2.1 Responsiveness while connecting

Introducing the fundamental aspect of how to recognize the presence of a connection it could be seen in the example of the ticket stamper, how this leads seamlessly to considering the process of connection itself in the sense that much like Gibson describes our environment by way of *affordances*, we tend to recognize connections by way of the modality of connecting itself. Further on we have already identified the significance of different stages in the connecting process.

At this point I want to illustrate how physical connections such as screw caps, nails or screws and others by the very nature of their form and structure respond to the user about the act of connecting during that very act. The decreasing distance between the head of a nail or screw and the part's surface indicates visually to the user what point the connecting process has reached and how much more user action is required to complete the process. The screw's resistance gives the user a continuous force feedback indicating the strength of the connection he is establishing in a similar way as the screw cap of a glass container is perceivably "well closed" when the user feels a force feedback against an ongoing turning of the cap.

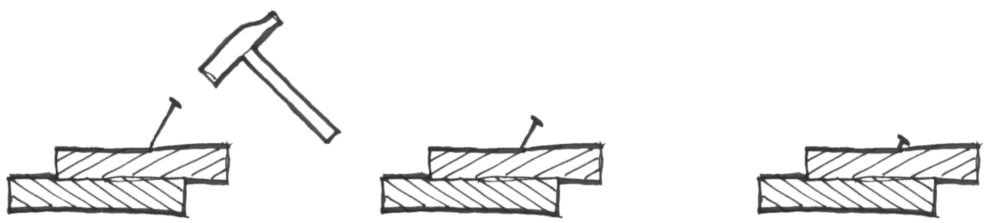


Figure 2.12: The decreasing distance between the head of a nail or screw and the part's surface indicates visually to the user what point the connecting process has reached and how much more user action is required to complete the process.

2.2.2 The bias of concluding connections

Considering the linkage of objects with digital information such as through the adhesion of a barcode or other digital identification tags, neither the object containing the barcode, nor the barcode reader reveals to the user any information about the connecting process until the link is successfully established. Only then, the conclusion of the process is commonly indicated by a sonoric or a visual signal.

This lack of responsiveness regarding the connecting process leaves the user uncertain until the successful connection as to how to achieve that very connection. Such an uncertainty increases especially with one or more unsuccessful attempts of connecting which do not result in any feedback to the user about why his attempts are not succeeding and how he should otherwise proceed.

In products such as barcode readers or smart cards used for access systems (at ski lifts, public transport or building doors), this lack of responsiveness of the connection process between a physical object and the corresponding digital information can lead to comical scenes when people rub their skiing jacket that contains the access pass over the card reader again and again in desperate attempts to establish a connection.

2.2.3 The progress of the process

While in physical connections a user can perceive the manifestation of the progress of the connecting process such as the nailhead that nears the part's surface during hammering, in connections involving digital elements the emphasis on indicating the end result rather than the progress poses limits regarding to the responsiveness of the connection towards the user.

Taking this insight as a basis for a project development approach, the designer's contribution can extend the focus to consider also all other stages besides the final stage of a connection process between physical objects and intangible elements of information.

In what ways, that is, can a designer approach the progress of the process of a connection carried out by a user? One important consideration regards the changing proximity between two parts that are brought together to establish a connection.

A recent research lead by Intel approaches the problem of proximity in connections with regard to a robot hand able to grasp objects. As Josh Smith, Intel senior research illustrates, today's robots "don't have the capability to perform spontaneous close-range interactions well" (Greene, 2008). While, when used in fabrication facilities, a robot's necessity of precise positioning of parts to be grasped is achieved by "designing away" uncertainty and surprise, in domestic environments, an increasing potential of robot implementation, people and objects do not behave and position themselves in predictable ways. Integrating the capability of better taking into consideration this context of randomness in the design of the product itself opens up new application scenarios in the domestic context.

In Intel's approach the robot's hand is equipped with what Intel calls "pre-touch" technology. In this approach induction sensors are integrated in the fingertips of the robot hand. An electrical field is created around the finger tips that alters with the approximation of conducting objects such as metal or all those that contain water. The sensors in the finger tip detect this change in electric field and the processor, analyzing the sensor data generates corresponding movements that are in consequence forwarded to the mechanics of the robot hand. The sensors used in this case are also known as electric-field (EF) proximity sensors. With their help it is possible to measure the position of objects and persons at small distance and they are used for example in cars to help trigger airbags in correct ways, relating to the presence and position of passengers (Greene, 2007).

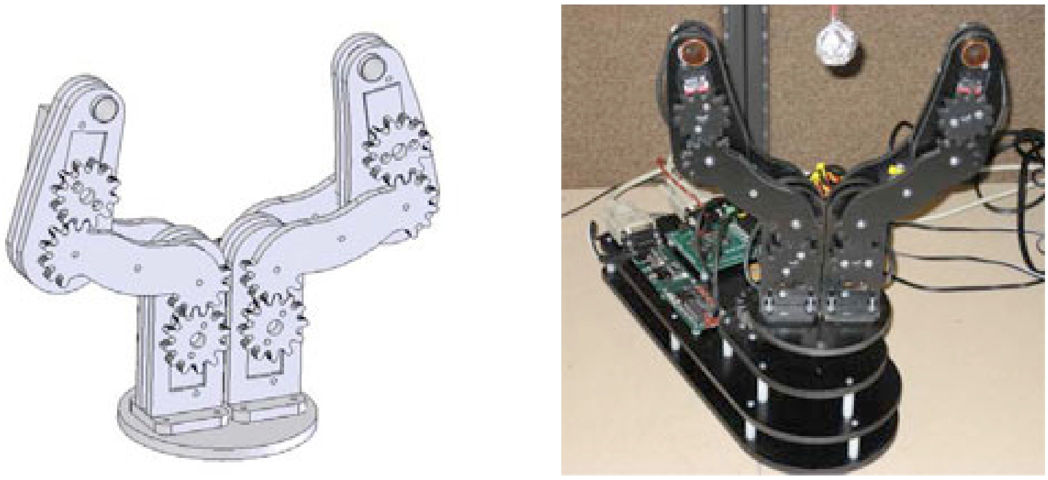


Figure 2.13: Intel's "pre-touch" technology implemented in a robot's hand that can sense objects in proximity before grasping them. September 2007.

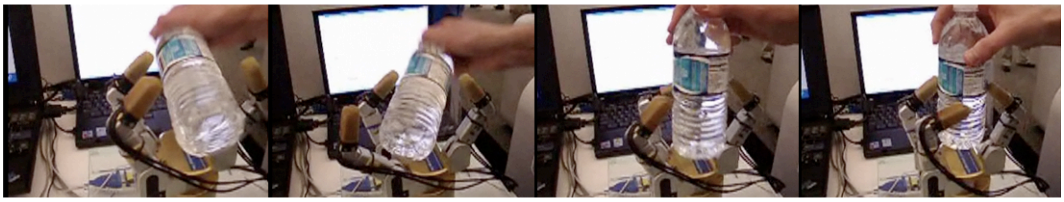


Figure 2.14: Further development of Intel's "pre-touch" robot hand sensing, adapting to and grasping a water bottle. June 2008.

Besides EF sensors, another and more common sensor type capable of providing data about proximity of objects are PIR (Passive Infra Red) sensors. These sensors, contrary to the EF sensors do not emit energy into the environment to sense how this energy is changed. Instead their working modality is based on passively accepting incoming infrared radiation from surrounding objects. They are currently used in a wide range of applications as movement sensors often associated with alarm devices and illumination devices that get triggered by the presence of movement within a certain distance around the sensor's position.

Figure 2.15: Two typical types of PIR sensors for domestic use as motion detectors.

Proximity sensors could provide an increasingly interesting field of study in considering connection phases before and after the actual completion of a coupling between parts and making the entire process more responsive to the user.

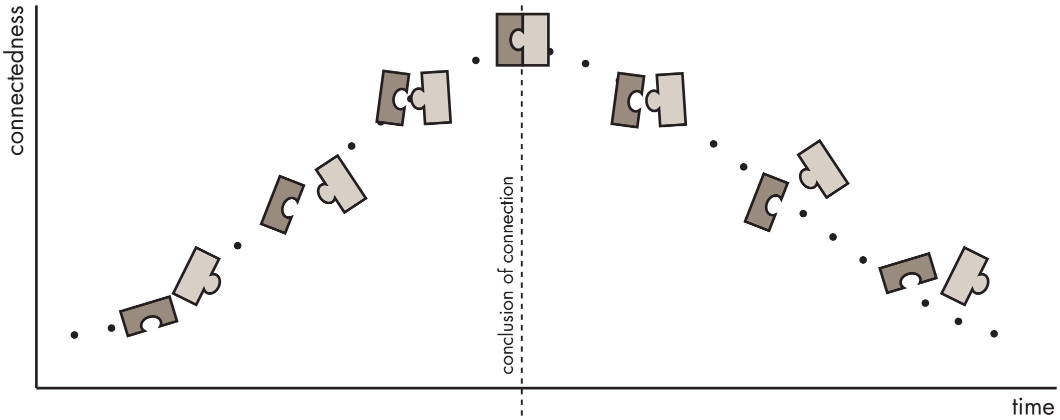


Figure 2.16: Considering the connection phases before and after the actual completion of a coupling between parts and making the entire process more responsive to the user opens up an interesting field of study for industrial design.

Being able to sense that a connection is "in the making" allows for a product to give a kind of feedback that guides the user in his task of completing the actual connection and in this way reduces the possibility of erroneous connections or also the interruption of the connection process due to the user's not understanding in how to proceed. Regarding the example of the contactless ticket reader presented above, this technology could form the basis for the design of an interaction process that accompanies the user along the ticket-reader connection.

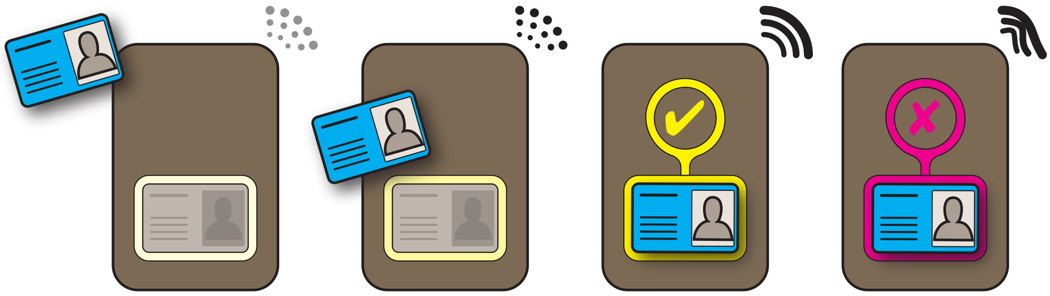


Figure 2.17: Interface concept of a contactless ticket reader with visual and sonoric feedback modalities. The contact zone of the ticket reader corresponds in its shape to the ticket. Moving the ticket closer, the luminous ring around the contact zone increases in brightness and a sound feedback accompanies the approximation. Upon conclusion of the connection, distinct visual and sonoric feedback types inform the user of the validity of his ticket.

Continuing on the line of proximity sensing, what brings up interesting questions regarding the design of products is also the modality of detecting a detachment of connecting parts and the subsequent phase of separation of parts. These questions might lead to considering what in a products functionality could benefit from the integration of such data into its modality of interaction with the user and other system parts.

An interesting possibility could be to have connecting parts consider user intentions in a correct way that regard processes of attaching and detaching and which, if attempted in an inappropriate moment, could be notified to the user. A product could incorporate the functionality of covering up delicate parts of connections that are revealed only when the user approaches it and get covered up upon detachment and moving away of the user.

2.2.4 A sequence of feedback

From the above analysis I have attempted to deduce a sequence of quite distinct feedback stages in the process of connecting parts that can be summarized in the following way:

1. Recognition of a connection
2. Understanding the connecting modality
3. Ongoing feedback about the progress of the connection process
4. Declaration of conclusion of the connection
5. Confirmation of the "rightness" of the connection
6. Understanding of the undoing of the

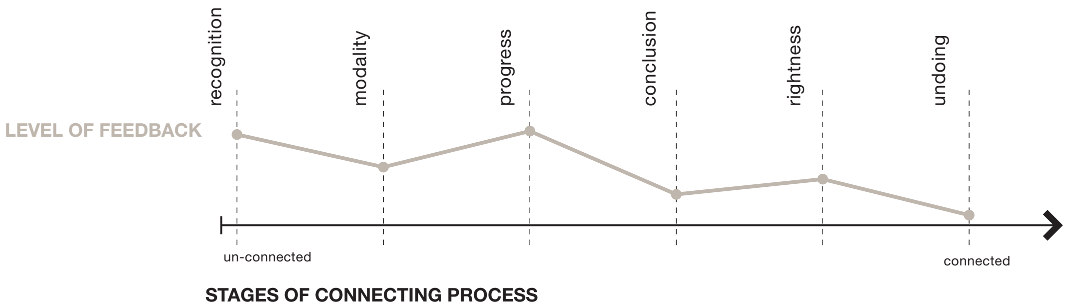


Figure 2.18: Diagram showing the sequence of feedback in connection process with indication of levels of feedback at every stage for a hypothetical connection type.

Tracing a critical evaluation of different connections on a diagram according to the effectiveness of the response given in each of these six phases it is possible to obtain a good idea in which of the phases user interaction with the connecting parts is encouraged by a connections responsiveness.

Reversely, I suggest that such diagrams can be useful tools in the design process of new types of connections in the way that they allow to plan a more comprehensive scenario of what the interplay between a product connection and potential users may look like and from this deduce appropriate design constraints.

An additional purpose of the use of such a diagram in the design process can be considered in the case that different user groups that interact differently with the product, shall be considered. A product might contain or be based upon connections that represent different functional roles in the product's operation with different users along its life cycle spanning from production, distribution, usage to the end of life (be it reutilization of different parts, assembly, disassembly or other). A connection that is critical to be recognized and correctly executed in the process of pre-sale assembly might favorably remain unnoticed during the usage of the product itself while in the process of maintenance specific connections assume a central role only in that specific moment. In a similar way, different user expert levels themselves can result in different modalities of interaction and thus levels of feedback from the connection towards its user. The diagram regarding the six phases of responsiveness of the connections will result in a different curve indicating different emphasis given to the responsiveness of connections at different phases according to specific life cycle stages and the use by diverse user groups.

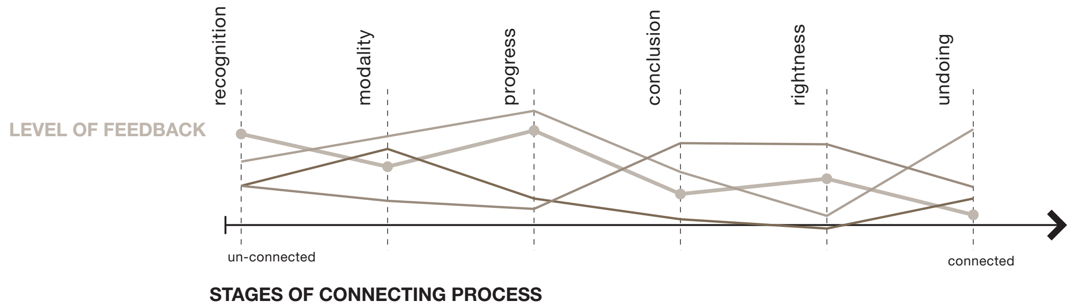


Figure 2.19: Example of different levels of feedback considering different user groups of the same product connection

2.3 Qualities of a connection

Independent from the dynamic of the connection process and the point at which a connection finds itself, a user needs to be able to identify a series of qualities concerning the connection in order to interact effectively with it. Whether he is able to understand, from looking at or interacting manually with parts of a connection, if a connection is open or closed, whether it will be possible to undo the connection in a second moment or what it is precisely that the connection does indeed connect, contributes to how the connection will be used and what goals it can be instrumental for.

Considering that there is a large variety of such qualities that a user might deem relevant to "read" in a connection, I have identified five that assume a particularly significant role in responsive connections:

1. *State of connection*
   The state of a connection concerns whether and how well the connection does convey whether it is connected or not, whether it is partially or differentially connected. Is it open or closed? Is there a partial or differential passage?

2. *Effectiveness*
   Is it working as it should? The effectiveness of a connection refers to whether a connection is operating as it is expected to, whether two parts are connected in a proper way, whether they actually do fit together and whether an expected flow across the connection occurs without problem.

3. *Inherent reversibility*
   Can a connection be undone once it is established and does the user understand this beforehand?

4. *Type*
   What passes through a connection once established? Force? Sound? Liquids or gasses? Does the user understand what can and what cannot pass?

5. *Directness of user interaction*

How close is a connection to direct interaction and manipulation by a user? Are tools or other sources of mediation needed or can a user interact directly with the connecting parts to establish a link? Is a collaboration needed?

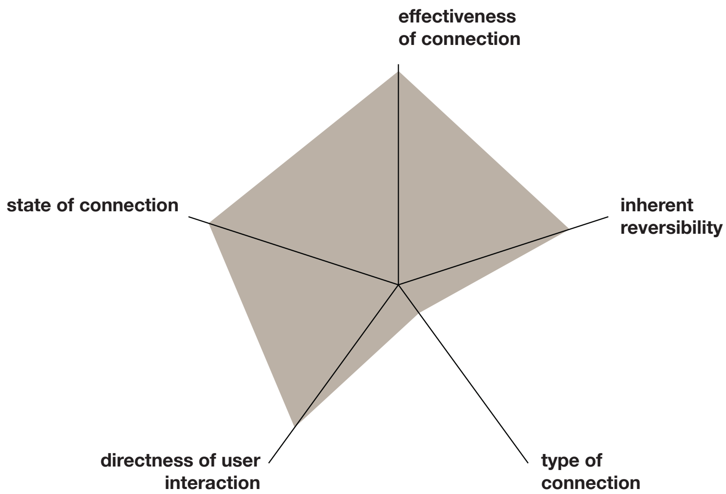


Figure 2.20: Star Diagram of communicated qualities for a hypothetical connection type.

This analysis of the qualities of a connection are complementary to the above mentioned sequence of feedback along the connecting process. As in that case, also the analysis of connection qualities in the form of the star diagram is a constructive instrument to better understand the diverse qualities of traditional connections. The awareness of how traditional connections communicate to the user these different qualities can become a foundation for the design process of new types of linkages in products.

2.4 Distant connections

2.4.1 Awareness of connectivity

Physical connections tend to give the user a feedback through their materiality, structure and shape. Any awareness related to the state or the modality of a connection emerges in regard to a specific connection the user finds itself interacting with, be it when assembling parts, combining modules of a system or attaching one element to another.

With the introduction of digital information elements in the dynamic of joining objects and parts, connections can generate data which in turn is processed into information about the connections themselves and parameters related to it. Now, if we consider that such information can be gathered in various contexts, in different locations and moments in time, not only can we consider the establishment of histories of connectivities in time but also something like a systemwide awareness of how objects link up with each other in different parts of the system. In terms of feedback that a connection gives to its user, the gathering of information in time and space enables a user to assume awareness of how his attempt of linking relates to linkages being made in correlated situations, in a historic or in a future perspective.

Let us consider the following example. How does a user scenario change when the ticketing system of a public transport system transitions from paper cards inserted into a slot of appropriate size and getting stamped with time and vehicle code to a ticketing system that involves a smart card carried by the passenger passed in front of a card reader that is linked up with the transportation system's computer network structure.

In the former case the information of a ticket purchase is memorized on the piece of paper in possession of the customer and remains with him and inaccessible to others except for the case of a visual control. In the second case, the company's network infrastructure retains the information that a specific client is using that specific vehicle at that time and in that place. As a matter of fact, this information is generated for all passengers at any given time.

Now, how does this system's potential impact the individual passenger at the moment that the system's information is shared openly with him?He can be made aware not only of a bus arriving but also of how many people are traveling on it and, furthermore, how the passenger numbers are likely to evolve over the coming hours based on historic data and future projections. What benefit can the system give to the individual traveller if it shares with him his personal history of usage of the transport system?

Aspects such as *how* and *in what way* a user is made aware of these informations become crucial when a system provides linkage between the effective usage of a product or service and the correlated digital information. For the designer an array of novel considerations emerge from this context:

- *Selection of data to be communicated*

  The designer finds himself involved in selecting the data to be communicated to the user out of often enormous sets of data. Since the choice of data is directly related to the functionality that the product offers to the user, these decisions must be taken together with who conceives the overall form of the product.

- *Mediating system awareness with potential user action*

  This aspect considers how the awareness of a systemwide connectivity can be best presented to the user in a way that is effective and useful to his imminent actions.

- *Time aspect of data*

  An extremely powerful aspect of considering digital data in correlation with product functionality is the time reference of this data. Digital information can relate to historic usage of a product system or to simulations that suggest future dynamics based on mathematical models. A third way of considering the time domain corresponds to real time which has been particularly emphasized in recent data applications. Real time data components in systems allows for systems and its use modality to happen in synchronous with actual dynamics present in the environment.

- *Location reference*
  Much of the fascination and potential in networked digital information such as the world wide web has been seen in being able to access any kind of information at any time and from any place. This however is also a great limit in cases when information that is relevant to a specific place is looked for. Physical objects, not like digital information, are present in a specific place and this fact offers a vast territory for design exploration in connecting data streams with material artifacts.

2.4.2 Wikicity - a case study

When I started work on the WikiCity project together with my colleagues at MIT's SENSEable City Lab, the aim was to work on a platform that allowed for the exchange of real time data of various kinds that are collected within the urban environment.

> "People moving and acting in a city base their decisions on information that is in most cases not synchronized with the time and place they find themselves in when taking that decision. How often have you arrived at the airport just to find out that your flight has been delayed, been surprised by a traffic jam, found that a product is out of stock or a service operator busy at the moment you needed it.
>
> In the same way, a person acting in a city contributes himself to dynamics of which others are not aware of when making their decisions. Looked upon in this way a city resembles what Deleuze and Guattari describe as a “rhizome” (Deleuze & Guattari, 1977). The rhizome is a philosophical network structure where every part is necessarily connected with every other part of the system. There are no preferential connections because every connection alters the overall network structure. As a consequence, the rhizome can not be plotted since the plotting action itself is part of the rhizome and thus in the very moment of plotting its structure, the structure changes.
>
> The WikiCity project, in a similar way, is concerned with the real time mapping of city dynamics. This mapping however is not limited to representing the city but instead becomes instantly an instrument for city inhabitants to base their actions and decisions upon in a better-informed manner. In this way the real time map changes the city context as well as that altered context changes the real time map accordingly, with the ultimate aim of leading to an overall increased efficiency and sustainability in making use of the city environment"(Calabrese, Kloeckl, & Ratti, 2008).

I believe the project of WikiCity indicates in many ways a new questions that designers will need to give responses to in terms of adequate projects: How can large scale dynamics be communicated to the user of products at the moment he is taking a decision? How can design happen at the moment that effectively very distant events impact the composition of products keeping it in ongoing mutation and adaptation? What benefits and risks are involved when increasing amounts of products can be tracked in real time, revealing time and location based data about their state?

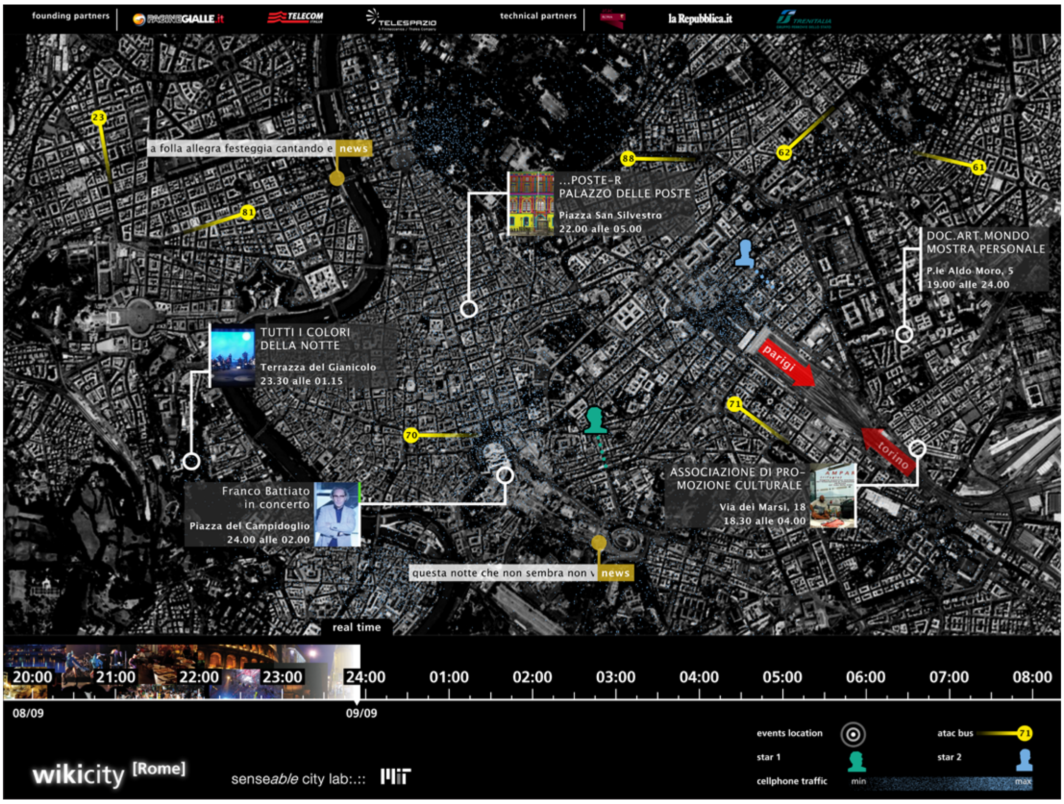


Figure 2.21: Interface of the WikiCity project. Designed by Kristian Kloeckl at the SENSEable City Laboratory, MIT, Boston

A first difficulty related to the responsiveness of an interface such as that of WikiCity is to single out those data elements that can be effectively communicated to the user and that represent useful information in those contexts users might find themselves in while consulting the interface.

> "A first implementation of the WikiCity concept was presented in Rome, Italy during the Notte Bianca (White Night, http://www.lanottebianca.it) on September 8, 2007. This demonstrator (see http://senseable.mit.edu/wikicity/rome) comprised the presentation, on a big screen in a major square of Rome and on the web through a web applet, of real-time population distribution by the use of cell phone data, the location of buses and trains, real time news feeds from a main Italian newspaper, and its mapping to certain events happening in the city" (Ibid.).

In the first implementation of WikiCity during the Notte Bianca event in Rome on September 8th 2008, the decisions in dealing with the data in order to render them intelligible to the user in that specific context have been the following:

Event announcements were indicated by small circles at the corresponding location and and due to screen space limitations only those would cyclically be enlarged that were about to start or those that were ongoing. Only when enlarged, the full information of the events would be legible. Furthermore, those events that were about to start had a green signaling element added to underline their special role linked to user decision to actually attend these events.

The visualization of the location of public transportation busses in the city posed the following questions. Possible data to be displayed were the bus velocity, the direction, and bus number. If all visible busses were displaying the full range of information, legibility would have been very poor. For this reason, the level of detail in information was increased only in proximity of the actual location of the WikiCity projection. The reasoning was that people watching the real time visualization on the one public square would in any case only be able to reach busses at close distance in the time relevant to a real time visualization of bus location. In this way, a member of the audience that saw his bus approach could manage to reach the bus stop in time to catch his ride.

Making the bus visualization instrumental for people actually taking rides implied also to calibre the interval at which the data about the busses' location was collected at 3 minutes instead of the previously set-up 5 minutes. Decreasing the interval further would have meant risking error values from the data management system.

Is such a 3 minute interval *real time*? Real time is starting to become a term suffering from inflation. With ever more products claiming to provide the user with real time information, a designer ought to gain clarity as what this exactly means and what it implies for the design of products. The following consideration has proven useful for the development of WikiCity and I believe that it can provide a constructive basis for the use of real time data in the design of products:

> "Often, the term real time relates to a system in which data is processed within a small fraction of time, a sensor that returns a measurement as a signal in the fraction of a second for example. The difficulty with this definition is that it does not provide a relation of the time intervals in question and this makes it difficult to judge any given system as to whether it is or it is not real time.
>
> A more useful definition is the one which refers to real time as “the actual time during which a process or event occurs” (Oxford Dictionary, 2007). Consequently a real time process implies that there is a deadline before which a given data is useful to the system while that same data is not useful or even destructive to the system thereafter. While the deadline refers to a process, identifying the usefulness of respecting such a process’ deadline implies the existence of a higher level mission. Considering now that it is evidently this mission that defines the parameters of the deadline we end up with an idea of real time in which there is no stringent necessity to speed up data transfer to arbitrarily defined “very fast” limits but rather to identify reasonable deadlines for data-transmission that are related to specific missions" (Ibid.).

What was set up for people and means of transport within the context of the WikiCity project has been happening for many years in the sphere of product logistics. Logistics as a matter of fact is a pioneering field for the combination of material elements with digital information. Objects are tagged in any possible way and subsequently tracked in their location at given time intervals or at the passage of specific gates of their supply chain. What is happing today in this field of logistics is about to enter the realm of objects at contact with the end user. In WikiCity it was the cellphone and the integrated GPS devises in public busses that allowed for the most relevant tracking of objects in one case and people in the other. Consider the recently released Amazon electronic reader Kindle. This object is fundamentally a book that contains an *always-on* cellular data connection through which permanent location tracking would be possible.

What are the new use scenarios that such a product articulation could enable? The design of products will in such cases have to enter in the merit of understanding how the responsiveness of objects changes once they represent outposts of large networks that enable entirely new types of information to be conveyed to the user. Objects in such cases become interfaces through which users tap into vast systems often distant from themselves.

2.4.3 Who knows about my connections

Considering the integration of digital information in a connection, a fundamentally new requirement emerges related to what a connection communicates to the user and that is what information is extrapolated from the connection process that involves the user and who is this data shared with. Will I leave traces of my connection and will I be identified with these traces?

Today, these questions tend not to be considered in the context of connection feedback. The integration of digital information is focused more on the the fourth and fifth phase of the sequence of feedback outlined in figure 2.18, that consider whether the connection has been established and whether the connection works.

Increasingly however, such questions will have to be contemplated already in the process of designing connections since neglecting them will potentially lead to people not accepting interaction with parts that do not upfront and in a continuous way inform about their modality of dealing with the diffusion of digital information linked to a specific moment of user interaction.

What then is the designer's role in the field of data privacy in the interaction with products? I believe the main contribution from the designer regards the informing of the user in clear terms about what data is collected, memorized and distributed. A user needs to understand how far away from his direct interaction with a product the data will be transmitted. Will the product memorize the fact that he actuated a specific connection only in order to re-propose to himself this data in the form of a use history or will his actions be accessible through online platforms by a large audience?

Subsequently, together with the creation of awareness by the user about how the information regarding his actions is registered and transmitted, the design of a product can consider elements of user choice in this process. The user himself can decide what digital information is generated by his doing and where to can it be transmitted for further usage. The design of how the user can bring himself into this choice is fundamental for the user to recognize and accept this option.

At last, even a system that is structured to protect from misuse, the case of it happening needs to be contemplated in the design phase. A system that informs the user if information about his actions has been generated, stored or transmitted in ways different from his intention or if these data got accessed from subjects different from those chosen by him, this needs to be signaled in a way that is useful to the user and that helps in building increasing trust in the system even in cases of misuse.

A project I was involved in during my collaboration with the SENSEable City Lab at MIT that addressed these questions is iFind.

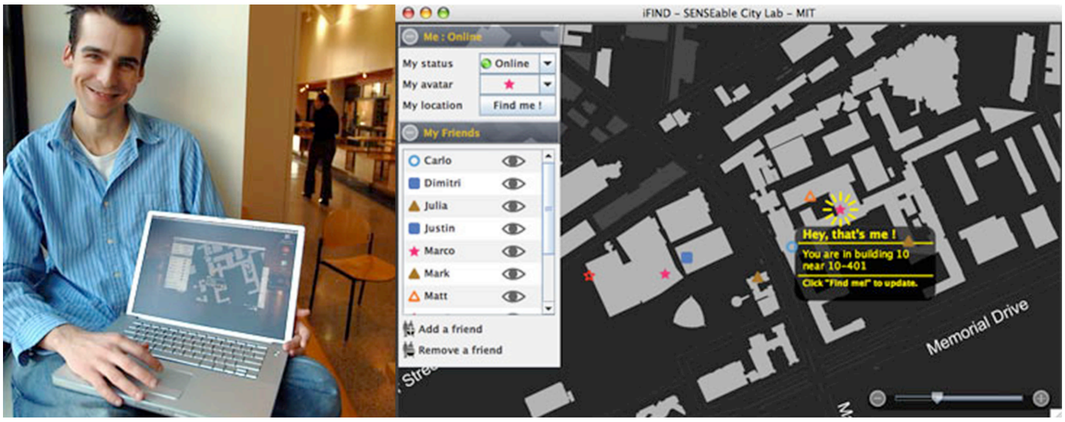


Figure 2.22: iFind developer François Proulx on the MIT campus (left) and the iFind interface (right)

The idea for iFind was born when Bill Mitchell and Nicolas Negroponte from the MIT Media Lab exchanged emails for a project. Bill was in Japan and from the time Nicolas responded deduced that also he must have been in that time zone. Asking about his location it turned out that they both were email from within the same Hotel in Tokyo and subsequently met at the bar downstairs to continue their conversation.

Like in this case, while telecommunication tends to shorten long distances, it often enlarges distances that they are physically short instead. iFind is a map interface that enables people using wifi devices on the MIT campus to share their location with their friends in real time. In this case, seeing the icon associated with a friend passing close, a user can *chat* to his friend arranging for a direct meeting around the corner.

The aspect of data privacy in such delicate application was dealt with in a particular way. Instead of basin the system on a central server that would continuously collect location data about each user, only a user's wifi enabled mobile device itself contained the information regarding its location. This location data would then be exchanged in an encrypted form only with those other users selected as trusted users.

In the increasing dynamic in which various applications and devices collect personal data about its users I believe that the approach of having the user control its data with his close proximity is a promising direction for resolving users' trust in data applications.

2.5 Designing the response

While the focus on the entirety of the connecting process has revealed itself useful for the understanding on how to design the parts involved, it has even more so brought to the light the increasing importance that design plays in composing the sequence of feedback necessary for the accomplishment of connections that involve new technologies.

From the above analysis of the responsiveness of traditional connections I can confirm that there exists a large number of variables that are communicated to the user at different stages of the connecting process and the emphasize on the entire process of connections as opposed to single stages of it has been instrumental for this understanding. By mapping how physical connections provide different kinds of user feedback at different stages of the connecting process, even when these elements of feedback are not considered or envisioned by the designer of the device, it has become evident what role they play for the entire user interaction with the product connection.

Looking at connections in terms of a connecting process consisting in multiple stages has furthermore enabled to understand how many elements of feedback of these different stages are in fact missing from new types of connecting modalities that have been created on the basis of technological innovation. Of particular notice in this regard are technologies related to data transmission in general and of contactless data transmission in specific.

The stage of the connecting process that has seen a particularly high level of attention in terms of emphasize of user feedback is the one related to the completion of a given connection. Also at the level of design activity, the focus seems to be put particularly on communicating that single aspect of a much more comprehensive process of connecting.

From this critical analysis, this precedence results as very critical and as a potential handicap in new types of connections in terms of usability since:

- it does not help users in identifying the existence of connection possibilities
- user guidance towards a successful connection is not contemplated and thus often missing from a connection
- the result of a connection is perceivable only in the moment of conclusion of the connection and does not imprint itself in any way for later tangible reference

Referring to the considerations made at the beginning of the chapter about Gestalt theory and Gibson's ecology of perception, this neglecting and even dropping of critical stages of the whole of the connecting process can be seen as a breaking apart the very *Gestalt* of such connecting processes, leading subsequently to a situation in which at the beginning it is not comprehensible what the end of the process would be once the whole is completed (this being one of the ways Gestalt theorists identified Gestalt in music or other processes of longer duration).

Just Wertheimer's early acclamation of "wo es fehlt und paßt"[6] to indicate a Gestaltist's view on how to join parts to create a satisfactory whole, such wholes in the

[6] Translation: "where it is missing and where it fits".

product sphere are difficult to accomplish by the user if critical parts of this equation are moved into the digital sphere where they are as such not perceivable by the user.

This observation leads to two critical new questions for industrial design. First, it can be through careful analysis of the connection processes that designers can contribute in creating a series of user responses from the connecting parts, that allow the user again to perceive this process as one entire *Gestalt* of which in its beginning, the end result is contained and in which, with every step, the user accomplishes a constituting part of the connected whole which is perceivable to him. Studies into sonoric feedback and interaction with products such as (Rocchesso & Bresin, 2007; Rocchesso & Polotti, 2008) are important steps in this direction. Other promising indications can be expected from a critical re-reading of (Katz, 1989) in the wake of new technological potentials in relating touch qualities and dynamics with digital information management of devices.

A second question comes from the above mentioned circumstance how digital technologies and subsequent contactless possibilities of connecting lead to a situation in which connections become less directly responsive in many stages of the connecting process. This opens up a new focus for the design activity which lies in designing the feedback modalities that accompany connecting processes.

New digital and contactless technologies in the sphere of connections can be seen as filters that pose themselves between the connecting elements and the user. A filter in the sense that the dynamic between the connecting parts involved can vary in its transparency and intelligibility from invisible to fully comprehensible. The composition of this filter is the zone in which design can in fact visualize and render comprehensible the connecting dynamics of the digital sphere. It is a powerful filter since not like in the case of physical elements that respond to user activity even if that had not been contemplated by the designer, these digital filters do not respond to user activity in any way at all if not designed in a specific way.

At the same time, the response generated by designing the manifestation of digital information involved in connecting processes can consist in a much higher level of user feedback just for the very same reason. Critical therefor will be the way in which designers take on the challenge on micro-designing the various stages of connecting processes and their manifestation within the realm of new technologies.

I have discussed ways in which the knowledge about the existence and modality of connections can be located at different distances between the connecting parts, the user and external sources of knowledge. The integration of digital information into material elements involved in connections provides a promising field also for the overall responsiveness of connections.

Another aspect observable in new types of connections that provides for a large scene of design activity is the drastic move from connection feedback limited to a specific case in front of the user towards a much wider awareness of connectivity dynamics part of large and often distant networks. The integration of digital information in physical parts of a connection opens up new scenarios in which dynamics of connections are recorded, memorized and shared in real time with other connections of a system. This novel configuration enables a user that is in the process of establishing a connection between parts to become aware of the impact his connection would pose on a wider system context. The critical question now is how such a larger awareness regarding connections can be effectively transmitted and made accessible to the user in order to result useful for evaluation and subsequent translation into real action on the basis on more comprehensive information.

Critical in this new perspective is the sheer amount of data that becomes available to confront the user with at any given moment and before any potential action. The designer assumes ever more the role of a selector. He takes decisions as to what data to consider and how to represent it in order to supply a user effectively with information that is useful to him in a given place and moment and help him take decisions as opposed to frighten him because of an excess of information.

The aspect of real time and location based information available as digital data takes on a particular role in this. And while the location aspect is less problematic conceptually, the interpretation of real time ought to be approached with care.

> It seems important to emphasize the interpretation of real time we have decided to adopt in order to clarify the use of the term and as a consequence the scope of its implication.
>
> Often, the term real time relates to a system in which data is processed within a small fraction of time, a sensor that returns a measurement as a signal in the fraction of a second for example. The difficulty with this definition is that it does not provide a relation of the time intervals in question and this makes it difficult to judge any given system as to whether it is or it is not real time.
>
> A more useful definition is the one which refers to real time as "the actual time during which a process or event occurs" (Oxford, 2007). Consequently a real time process implies that there is a deadline before which a given data is useful to the system while that same data is not useful or even destructive to the system thereafter. While the deadline refers to a process, identifying the usefulness of respecting such a process' deadline implies the existence of a higher level mission. Considering now that it is evidently this mission that defines the parameters of the deadline we end up with an idea of real time in which there is no stringent necessity to speed up data transfer to arbitrarily defined "very fast" limits but rather to identify reasonable deadlines for data-transmission that are related to specific missions (Calabrese, Kloeckl, & Ratti, 2008, p. 396).

Such a perspective positions the potential of real time connections between objects within a realm of design decisions of an object.

Events that are meaningful moments of interaction between objects are determined at a larger scale of the overall mission of a user and of an object's possible support in these. The time dimension of the responsiveness of connections has in this sense come full circle. It is evident, that when talking about traditional physical connections with which users interact directly the feedback clues a user receives from interacting with the parts are as a matter of fact provided in real time. Every action is followed by a response from the material interfaces of the product's parts that a user perceives as aversion or as confirmation in his attempts. The insertion of technological filters in this immediateness interrupts at first the flow of feedback between an object's part and the user. This interruption as I have shown, however, opens up new potentials for designing in a more controlled way the modality of user feedback.

Introducing real time interaction at a level between vast networks of connections now realizes what in fact did not exist previously, that is, an immediacy of responsiveness of networks of connections at event real time.

3. Compatibility

3.1 Good fit

3.1.1 Three layers of compatibility

Speaking of connecting products and its parts, one key aspect is whether these parts do at all fit together, whether they fit badly or not at all. Under compatibility we understand the "ability to exist or occur together without conflict" (Soanes & Hawker, 2008) which in other words can be expressed as a situation of "good fit".

In the realm of industrial design, the question that arises is what determines, that multiple parts and products fit well together and what benefit does it have that they do? Are there situations where the opposite of a good fit might be desirable and convey benefits to the user or another stakeholder as well?

The acknowledgement of the possible existence of compatibility implies at first the knowledge about what the combined functionality of two or more parts will consist in. In this respect compatibility can be interpreted in terms of correspondence to specifications. As such, compatibility is, by itself no predetermined condition but it rather results from the derived functionality, expected from a specific combination of parts or products.

As a consequence of this reasoning, the concept of *limited compatibility* shall be introduced, which indicates a situation in which the expected outcome of a combination of parts is achieved to a certain extent but not fully.

The aspect of compatibility not being a condition intrinsic in the parts themselves but triggered by the defined outcome of the combination of parts reveals a particular interesting aspect when considering product innovation that does not originate from the manufacturing company but from combinations of parts generated at a later stage. In this context, parts, that were not considered as compatible at the design stage might be considered so under the light of modified definitions of functionality of the parts' combination.

An element that connects between two components or the connecting zones of two joined parts are by definition part of both the contexts of whatever they join. These parts must fit two possibly dissimilar contexts equally well and the connection as such is the only element that "knows" something about both parts which are otherwise distinct. This "knowing" can consist in information at different levels. Information that is expressed in a shape correspondence, a material correlation or a functional integration. I propose these three aspects in particular as the three distinct layers of compatibility to consider in correspondence with the analysis and practice of industrial design.

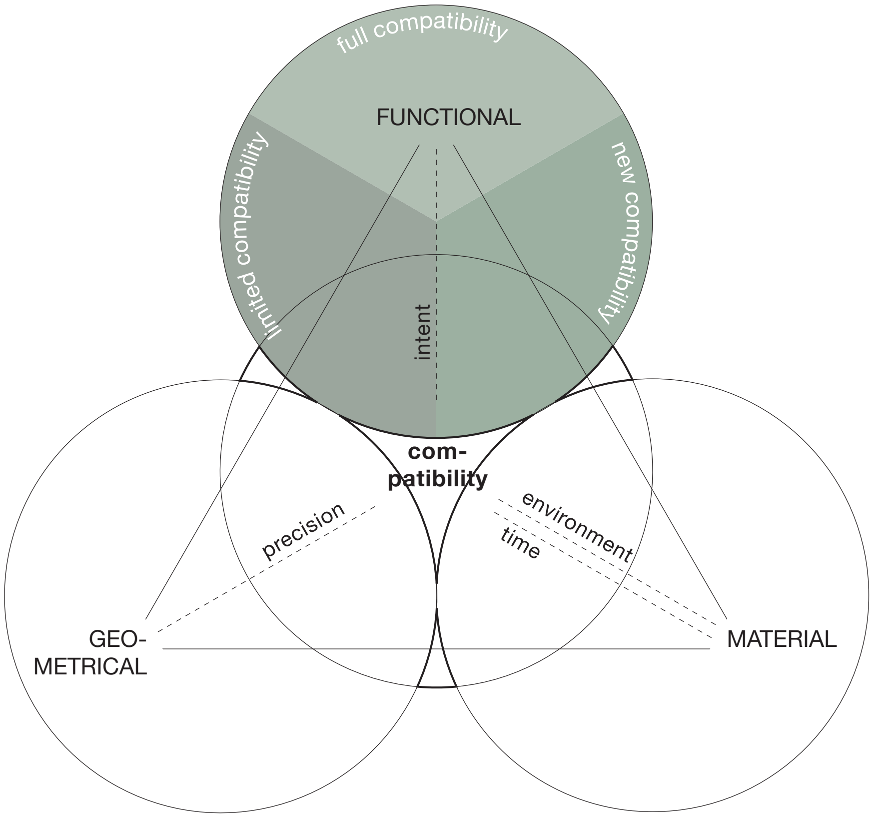


Figure 3.1: Three layers of compatibility: material, shape geometry, functional

3.1.2 Material compatibility

On the level of material compatibility, aspects of relevance can be linked to what chemical reactions are caused by the combination of parts made of different materials. Corrosion, as an example, is one of the results of joining two parts that consist in materials which cause either one or multiple parts to decrease in its integrity due to the combination. In this respect, a careful study of the chemical reactiveness of parts to be joined is not to be limited to the parts' materials but ought to be extended also to the chemical agents present in the environment in which the combination of parts finds itself in at the different stages of its product life cycle. The environment can have a protective or aggressive role in the compatibility between parts, enhancing or counteracting chemical reactions occurring between the parts directly.

Besides the environment surrounding the parts, the other aspect of relevance regarding material compatibility is linked to time. In fact, material characteristics might change over time and potentially change the formerly established mode of compatibility.

This in turn can be exploited in the design process and integrated in a connection's characteristic. An example for such a case is an elaborated version of the suction cups, that are used to attach radio transmitters to the backs of whales (Cetacean Research Technology; Wake, 2000, p. 170). These suction cups are used in order not to hurt the whales while still guaranteeing a strong connection to the whales skin. The enhanced version of this connecting element is made of a gelatin-based material that dissolves after a specified time by itself.

Detaching from the whale after a predetermined time that corresponds to the research period for which the radio transmitter is needed in place allows for the whale to be freed from this device soon after it ceases to be of interest for the marine researchers.

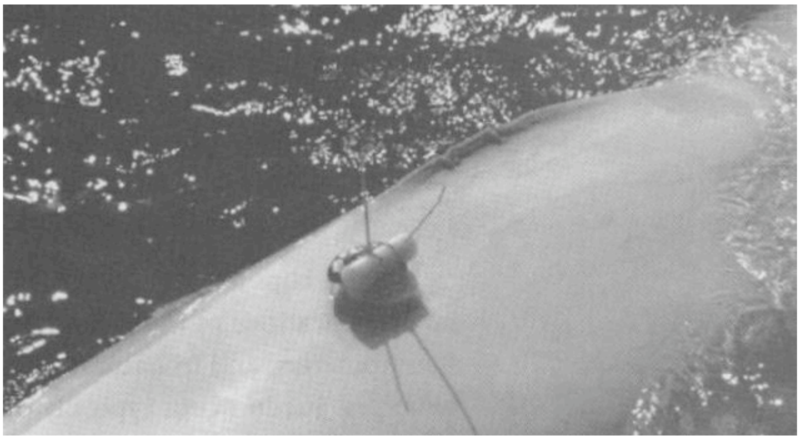


Figure 3.2: Image of a radio transmitter attached to the back of a Beluga whale for the purpose of tracking the animals movements. The GelRelease™ suction cup used for this temporary attachment was first developed in 1994 by Cetacean Research Technology to allow for radio transmitters being automatically released from their host animal after a predetermined research period.

In this way, leveraging the time aspect in terms of part compatibility I suggest to consider connections that are *time controlled* in their operation. Contrary to most approaches that trigger disconnections after a specified time interval through an electronically or mechanically controlled mechanism, in this approach it is the accurate study of material compatibility and its alteration at contact with the counterpart material and the surrounding environment that is harnessed to provide a time trigger for the connection and its release.

Creating time triggers in connections through the material compatibility aspect has recently received additional attention in the field of nanotechnology where molecular sensing focuses on precisely that.

3.1.3 Geometric compatibility

The geometric aspect of compatibility is probably the one most commonly considered by a user of products in understanding whether and how parts fit together. Compared to the previously described material fit and the following functional compatibility, in a first approach, the geometric relationship between parts can be associated with something like an apparent intelligibility of their potential connectivity.

Without touching parts, without implementing a connection or awaiting the result of something like a chemical reaction in a time interval (such as is needed to fully understand material compatibility), whether parts fit can be observed in appropriate cases for reasons mentioned in the chapter related to the responsiveness of connections. As such, in fact, it is a most relevant issue in guiding a user towards a product's functioning and offers concrete modalities of user action.

Real world applications of geometric compatibility however do face immediate confrontation with the correlated question of "how compatible" parts fit together on the basis of shape geometry. How precisely or how loosely do parts fit? And can a connection be too precise or too loose as to be compatible?

Precision is commonly associated as a quality feature in absolute terms. The more precise the better the fit, is what is often assumed. A precise fit between parts enables a better mechanical transmission of force, reduces abrasion and avoids alien particles and objects to get into undesirable positions and interspaces. A precise fit enables parts' positions to be more fully respected which translates into a better functioning of links and result in a better adherence to the overall form determined by the designer. It also results in more clarity at different stages of the product's life cycle such as during assembly. A precise fit narrows the range of what can and what cannot happen to parts that connect. It determines and gives implicit specifications as to what connects, how it connects and what will be the resulting whole.

This last point brings brings me to consider the limits of geometric precision in connections. Instead of narrowing down the possibilities of connections by a precise interface, a looser fit between parts represents an aspect of flexibility for the connecting interface; it opens up possibilities of connecting the unexpected.

Think of connections provided by ribbons, cords or straps as opposed to those enabled by screw and nut connections. While screw and nut connections clearly require a precise geometric correspondence between the parts, strings and ropes or adhesive tapes are very tolerant in their requirements of shape geometry of the parts they connect. In fact, these connection elements are found in cases where such tolerance is a requirement of the use context. A number of connections can be identified that are developed just for cases in which it is not clear what are the parts that will be involved in the connection and what overall shape they might have. Instead, they have just this openness and flexibility as a requirement. The situations shown in figure 3.3 can serve as examples.

Figure 3.3: Examples of connections in which the loose fit is at the core of its specifications and use modality and a requirement for their functioning. From top left to bottom right: shrink wrap connecting boxes of different sizes, shrink wrap keeping bottles together, metal chain locking two parts of a door, cable tie, nailed metal strap, rope connecting a boat to the border of a canal, node connecting two poles.

Especially the example of nodes formed by ropes or other elastic materials illustrates well how a more loose fit of a connecting modality implies a necessarily larger contribution from the part of the user, a higher level of ability in connecting the parts. In the case of nodes, a user needs to have learned a sequence of turning and bending the rope in order to create a connection, in the case of the chain lock it is up to the user to decide how tight or loose to position the lock and which parts to make meet while in the case of the shrink wrap, the positioning of parts is fully up to the user who has to consider by himself the appropriateness of the resulting overall shape once the shrink wrap connection is applied.

3.1.4 Functional compatibility

The layer of functional compatibility takes on a special position in this threefold division of connection compatibilities.

For once, it is determined by the intent that was given to a product and its connections by who conceived it. A designer, manufacturer and its development team intend to resolve a number of functionalities through the conception of a product. Parts of the product are joined in a way to adhere to these intentions or product specifications and the product as such enters in relations with other product systems in a way that favors the achievement of these goals. Any consequence of these combinations of products and linkages of parts that favor such an achievement can be considered compatible while any connections that defeat these incompatible.

Examples for functional incompatibility can be observed in a data connection where formats of data are exchanged that the connection has not been designed for. The geometric connectors might fit, data is sent and received but the received data does not fit any of the receiving program's tasks and thus none of the tasks oriented towards the set goals can be accomplished through this connection.

Such cases happen, for example, if inappropriate electronic tickets are brought into contact with a ticket reader or if a barcode is scanned that does not correspond with any of the products registered in the database the reader is connected with. In the more physical domain, a hollow tube and a full body tube might fit together through the geometrically corresponding thread connection but liquid cannot flow through the full body part of the resulting system.

Now, if it is true that the functional intent of a product tends to be attributed in the design phase of the product, such an intent is not necessarily static. The goals for which products are used can in fact change by a shift of intent attributed by the user or any other agent that comes in contact with it after it has been designed. An entire field of design occupies itself with aspects of re-usability of products after they cease to be used, often altering the functionality of parts. Various products are either used in a different way and for a different purpose than what they were designed for or get joined together with other products to form a new object with a different functional intent altogether.

In this way, alterations of functional compatibility between product parts do not limit themselves to that level of compatibility but can be considered also in their wider impact on the other two layers of compatibility. In fact, the change of intent of a product might lead to a reinterpretation of both material and geometrical compatibility.

As in the example of the time triggered suction cups for whale research on page 49, the change of intent that leads to defining the goal of these connecting elements to not adhere indeterminately but only for a specific time and then detach has altered the terms of what material compatibility means in this context. In cases such as this I suggest to speak of *new compatibility* that is generated or emerges through a shift of the functional intent.

Another issue at hand on the level of functional compatibility becomes clear as soon as we establish the concept of functionality not as discrete in terms of on/off or yes/no but as a continuous between these two extreme states. In this way I suggest to add the realm of *limited compatibility* to those of no and those of full compatibility.

Limited compatibility can be observed in the joining of parts that do not fit properly but do fulfill some of the functional requirements. An example for such limited compatibility can be found in Nikon's transition from analogue to digital SLR cameras and their lens systems. A substantial change of structure has seen the motor that drives the autofocus to be integrated into the lens system directly while omitting such a motor from the camera body. Without this motor however, it is not possible to drive the autofocus feature of older lenses which did require a body-based motor for this functionality. As a result, in some cases older lenses still do fit the new SLR bodies but can only be focused manually for which we can speak of a *limited compatibility* in this case.

This example of camera lenses illustrates well how issues of compatibility between parts become particularly critical if one of the parts change. Often, such a change is introduced to improve the product or parts of it in a dynamic of *product innovation*.

3.2 Compatibility, competition and innovation

3.2.1 Compatible connections and innovation

Being able to connect a large part of products or components with each other to form a beneficial whole is generally considered an advantage compared to not being able to do that. Functions of components can be incorporated to create unprecedented combinations, multiple agents like manufacturers and users can participate in the innovation process of the single parts that then feed back their innovative contribution to a large number of integrated solutions[7].

In the field of economy, compatibility has been extensively studied from how it contributes to the process of innovation and in the following paragraphs, various cases and theories from that field have been considered in their relevance for the process of designing connections. While tapping into the study of economics has revealed some most interesting aspects that see novel implications for the design disciplines, there are limitations to this interdisciplinary transfer of knowledge. A very apparent one stems from the discrepancy of focus which economics puts on the *buyer* and *consumer*, while industrial design tends to be more interested in the *user* of products and services. This of course has consequences in what parts of socioeconomic and socio-technical interaction both disciplines follow in their analysis. There are however a considerable number of topics related to the innovation-compatibility discussion in which both disciplines overlap in their interest and subsequently can extract new insights when confronted with each other.

Talking of compatibility, making products and parts fit one with the other, can be closely linked to the discourse of standardization concerned with agreeing on a level of quality and measure in the largest sense. We can speak in fact of compatible or standardized goods when different manufacturers are providing more interchangeability than is logically necessary, such as in the case that there are fewer spark plug types than automobile types (Farrell & Saloner, 1985).

There are important benefits of such standardization, which is in fact why governments tend to favor the development of such standards. Standards can be imposed by a

[7] A very detailed study of user centered innovation can be found in (von Hippel, 1988).

commonly recognized institution *super-partes* in which case they become norms or conventions or they can be *de facto* standards in which case their general recognition is not imposed by any one player but instead has emerged from a number of alternatives as the informally accepted reference which in most cases the majority of products adhere to. The second case takes place also in situations when multiple players such as various manufacturers out of free will decide together on technological solutions they would adhere to in their future development. The fact that such inter-competitor orchestration is tolerated by EU law and needs not be notified (Boom, 2001) gives a clear idea of the importance that such a form of compatibility issue is given to by policy makers.

Connections are often subject to standards because of their obvious critical position and relevance to multiple stakeholders of various phases of life cycle of product systems. As an example one only needs to consider screw dimensions and typologies on the more traditional end of the connection spectrum and personal computer connectors such as USB, Ethernet or Firewire on the end that is touching the digital sphere.

Following the above outline, I have divided the modalities by which compatibility can play in favor of product innovation into four areas and which is also illustrated in figure 3.4.

1. *Multi Participated*

   In this dynamic, one product disposes of a connection interface that allows various players to contribute with complimentary parts to the creation of diversified wholes. This is the case of the iPod connector for instance as well as the screw connector of the water tap. Such a connection allows various manufacturers to produce compatible parts that improve or enhance the overall functionality of the product. A product connection allowing for contributions from multiple sources has advantages in:

   . gradual improvement in substituting parts of the product
   . extension of functionality
   . maintenance support from multiple sources

2. *Multi Participatory*

   This is the case of the spark lamp, mentioned earlier on as well as the various lamp bulb connectors. Apparently it is only the inverted case of the above scenario "multi participated". The difference however is that here it is the connector configuration of a specific part, which gets respected by multiple manufacturers of which this part is a component. Such a situation emerges in cases in which a component has reached a high level of maturity and innovations in its field are beneficial to a large variety of products it is combined with for which it is those products that benefit from remaining compatible with the component as instead of interrupting the potential benefit gained from this combination and future updates.

3. *Unexpected Emergence*

   Compatibility between parts can be designed for or can occur without an *ex-ante* intention. One famous example that can be considered in this section is the emergence of the post-it note from research done in glue characteristics in which the actual post-it note glue resulted as a failure. It's characteristic to adhere well to the paper it gets mounted to during the production process but remains easily detachable and re-attachable from most other surface materials has been recognized unexpectedly by one person involved in the research process. (MIT, 2008)

4. *Partial Innovation*

   Partial and continued innovation happens in the context of compatibility when the presence of an interface compatibility is designed or used for gradual improvements of single components of an entire product. Examples of this can be considered to be the interface for memory cards in electronic devices such as cellphones and media players which can be gradually exchanged as the same sized part contains more or faster memory. The compatibility factor here is put to the advantage of designing a product which has an inherent potential of gradual improvement that is built in from the very beginning. Taking into account ever more rapid innovations in fields such as digital electronics and material science, this consideration in the process of designing products can be considered as crucial in prolonging the value of products towards the user.

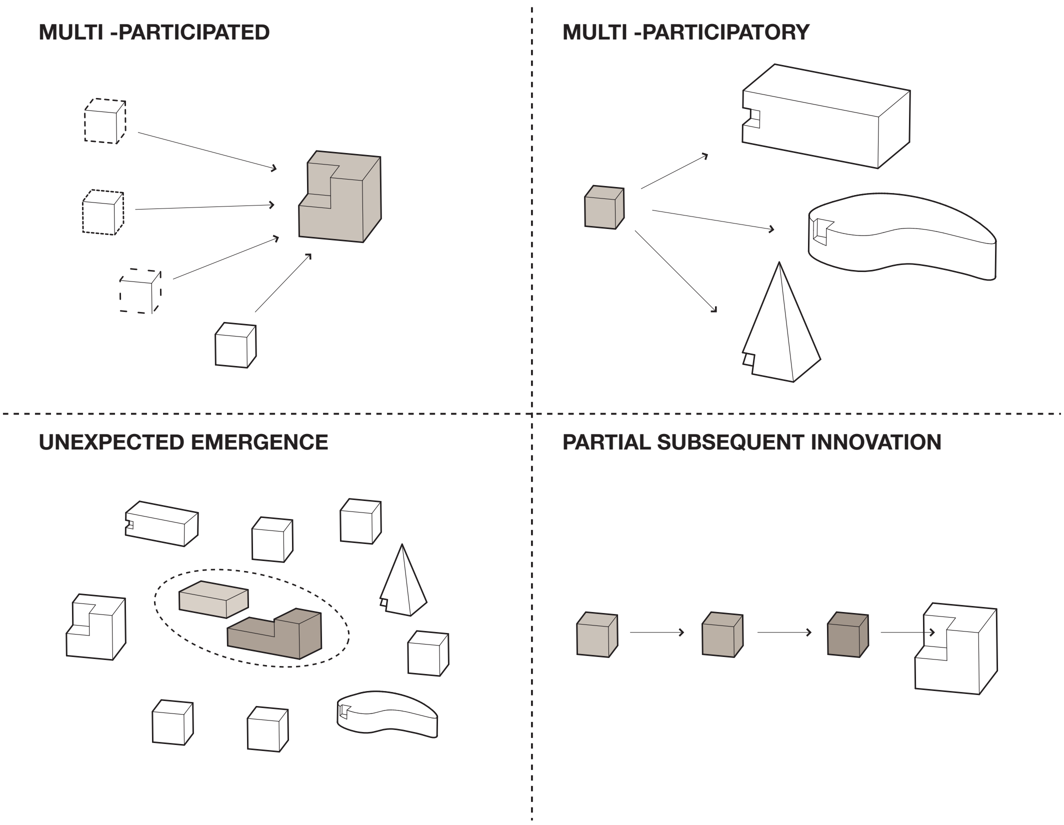


Figure 3.4: Compatibility for innovation

All these dynamics of innovation which result from compatibility of parts in product systems happen on the basis of the common consideration that if more players work on products and technologies that function well together, the overall beneficial effect of their effort will be multiplied and that if many product systems make use of components and parts developed by multiple players, the result will be a more beneficial situation than working out individual solutions.

Recognizing the benefits of standardization of a product for consumers or users and companies, (Farrell & Saloner, 1985) examines "whether these standardization benefits can 'trap' an industry in an obsolete or inferior standard when there is a better alternative available" and comes to the conclusion that there can indeed be such an inefficient inertia or inefficient innovation difficult to overcome. In such cases the establishment of standards which initially had helped innovation to take ground and diffuse, in a later stage can, as a matter of fact, hamper the very continuation of this innovation path because of the dominance and diffusion they have obtained.

More on a business strategy side (Ibid.) indicate how "a dominant firm may choose to remain incompatible with a rival because it will suffer a substantial decline in market share if it becomes compatible,[…]". An example for such a situation from the software industry is the CAD file format .dwg retained by Autodesk and which is notoriously not released or licensed to competing software companies in its most recent version. The connection between a project coded in the .dwg file format and a different CAD program is enabled only through either older file format versions or different data exchange file formats. In both cases these modalities of connection through an exchange file format are limited in functionality representing in fact a digital equivalent of the classical situation of adapters that I will describe below.

3.2.2 Network Externalities

So far I have identified dynamics in which compatibility between products and parts plays a role in product innovation and how this relates to the design of connections. A different but correlated point regards the compatibility of elements that are part of a system of products or a network.

These are situations, in which one user's value for a product increases when another user has a compatible one such as in the classically cited case of the telephone network or personal computer software. If I chose to use a computer I value the fact that also others do chose my same operating system because this suggests that more developers will be writing software programs for that platform allowing for interchangeability of files with these users and faster and more intense development cycles. Similarly, owning a telephone has a value only if other people I will want to connect with also do own a telephone that is compatible with the transmission network my phone is using.

Katz and Shapiro (Katz & Shapiro, 1985) called the effect, in which consumers value a product more highly when it is *compatible* with other correlated products, *network externalities*. To give more examples, *network externalities* can be identified in the product system of various kinds of media players where the different technologies of the players are heavily influenced by the availability and compatibility with various media supports such as LP's, CD's, audio tapes and similar. Another example would be again the SLR camera, which assumes a substantial part of its value to the user from the fact that it is compatible with a large number of lenses and other accessories like flashes or tripods. The SLR camera is a typical example of a product structure based on a base-platform that gets enriched through a range of elements to alter and expand its functionality. Moreover, it is an extreme case of such a system structure since the base-platform, as a matter of fact, does not have any exploitable functionality if not connected with at least one lens element.

Being confronted with such a type of product the user thus not only opts for the product of his choice but for an entire product system of future connections. Choosing the platform correlates with a lock-in effect in terms that it limits the choice of added functionality to compatible elements that are or will be available in the future.

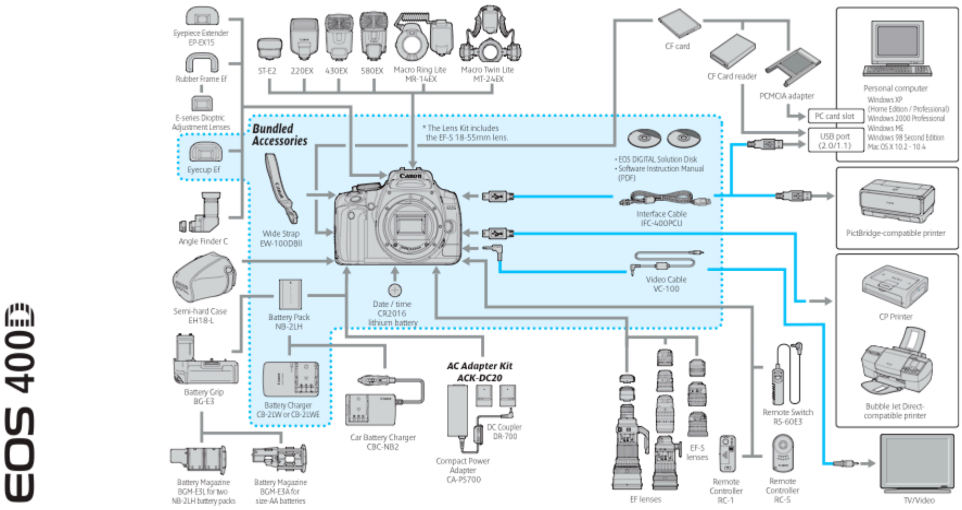


Figure 3.5: SLR camera system with compatible lenses, tripods, flashes and other accessories.

Three possible sources of such *network externalities* identified by (Ibid.) relate to the areas of direct physical effect, indirect effects and post-purchase services of compatibility. Linking these discussions to the field of industrial design I have developed the diagram in figure 3.6 on the basis of this three-division.

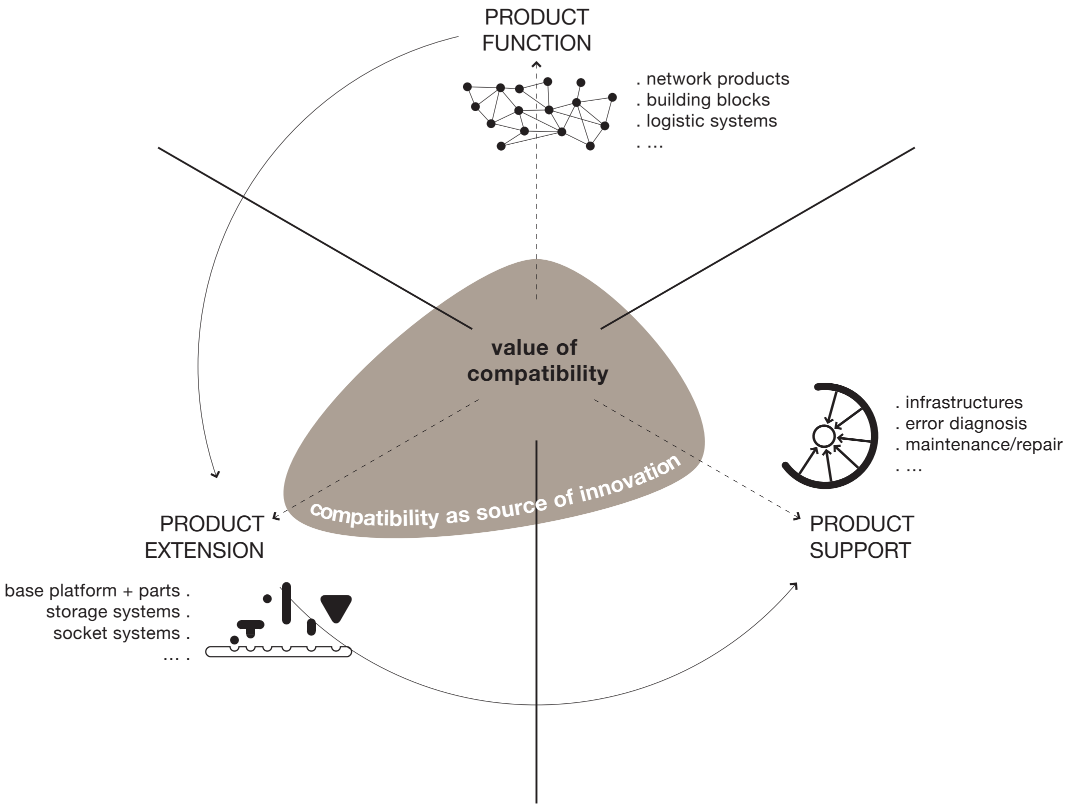


Figure 3.6: Three sources of value creation by compatibility

Correlating the three sources of value creation to aspects closer related to industrial design one can speak of them in terms of *product function*, *product extension* and *product support*. These three source areas can be viewed in a time sequence considering the progressiveness in which a user comes into contact with each of them one after the other or also in terms of apparent proximity to the considered product.

Compatibility for network externalities from *direct physical effect* can be related to the core aspect of the *product function* in that it considers compatibly issues between parts which are directly related with the main functions expected from the product. This field considers network products such as cellphones, lamp bulbs or digital file formats, building blocks such as children games or furniture systems and logistic systems such as the RFID tag on products or the more classic barcode in its 1D or 2D versions. In all these cases the value derives from the fact that having many elements being compatible enhances the overall functionality of each single one of them.

In the case of network externalities coming from *indirect effects*, related to the field of design they can be considered in terms of *product extensions*. In such cases products do work on their own without other compatible products but through compatible elements various new, improved or modified functions can be disclosed. In general this case is observable in most product configurations that are built on a base product that is in itself functional but that can be expanded. As such, a multi-tool product such as the Leatherman series can be considered in its use value according to additional tool parts that can be connected with the main tool or a system of conference chairs be evaluated in terms of the correlated accessory range such as brackets to join multiple chairs, note taking tables or armrests that can be linked to the main product.

The field of product extensions as a source of value attributed by the user to the overall product system has a particular interesting aspect if considered in its time dimension. Users might evaluate products differently on the basis on their expectation of future compatibility with extension parts that do not exist at the moment of sale. Such expectations can be based either on the trust in a company's strategy and behavior based on past actions or/and it can be based on characteristics of product design in the sense that the product structure and form contains and communicates concrete possibilities of connectivity and thus expandability of the functional potential of products.

The third field of sources of value for a product gained from compatibility in terms of network externalities lies in the area of post-purchase services which can be related to as *product support*. This field is of particular interest to products that are part or do heavily depend on infrastructures of various kinds. In the usage of wifi enabled devices the value of such devices is correlated to the wide availability of wifi signal infrastructure while the user of an electrical car attributes value to the wide availability of public recharge stations. Other aspects of product support compatibility as a source of value for the use of a product lie in the aspects of maintenance and error correction. In terms of the industrial design of products considering this source of product value means considering the existence of such support agents and networks within which to position the product to be designed or otherwise the planning and development of such dynamics of product support and the necessary connections with it.

3.2.3 Asymmetric compatibility

A particular case of product compatibility with interesting design implications is that of *asymmetric compatibility*. In this case one product is compatible with others while the same is not true for the opposite direction.

An example of such a case is the once much used safety razor blade. In 1904 King Camp Gillette's razor company introduced its unique and patented disposable safety razor blade with the characteristic three holes that made it fit its razors.

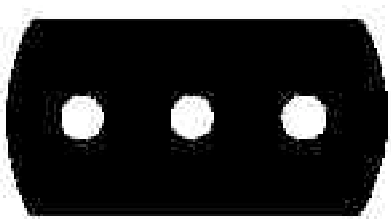


Figure 3.7: 1903 Gillette safety razor blade design

When Gillette's patent expired in 1921, other companies were free to produce razor blades compatible with Gillette's razors of which by then 15 million pieces had been sold. Henry J. Gaisman and his company Probak Corporation in 1926 introduced a razor and razor blade combination that was very similar to Gillette's product. However the interface between blade and razor was slightly different in a way that allowed Probak's blades to also fit into Gillette's razors, while the other way round, Gillette's blades would not fit into Probak's razors because of the non correspondence of the cap configuration of Probak's razors.

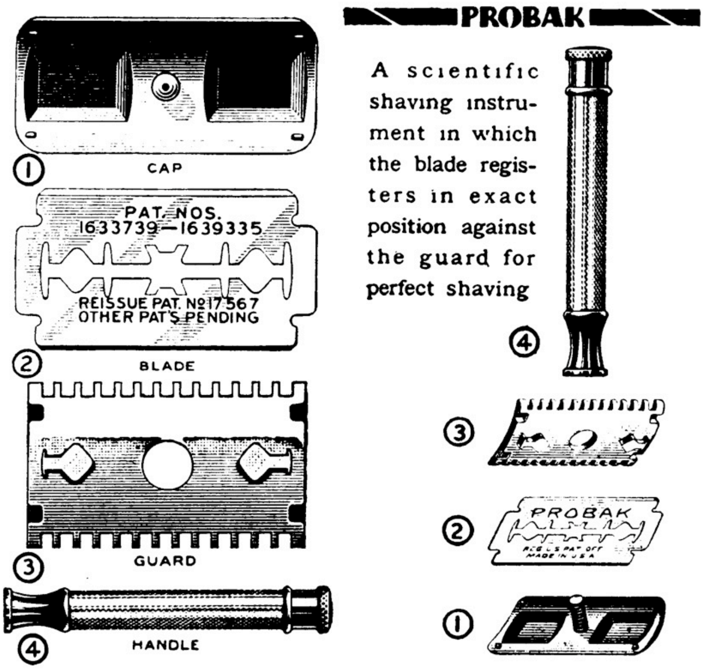


Figure 3.8: The Probak Razor and Razor blade product system from 1926

It was by the design of the interface that allowed Probak's razor blades to be used with the razors of its creator company as well as adding value to a large number of existing Gillette razors with which it was compatible. This case is an example for a situation in which one company tends to obtain network externalities for its own products while at the same time avoiding a similar privilege for its competitors (Farrell & Saloner, 1985). The design of the connecting interfaces between parts is determinant in situations like this.

3.2.4 Incompatibility for innovation

Above, I have identify a series of dynamics in which compatibility is part of innovation processes that have repercussions on the way industrial design operates in regard to connections. Does this imply that design choices that generate incompatibilities will instead become obstacles to innovation in any case?

One of the commonly used arguments in favor of incompatibility for innovation is its potential of diversity.

Constraints from connectivity with existing products and technologies or standards do in part lead to equal answers to equal problems. Introducing in this way economies of scale and other favorable circumstances outlined above, diversity can indeed give way to uniformity. Instead, opting for solutions that do not observe the fitting together with existing elements can introduce elements of diversity and one could argue that the more diverse solutions towards commonly recognized problems exist, the more likely it is that possibilities for better solutions emerge.

Secondly, respecting the compatibility with existing parts makes the design of new parts more complicated by adding additional constrains. This consideration can become critical in areas where material and technological innovations allow for increasingly smaller sizes of parts and connectors. An example for such a case are memory cards that fit into digital devices in which the design decision to be made is whether to allow for compatibility with a large part of existing components having larger dimensions or instead break this compatibility in order to harness smaller size components that would benefit the overall product.

A third case in favor of incompatibility and innovation lies in the reward for the innovator. As in the case of the Gillette razor blades of 1904, patent policy effectively blocked any design solutions compatible with that product. While this situation can arguably be regarded as a way of slowing down improvements on the basis of past inventions, such a "winner takes it all" approach does pose an enormous incentive for product innovations to be generated in first place.

Lastly, incompatibility can be identified as a mentor of innovation in all these situations where product systems undergo radical changes of technology. Designers and manufacturers in such situations are confronted with the decision of either sticking with the existing and compatible technology or instead make use of technological changes that provide new benefits on the basis of breaking with the existing way of doing things.

A notable case observable since many years is the struggle of understanding how to introduce, on a large scale, electrical personal vehicles on our streets and in our cities. Passing from petrol driven cars to electricity powered vehicles presents a clear cut in a series of technology systems that enable these methods of transportation. While petrol engines link up with an existing and large network of support in terms of refill and maintenance, electric cars do not have the necessary complimentary networks of these extents. What emerged form this situation is a compromise which by many is judged a necessarily transitory one in the form of the hybrid engine. A petrol engine drives the car most of the time but from the car's functioning motion energy is extrapolated in certain moments and is converted into electrical energy and subsequently used to power the vehicle in other moments.

This solution of maintaining the compatibility with the existing network of technology represented by petrol stations resulted in a product structure which is far more complex than any of the two alternatives but which was favored instead of a clear cut radical change that would have meant opting for incompatibility.

Figure 3.9: Diesel engine, Hybrid engine, Electrical engine

Another example in which radical change associated with incompatibility was arguably associated with benefits to a product's user base regards a case in which the value of existing products or technologies is based on important network externalities which introduce an inertia in switching even to a superior product standard. The classical example of the QWERTY keyboard, often referred to in design literature, maintained its dominance even in light of the occurrence of the arguably superior standard of the Dvorak keyboard layout. In this case the large installed base of existing keyboards can be seen as an example of such a dynamic of an excess inertia.

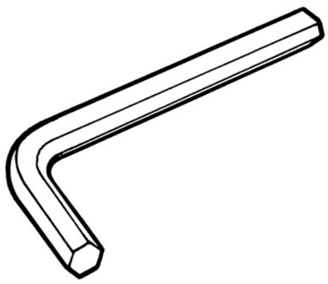


Figure 3.10: The allen key - number 00001 has been the classic IKEA mounting tool for half a century and comes with most furniture products to be self-assembled by the customer.

User knowledge of a product is another argument that can lead to sacrificing a potential innovation for the benefit of compatibility. The process of users understanding and learning to use products and technologies is a worthwhile consideration in the overall value associated with a product. Sticking with modalities familiar to the user base eases the users' approach to new parts of a product system on one side and enables a gradual accumulation of competence in dealing with such products on the other. In the best case, such continuity leads to forms of mastery providing increasing gratification for the user while on the more pragmatical side it reduces error in the usage of goods. Considerations which might be part of the reason why a company such as Ikea has chosen to carry on using the same connecting element and tool for decades, possibly missing out occasions of product innovation but assuring its customer base ease in dealing with the assembly activity which is left to them.

3.3 Enabling compatibility

3.3.1 The adapter

Having identified various incentives for both compatible as well as incompatible connections, one ought to contemplate that decisions made in this regard might be revised *ex-post*. Compatibilities might be broken at later stages of product development as well as it might turn out that compatibility is required where there was none at the design stage. Necessities such as these have lead to a very peculiar element in the considerations of compatibility of connections: the adapter.

As adapter we understand an element which interfaces two technologies, products or parts with each other that were not initially meant to fit together and by themselves do not. As such these interface elements can be thought of as having critical roles in the transition process from an existing technology to a newer technology on the one side and on the other, to reconcile the seemingly opposites of having a large product variety while still maintaining interoperability and connectivity within large networks of complementary products, parts and product systems. This second aspect however would be wholy true only if such adapters would provide a full substitution for the use of another other technology. In most cases this is not so, instead the use of adapters represents in most cases an approximation of the use scenario of the other technology, not being equivalent to it (Gilbert, 1992).

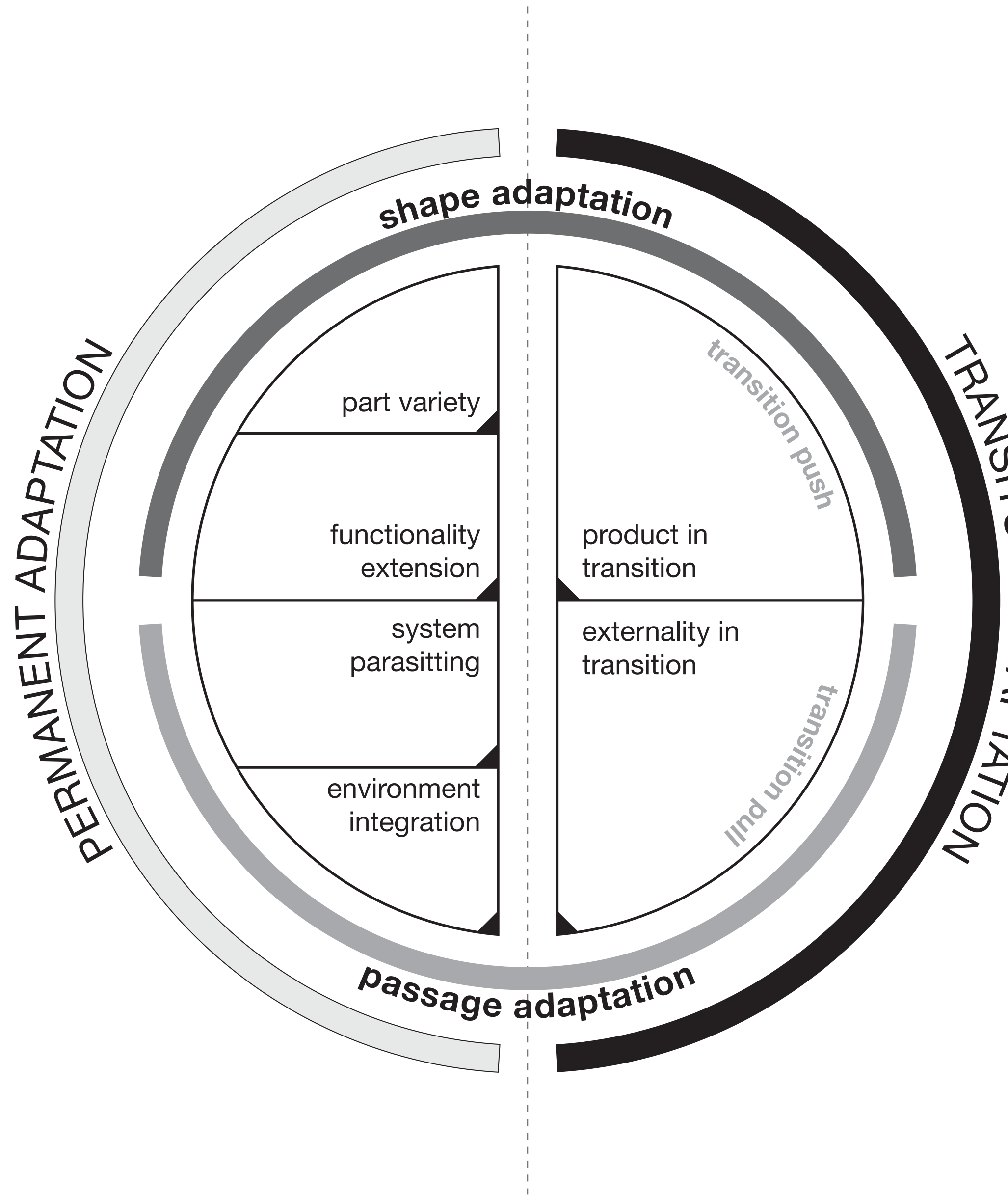


Figure 3.11: Adapter characteristics

From the analysis of a large variety of adapter products and the dynamic they are involved in as well as literature on the topic I have synthesized several relevant aspects in Figure 3.11.

A first large and important distinction is related to the time dynamic of an adapter's role. Is it an adapter that is designed to ease the transition between one product or technology and another while still being able to interface with correlated products? Or is the objective to design an adapter that will play a more permanent role in use scenarios?

A second distinction is that between adapters that make two parts fit or adapters that focus on what passes through the connection of parts. In the first part we would consider adapters that translate between two parts with non-corresponding shape geometry while in those of the other kind, the adapter (or in these cases often referred to as the converter) alters what passes across the connection in order to translate it into a compatible format for both connecting sides.

Permanent Adapters

Subsequently we can identify four subcategories of permanent adapters: firstly those that address the above discussed contradiction between compatibility and variety. Adapters in this case are often part of product systems and conceived together with the development of the products themselves. These adapters allow products to interface with a wider variety of correlated products than their own specification would allow. Often this is used in cases in which the most relevant externalities fit with a product while for those less often used, an adapter is provided.

Secondly, adapters can play a permanent role in that they extend the functionality of a product. This is particularly useful when introducing additional functionality features to a product *ex-post*. The new functionality might not aim at substituting any of the previous ones which gives this adapter a permanent characteristic.

The third category of permanent adapters relates to a dynamic I want to call *system parasitizing*.

With this I describe all these situations where a new product makes use of an already existing product or system for a purpose that is different from its original intention. An adapter is the functional link that adopts one product functionality with that of the other one. A classic example of this type of permanent adapters are those that interface the cigarette lighter integrated in most cars with various electric devices.[8]

[8] An interesting circumstance of the cigarette lighters built into cars is that these were originally designed for the use with cigars and are in fact more correctly called Cigar lighter receptacle. For this reason they are unusually large in size and light at the edges and not in the center which is suitable for cigars but much less so for now more commonly used cigarettes. These sockets have not been originally designed to be used as electrical power supplies and are in fact not well suited for this purpose for their small gauge wiring often used and the consequence of unreliable power connection as well as their inadequacy for high power supplies. Nonetheless, they have become extremely popular interfaces for a wide range of uses correlated with electrical power driven products fitted by adapters.

Figure 3.12: Cigar lighter receptacle. An example of an adapter showing a parasitic behavior.

This approach of parasitizing into already existing product systems is extremely relevant for the discipline and activity of industrial design. To a full extend it emphasizes aspects of the design process such as analysis of existing product environments, existing use habits of the user group one designs a product for and making best use of resources in terms of valorizing already existing context elements for new products and services. This modality of creating compatibility between one product system and another one with different original functional intents, in its design approach, can be compared to a certain extent to the process of *hacking*[9].

The last group of permanent adapters are those that relate products to different environmental contexts. An example are baby seat adapters for car passenger seats or the height adaptability feature in furniture legs supporting cupboards or similar objects in level on the basis of uneven floors. Also in this group we shall consider adapters for electrical plugs of different geographic contexts. These adapters can be considered permanent even though they implicitly address the changing nature of environments a product might be interfaced with.

Transitory Adapters

While these above four groups of adapters are those of a permanent nature, the other two categories refer to adapters of a transitory nature addressing situations of transition from one product or technology to another, considering cases in which either the product or the externalities in transition. In their role they play a critical contribution to dynamics of product innovation and as we shall see these dynamics present some not so obvious complications which one ought to consider in approaching their design.

Compatibility enabled by an adapter can act as a deterrent for innovation in the transitional phase from an existing to a newer technology. To understand how, it is necessary to appreciate the difference between the two possible directions an adapter might cater for. In one case, an adapter enables an existing technology to remain compatible with elements of a new technology. This ensures and is motivated by the fact that existing

[9] The MIT community is one with a longstanding tradition of hacks, some which can be seen under http://hacks.mit.edu/ where also a hacker's ethic is stated: http://hacks.mit.edu/Hacks/misc/ethics.html

products maintain their use value. In the other case, an adopter makes sure that a new technology which has not yet a broad user base can tap into the large network of existing complimentary products or network externalities (Katz & Shapiro, 1985). Considering that an adapter, in most cases does not encompass the complete functionality of a product system, the balance between two distinct technologies that are in a phase of transition, is a biased one with one of them being dominant.

Now, considering the standpoint of an industrial designer interested in enabling a transition from an existing product or technology towards a newer and improved one, the aim is to construct an adaptation system that facilitates this transition and in such a situation the direction of the adapter becomes critical.

If the "wrong" user group makes use of such converters, that is, the user group of the new technology, there is little incentive to abandon the old technology and even though the installed base group of new technology grows larger than that of the old technology a situation can emerge in which the old technology still remains the *de facto* standard. Put in economic terms: "The new consumer group will be a minority at the advent of the new technology and will remain so if the new consumer group continues to buy converters" (Choi, 1997).

A present day example of such a case is the video connector type on computers. When IBM in 1987 introduced the analog "Video Graphics Array" (VGA) connector type for connecting a personal computer's video card with external visualization peripherals (Polsson, 2008) it soon became the standard video connection of PCs. With the gradual introduction of the digital connector type "Digital Visual Interface" (DVI) in 1999 by the Digital Display Working Group (Group, 1999), a new standard for an improved PC-video peripheral was introduced. Since the new connector type is not compatible as such with the old one, an adapter was released that would allow new personal computers with DVI connector to attach to older peripherals having a VGA connector. This created a situation which is still largely unchanged today, that the VGA connector type is still the *de facto* standard most diffused amongst PCs and video peripherals like projectors and displays. In this case we can observe a real world example of what Choi described as giving the adapter to the "wrong" user group and as a consequence in fact humbling innovation.

There is another dynamic in which the existence of converters may not facilitate innovation. Converters can easily be seen as providing for a best possible compromise between having a wide variety of product specifications and technologies and at the same time having the interoperability between them through converters. The benefit of such a situation is however limited in the case that network externalities are important for the overall value of a product to its users. In this case, a fragmentation of the product spectrum into incompatible product and technology typologies may well create a hindrance towards a wide variety of complementary products and as a consequence reduce the social benefit of the comprehensive product system (Farrell & Saloner, 1992).

3.3.2 Adapters and new developments

Now, how do adapters evolve under the light of recent technological developments? One large aspect is without doubt connotated by the increasing diffusion of digital technology in an increasing number of products. Products connecting with other products by exchanging digital information have opened up the possibility of rewriting the adapter's functionality every time necessary.

In computer programming Application programming interfaces (API)[10] are just one of the software module types that resemble the functionality of physical adapters but with the advantage of not manifesting themselves in material ways allowing for change and adaptation to an evolving context more easily.

In this respect it becomes increasingly interesting to see how the combination of digital information and physical elements in the articulation of connections leads to possibilities of updating only the software adapter within physical objects. How does this new possibility translate into increased longevity of products?

I believe we have to start considering products that reflect distinct internal speeds in terms of life cycle, the *solid* and the *soft* part. While the part of a product that deals with digital information can undergo repeated and frequent change and adaptation, the physical part of it can remain unchanged. This would result in an overall product that adapts well to a fast changing environment without necessitating the substitution of the entire product to keep up with innovation dynamics.

An exciting approach to this otherwise little treated theme in the design context can be found in (Manzini & Susani, 1995). In the context of different speeds of change that can be addressed in such a way, software adapters evidently reformulate the question and terms of durability and longevity of the so-called solid side of things in new and interesting ways.

Connecting between products of digital information, a noteworthy recent phenomenon relating to dynamics of adaptation are the so called *mashups*. The term originates from the musical mash-up that indicates when in a piece of music vocal and instrumental tracks from different songs are synchronized and overlaid to compose a new piece of music.

In dealing with digital information a" mashup is a digital media file containing any or all of text, graphics, audio, video and animation drawn from pre-existing sources, to create a new derivative work." (Wikipedia) Well known examples of mashups can be found on several websites on which a geographic map is overlaid with visual indicators that are linked to data from an external database. In this way, the position of car fleets are visualized or the fluidity of traffic along roads is indicated graphically on a street map. In such cases two or more sources of digitally stored information are fused into one new application.

[10] An application programming interface (API) is a set of declarations of the functions (or procedures) that an operating system, library or service provides to support requests made by computer programs. (Orenstein)

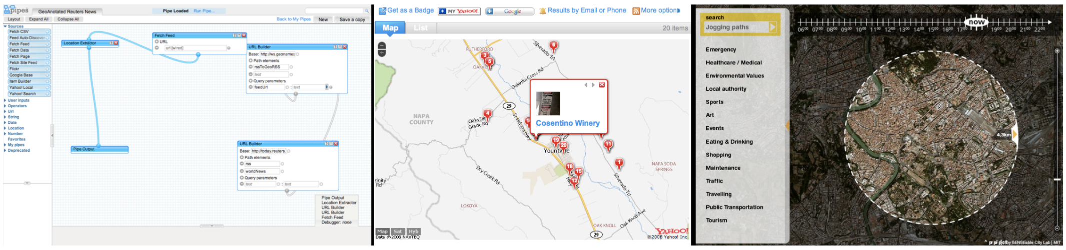


Figure 3.13: Interfaces of mashup applications. Yahoo pipes online application to create mashups integrating different kinds of source data (left), a geoweb mashup application made with yahoo pipes (middle), a prototype interface for the WikiCity project (right)

The WikiCity project is a custom made example of a mashup integrating multiple sources into one digital application, overlaying real time data feeds related to cellphone positions, public transport positions, location based event information and news feeds over a city map. It is custom made since not all the data streams existed already but some of them were specifically generated and processed for this project. Combining such diverse types of data into one application results into something more than the sum of parts for the user since it can respond to queries such as "how to arrive at a given event with public transport in the fastest way considering the real time traffic situation" or " where is the nearest jogging path", considering the user's health condition, air pollution as well as noise level and traffic congestion data.

What is interesting for this study on connections is to observe the ease with which different digital products in the form of data-sets are combined to form new types of products. Through APIs, different data streams can be integrated to form a new whole, a new application, a new product with functionalities and use characteristics not directly ascribable to any single source of the mashup. What might be the physical equivalent of such digital connections or how can such new digital entities be formed through manipulation of physical matter?

How can physical elements be "mashed up" together with digital sources. Compared to conventional digital data streams, physical objects have the characteristic of being present in a specific physical space and time. These characteristics are therefore interesting types of data to combine with digital sources due to the time and location relevance of many mashups.

Similar to API's mentioned above, the common elements of digital exchange file formats represent a case of which to take note when considering adapter elements for connections. Such exchange file formats (like those of .dxf, .iges or others in their various contexts) are adapters by all means. They link two products (digital tools in the form of programs cooperating for the creation of digital products) in a way that has several characteristics in common with physical adapters. Exchange file formats tend to not convey the complete functionality but only a limited set of them, they can be unidirectional or bidirectional as well as being either transitory or permanent.

The contactless interaction between devices is an interesting development since in many cases it avoids the need of physical adapters. Many cases related to this field can be found in the links between electronic devices such as PCs and mobile phones and their peripherals. As long as physical connections are required, the geometric fit of connectors is a first barrier of compatibility and adapters play a fundamental role in this dynamic. In the absence of a physical connection between devices, the adapter is shifted into the digital domain without a material manifestation. Code can be written, rewritten and distributed without much effort and at different stages in the products' life cycle, contactless devices can be made compatible with other devices and products without the need of physical objects contributing to this form of adaptation.

A last example of recent developments related to the adapter concept is based on the still very relevant miniaturization of parts. Since the development of the microprocessor in the 1970's miniaturization has been one driving force for the design discipline to reconsider its role and methods of analysis and operation and it seems that this continues just so as ever new aspects of material culture are embraced by the dynamic.

While means of storing memory in the recent past maintained their form factor for considerable time spans (such as in the case of audio tapes, LP's, books and others), storage devices of digital information continue its size reduction in ever increasing speeds. The speed of this size reduction has accelerated to such an extend that even during the already short life span of electronic devices such as cameras, media players or cellphones, the size factor of their memory storage devices shrinks. In the case of digital memory cards, this leads to the noteworthy situation in which one product becomes the adapter for its successor in a sort of *Matryoshka* doll fashion, the new technology vanishes in the size of the previous one which maintains its functionality by continuing to guarantee compatible connections.

Figure 3.14: Matryoshka dolls in which one puppet fits perfectly into its larger sized version until all puppets disappear into the largest one. On the right an illustration of a memory card adapter (from United States Patent 7179129) with the larger sized elements not actually being memory cards as such but adapters for their newer, smaller dimensioned equivalents.

3.4 Compatibility in time

Time has already been introduced as an aspect relevant to connection design in the above discussion of the adapter element and how it can enable compatibility at a later stage or ease the transition towards new technologies. More in general, there are three large time issues in compatibility and which are compatibility at present, backward compatibility and forward compatibility.

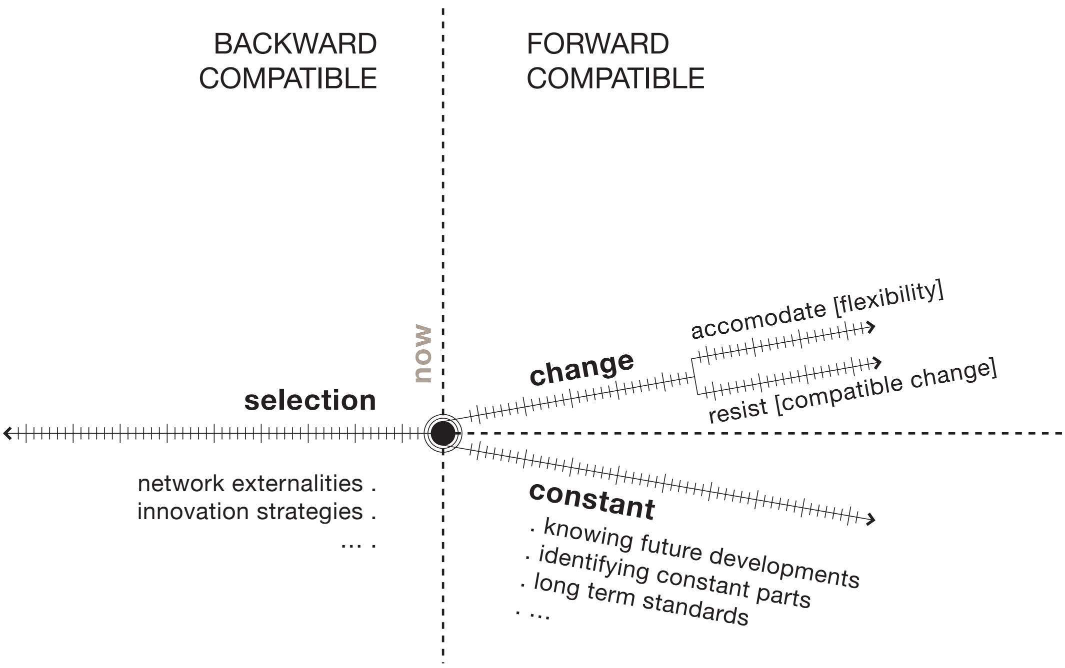


Figure 3.15: Backward and forward compatibility of connections in perspective

Out of these three the most complicated to deal with and most difficult to achieve in the design of connections is the one oriented to future changes. Forward compatibility is the ability of a product or system to cope with connections intended for future versions of itself. The difficulty for designer lies in the fact that it is not always evident with what a product will be confronted in the future.

In order to achieve future compatibility for the connections of a product, the two main approaches I have identified relate to either opting for future constants or instead focusing on future change. Basing a product on future constants means devising a product that can remain unchanged and still remain relevant in the context of future change. To obtain this, a designer needs to identify elements of a product context that are likely to remain stable and make use of long term standards strategically in the design of his product.

The alternative approach focuses on developing a product keeping in mind all those elements that ought to change in the future. A product can remain relevant being directly confronted with future change if it can adapt flexibly or if it manages to resist such a change without own alterations.

Future compatibility is a powerful design approach because it can increase the longevity of a product, making it fit to remain relevant in a future context and by this avoiding the need for product replacement.

An example of forward compatibility is a web browser that ignores the HTML tags that it does not yet recognize. Another example of forward compatibility are all those products which consider the use of adapters in their normal state of operation, by this accommodating future change through this flexibility zone.

Considering a socio-technical environment that is connotated by an increasing rate of change, forward compatibility is becoming at the same time increasingly important and at the same time ever more difficult to achieve. It boils down to how a product will connect with elements of its future context sphere and I believe that the most promising way to approach this is being a design approach that integrates possibilities of adaptation, reconfiguration and extension into its products upon conception.

Adam Greenfield has pointedly summed up this strategy in his presentation at MIT[11] by call for the "building of objects with hooks" referring specifically to digitally enhanced artifacts. Integrating computing into all sorts of new objects in our environment, Greenfield emphasized the fact of creating these objects in a way so that other objects or components can be connected to them at a later stage, that they can be expandable and upgradable on an open platform basis.

On the opposite end of forward compatibility lies backward compatibility which is concerned that a part or product can take the part of an older element and interact well with parts that were designed for that older product. It is easier to achieve than forwards compatibility since the different system parts are known to the designer. The design choices linked to backward compatibility are mainly linked with making use of existing network externalities and are strategic choices of how to innovate while still tapping into existing networks and at the same time how to maintain these networks of products relevant for newer products.

A curious technique of backward compatibility is emulation: one device tricks another device by imitation in order to achieve compatibility between the parts and functional commands.

3.5 Compatibility in space

Due to sociopolitical and economical changes on one side and socio-technical contexts on the other a situation has emerged in recent years in which the development and design of parts that compose a product are to an increasing extent developed and produced in multiple locations often at large geographic as well as cultural distances from each other. On an enterprise level, this means that companies constitute a network of suppliers that take care of either or both development and manufacture or within a

[11]Adam Greenfield has been giving a talk organized by the SENSEable City Lab at MIT on April 14th, 2008 in building 3 at the MIT campus in Cambridge, Massachusetts.

single company structure company sites are initiated at distant locations. The problem of how to make these different sites of development activity meet and parts that come from them connect into a single assembled product trickles down to the sphere of industrial design in multiple ways and we shall see, what specific and new situations and considerations arise from this new context.

Considering a network of development and production sites that interact in the creation of a product, it becomes evident that in any situation a key element is *exchange*.

In the development cycle, a part developed in one site turns into a set of specifications for those developed in others that need to connect to it during assembly. The design specifications for these other parts become therefore instructions to be followed by designers which need to be treated with delicacy. Delicacy in a way that altering these specifications or ignoring them would result in possible difficulties in connecting the parts successfully to form a product at a later stage.

If however the necessity arises within one development unit to alter the specifications for product improvements on their side, this can happen smoothly only if it is correlated by an exchange of information with the other unit that had initially produced the specifications and also with all the others involved. Limiting this exchange to the shipment of physical objects implies larger intervals of time between one exchange of information and the next. A part might be modified in one development unit and by shipping the part, the drawings or the specifications to the other units, the information about the change is passed on assuring connectivity between parts. The more rapid this exchange of information happens, the less time is lost by other design groups in developing in a direction which might be abandoned.

In an ideal situation, therefore, such exchange of information between all sites happens on a real time basis, meaning that as soon as one unit changes parts that effect connections with parts developed elsewhere these other units are aware of the changes and can integrate them into their parts and consider them for further development. Exchange of information in this way becomes continuous, approximating a situation of physical proximity.

The case of the last moment difficulties encountered in the development process of the now released Airbus A380 aircraft illustrates well the complexities involved in putting together parts that originate in different development and manufacturing contexts. In this case I suggest to consider such complexities at two levels: The first level concerns the tools used by development environments to generate parts that fit together with those developed elsewhere. The second level instead concerns an actual problem of connectivity within the product itself and its increasing complexity resulting from scale[12].

Airbus is a peculiar manufacturer due to the fact that from its very beginning in 1970, the fact of consisting in multiple development facilities located in different national contexts not only was a given but was the core idea of a pan-european aircraft

[12]This second level related to scale will be treated in the final chapter about scale in connections later on.

manufacturer. Different parts of the aircrafts get developed and produced in different countries and then shipped to the Toulouse, France facility which assembles all parts.

When, in 2006, at the end of the A-380's development cycle, parts from the German plant arrived in Toulouse not assembled to specifications and structural changes in the plane had to be compensated in redeveloping parts of the wiring, a trickle-down effect was started that brought to the light what impact it had that within the various Airbus development centers, different versions of CAD software were in use, generating file formats that were incompatible between each other. Specifically, engineers in Germany and Spain were working with CATIA[13] V4 while CATIA V5 was used in the UK and France even though it was known that the file formats of these two versions were incompatible. This incompatibility became pressing at the moment that structural changes of the plane required a reorganization of the wiring of the plane since these connections were now too short. The problem of wiring and electrical connection within a product of these dimensions is impressive as such, consisting in no less than 530 km of cables, 100.000 wires and 40.300 connectors (Wong, 2006). Not being able to integrate one development with the other, these updates could not be reflected in real time within the comprehensive digital model of the plane but had to be hand inserted with the respective delay in development time.[14]

The compatibility issue that seems of interest to my study here is how, in an interconnected network of development locations, compatibility of parts moves from being an issue of setting up static product specifications that subsequently guide each of the network's parts, towards representing a dynamic environment in continuous flux. As development proceeds at separate locations, so do connectivity specifications and requirements for other parts that need to connect to them, and the same happens in all locations involved. Digital design software can be a powerful tool for integrating these dynamics in a way that leads to an overall beneficial development context since they allow for changes in interface design to show up in all development contexts involved and can be addressed. This exchange happens and needs to happen instantly so that one unit can implement the changes which become new prerequisites for all other units involved.

In the case of the fabrication chain of Dell computers a situation can be observed in which only on the grounds of continuous exchange of information related to interconnected parts of a product allow for a realization of the final products within a very specific supply chain context. A detailed description of how the parts of a DELL notebook come together in (Friedman, 2007, pp. 581-585) illustrates how, starting with one customer order, a very complex system of suppliers located at short distance from the

[13]CATIA is a CAD (Computer Aided Design) program developed by Dessault Systemes and commonly used in various industry sectors.

[14]Documentation on the circumstances of the development difficulties of the Airbus A-380 linked to the software incompatibility and the resulting wire connection problems can be found in various news sources of the period of late 2006. Some good articles on the topic are (Rothman, 2006), (Wong, 2006), (Clark, 2006) and (Sommer, 2008, pp. 90-91)

DELL assembly facility is triggered. Parts are produced to specifics and dispatched in a way that maintains at any given point the information within the system as to what notebook specifically they belong. By means of identification tags, none of the components dispatched from the supplier companies is every an anonymous object but with the start of a customer order the become connected with that order specifically, maintaining a high degree of trackability throughout the entire supply chain.

Logistics in this way attaches digital information to each part, rendering it consequently recognizable and identifiable throughout the different passages of movement. These tags enable different objects for specific connections with a handling system creating a situation in which the movement of products in the supply chain has been transformed from a repeated generic handling to individual moments of tagged identity recognition.

3.6 Incompatibility and user guidance

When illustrating limits and potentials of loose and precise fits in section 3.3.3 I have emphasized how connections that enable a looser fit are more appropriate to accommodate parts which might vary in size and constitution but that in many cases they require a greater user contribution in terms of technique and knowledge on how to implement the link. Instead, connections that require a more precise fit and higher degree of correspondence between the parts can guide the user towards the right connection through this very characteristic of part correspondence.

Imagine a screw and nut connection; it is very difficult to imagine many erroneous ways of connecting these two elements. Instead, thinking of a cord to be tied to a not, many potential failures on the part of the user based on a lack of knowledge and technique are possible.

User guidance in connecting parts can thus be an compelling aspect to consider in designing connections. This approach has the advantage of avoiding the need for separate usage and assembly instructions to guide the user. Integrating these instructions instead in the way the connecting parts are constructed and the way the user is guided alongside the connection process is a way of increasing the overall use value of a connection and subsequently the entire product.

Shape incompatibility is a very direct form that communicates to the user that two parts do not fit together. If all parts of a product that requires connecting by the user had differently shaped parts and connections, a user would know how to position these parts since they would only fit into one specific position of the whole. Leveraging this shape characteristic of connecting parts is useful also in helping the user understand in how to orient a part before connecting it with others. Consider the red dot found at the lens connector of SLR cameras that indicate how to orient the lens over the connection ring before bringing them into contact. Another example are the recent Secure Digital (SD) memory cards which introduced an asymmetric shape factor, different from precedent memory cards, in order to improve user guidance during the process of connecting the card with its connecting slot.

An interesting new direction in designing connecting parts with a supported assembly process in mind can be seen in the usage of customizable production methods such as rapid prototyping. As indicated by (Sass, 2006), in subdividing an object into small enough parts that can be produced with such a method, the possibility opens up to integrate the connection zones into the parts themselves, doing away with separate connector elements. A second aspect is to design each of the connections between the parts differently in order to allow for an automatic recognition of which parts belong together to complete the assembly. If all connectors in an assembly are equal, it is difficult to know where the parts belong, while if a shape distinction is made at that level, the user is guided along the assembly process by the very shape of the parts, no needing in the best case a separate instruction manual.

Attempting to translate this intriguing potential of user guidance in connecting processes towards new types of connections that involve digital data, I believe that this opens up a new field of investigation. How to use perceivable incompatibilities to indicate digital incompatibilities otherwise hidden to the user?

Consider magnetic repulsion to name just one example besides mere shape incompatibility in order to indicate to the user that a part is not appropriately positioned to allow for digital connections. In this way a user could be guided along the composition of his own product and if the perceivable feedback of incompatibility is applied in dynamic ways (such as electronically controlled magnetic force) the instructions for assembly can also vary according to a changing context.

3.7 Compatibility as design strategy

What has been perhaps the most striking outcome of the above analysis is how ambivalent the aspect of compatibility is within the context of industrial design and the design of connections in particular. It became evident from the analysis of examples how compatibility between parts can result in favorable dynamics for product innovation while in other circumstances it can represent a deterrent for such processes.

Key to the understanding of this has been the identification of functional compatibility in connecting parts not as a given or static element but as something that is both part of the design process and that can also evolve after a product's conception. For this to be part of a design approach that views compatibility as a functional element the time component is critical, requiring a designer to reflect about the behavior of materials and technologies in a long term perspective.

The ability to interfere with the molecular structure at the nanoscale of component surfaces opens up material compatibility of a new level. Not only however, as showed the example of the cetacean suction cups used in whale research, does the creative potential of compatibility need to be restricted to the well fitting of parts. Instead a creative approach to this topic especially from the side of industrial design that considers in different ways how the fitting and not fitting of parts and how the change of these dynamics in time can play multiple roles in products still contains ample space for exploration.
New technologies of contactless interaction between parts facilitates dynamics of com-

patibility because of a reduction of the contact to software aspects which are more easily modifiable *ex-post* than the adaptation of material components. In fact, in many new areas of product design that are originating in the digital realm such as mashups presented above, it is at present the incompatibility of data streams and data formats that pose a problem for further integration and the structuring of new products.

As can be observed at present in the case of mashups, compatibility and correspondence of common exchange interfaces tends to come in a second moment after dynamic phases of product invention. . New and innovative developments tend to have difficulties in being compatible because it is difficult to design novel solutions that from the beginning take into consideration a large part of constraints coming from a larger system of correlated products while developing an innovative solution to an identified problem. The phase of reaching compatibility with other products, for a very innovative product instead can be seen as reflecting a moment of stability and consolidation of the novelty, offering further inventiveness on the basis of interaction between the now fitting parts. In one way therefore innovation emerges just because of the presence of compatibility while in the other, accepting incompatible can be a driver for the creation of novel solutions.

The reduction of time in innovation cycles concerning many technologies has notably changed the role of adapters in product systems. While I have discussed different dynamics that involve adapters in the transition from an existing to a new technology, increasingly these enablers for connectivity are exploited to jump innovation steps altogether. For the industrial designer this means a new role for adapters in designing product systems, considering their presence from the very start of a product's life, enabling it to remain compatible with a changing context through the adapter element that enables easier modification or substitution.

Also in this respect, there are still to be exploited opportunities of combining the ease of digital compatibility through immaterial adapters with the consistency of physical parts.

4. Articulation

4.1 The shape and manner of making parts meet

Investigating the filed of making parts meet, one aspect of particular relevance to industrial design is the question of "how" to make parts meet. In considering this question I have therefore contemplated within the concept of articulation those aspects that have to do with the shape or manner in which things come together and a connection is made. A common distinction that is made between the engineering disciplines and the more user centric industrial design discipline is that the latter is concerned with "*how* to make things work" as opposed to "making things work" of the former. Industrial design, in resolving connections is concerned with taking decisions regarding to how to make parts meet, how to connect them and in what modality. In abstract terms, in each design of a product or product system, it defines which are the nodes and which the links of a whole and subsequently which nodes can be connected by which specific links and in what way.

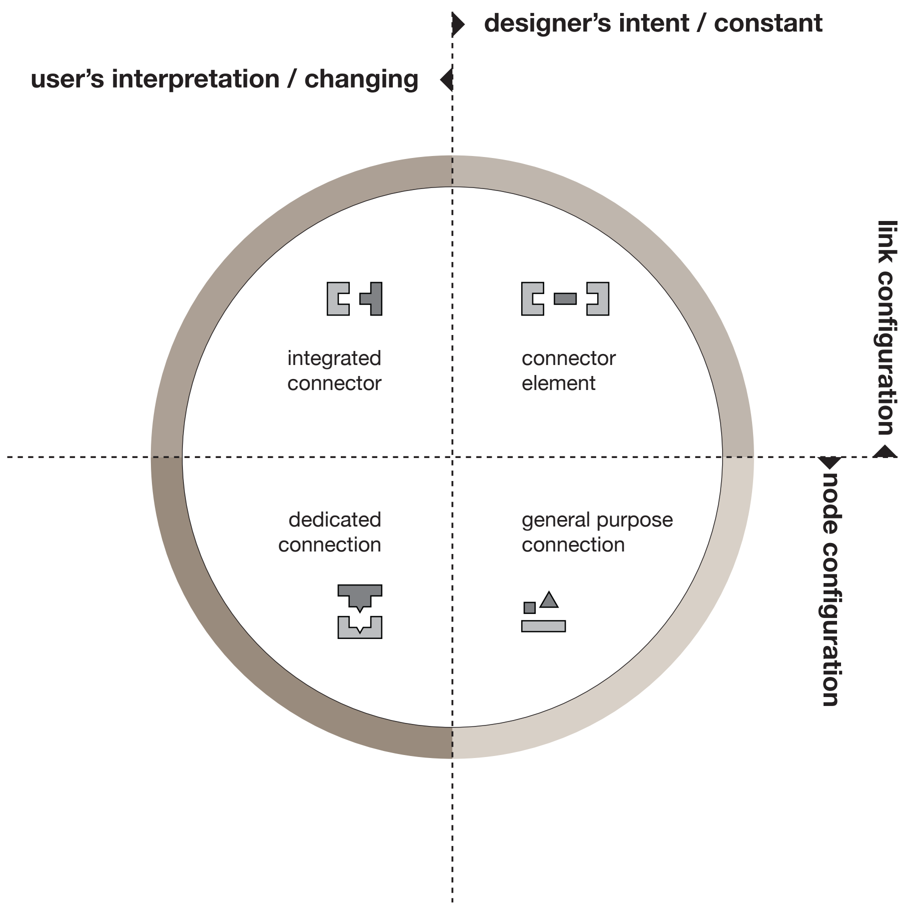


Figure 4.1: Articulation of connections

In taking these decisions during the design process, a designer can approach the vast variety of joining modalities by distinguishing them through what I have attempted to represent by way of a four quadrant diagram. These four quadrants are formed by two major distinctions or connection modalities.

The first distinction focuses on whether it is the designer or the user that contributes the main part of the implementation of a connection. Consider a key lock – by design only one key fits into the lock to open or close it, leaving the user with the only contribution of actuating this connection that has been constrained in large part by the designer of the lock. Instead, consider an adhesive tape – here the designer defines a context of operation of this connection element but it is largely the user that concretizes the shape and manner in which he utilizes this element to form a connection.

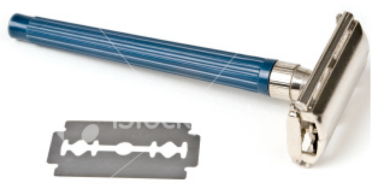
A second distinction can be made between whether the emphasize in designing a connection is put on the links or the nodes. Taking the case from above, connections made by adhesive tape are connections in which the characteristics of the connection in terms of a product have been given to the connecting element, the link element in form of the adhesive tape. This tape in consequence has a series of qualities which allow it, as a link, to joining a wide variety of different parts. Similarly in the case of post-it notes, it is the link in the form of the adhesive stripe, that distinguishes the product which can be applied to a wide variety of surfaces even though the linking part or zone is integrated into the rest of the product part which is the sheet of paper. On the opposite side of this mode of distinguishing is a connection design approach that focuses on the nodes or parts of a connection. What parts can be connected is the question that forms the base consideration of connections in this area. Is it a specific group of parts like in the case of a lamp holder accepting only one specific thread connection of a light bulb or is it instead a cloth peg with the help of which it is possible to grasp and clip together just about anything as long as a certain thickness is not surpassed.

The four quadrants formed by these two distinctions are the following:

Connections with integrated connectors

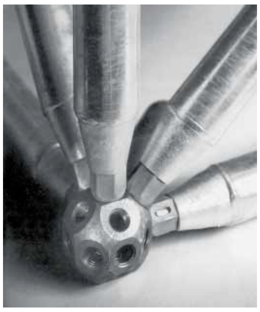
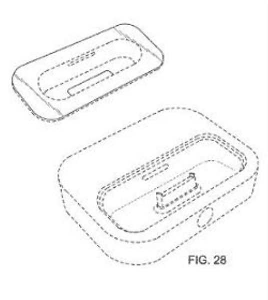
Examples of these connections are cases in which two or more parts connect without the need of a separate connecting element such as lego building blocks or post-it notes but also product combinations like the safety razor holder and the razor blade or the box and its cover to name but a few.





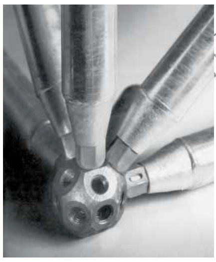
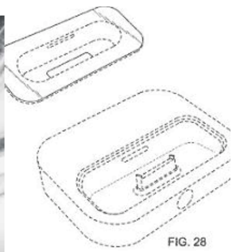

Connections with a separate connector element

Often two or more parts connect under the presence of a separate element that links them together. Examples we can consider in this group are Max Mengeringhausen's Mero connector spatial system made up of struts and nodes, the recent ipod dock connector, cable connections or hooks like the climbing hook.


Dedicated connections joining only specific parts

Under dedicated connections we consider cases in which parts or connectors are designed in a way to only connect with specific other connecting parts. Using examples from the above two categories we can include in this group the screw connection of the Mero system, the ipod dock adapter, the lego bricks and the safety razor handle and blade.


General purpose connections open to a variety of parts

Instead in the group of general purpose connections we consider types of connections which distinguish themselves by the fact of being able to accommodate parts with various conformations, also such ones not specifically made for connecting with the other part. Again from the above examples such cases would be the climbing hook and the post-it note, while we can add the adhesive tape and flexible ropes.




This first distinction of connections in terms of their articulation seems interesting since a designer, by characterizing a connection in one way or the other, effectively determines whether a product results in an open or closed system of parts. Whether the user is faced with many possible parts to connect with his a product he uses and which may lead to the emergence of unprecedented combinations or whether instead he is limited to a smaller subset of parts that fits a specific interface.

A designer determines whether connection interfaces are zones integrated into parts and products and remain static or instead consist in a separate connector element that allows for the flexibility of altering the product system by modifications applied to the connector element alone.

4.2 Putting parts together - designing assemblies

Within the dynamics that contribute to the constitution of products there is one field of study that is specifically concerned with studying how to and in what ways to join together the various components of a product: Assembly design, having originated in the context of production and manufacture processes, "focuses on specifying characteristics of the collection of parts in an assembly, rather than the design of the individual parts" (Heisserman & Mattikalli, 1998). In assembly design, according to Heisserman and Mattikalli, the characteristics of an assembly can be identified as:

1. Grouping of parts into subassemblies along with their spatial locations.
2. Alternate groupings based on functional or manufacturing viewpoints
3. Behavior (mechanical, electrical,…) and function of parts and subassemblies
4. Relationships between parts and subassemblies (mating, degrees-of-freedom, adjacency, separation,…)

The last point of this list can be further specified in terms of:
- relative spatial locations
- system connectivity
- relative degrees-of-freedom
- datums, tolerances and fits
- assembly precedence
- dimensional compatibility

The following aspects related to assembly design are of particular interest to our research on connections:

4.2.1 Functional and actual level of products

In composing the single parts to form a desired whole, two perspectives combine: a *module-oriented view* which is concerned with the formal and material aspect of the single components and with the fact that they combine and fit together in a way to form the desired whole, and a *function-oriented view*, which sees the product as a series of dynamics, interactions and functional relationships between the parts.

The geometrically and physically focused *module-oriented view* tends to be more familiar to us and is the mode of representation we encounter in most CAD software programs today. Geometries of the parts and of the whole are defined in this way. In the complex dynamics that contribute to the development of a product and the subsequent actions that lead to the setup of production, the *module-oriented view* of an assembly does not keep track of many important pieces of information regarding the design intent coming from different expert contributions in the various product development phases. Thus, having the possibility of annotating functional aspects together and in parallel with the geometric informations of a product and its parts helps to safeguard the intrinsic value of complexity and variety of the product's evolutionary process.

For the industrial designer, this consideration is relevant because by definition he is involved in the product development process by means of making various functional requirements join together in a compelling way with the geometric and material composition of form and for this reason it is a major concern of his to maintain an effective supervision of this binomial also during the subsequent evolution of the product during the various stages of the development cycle. Besides, it seems interesting to consider this combination of *functional* and *modular* view onto one single product also in perspective of the application of the product by its user and in context of the relations it enters with its specific environment. Emphasizing these two distinct ways of looking at a product's composition explicitly, it does become interesting to observe how they both evolve after a product is developed and released and within different use scenarios.

In the field of assembly design, a conceptual framework has been developed in order to approach in practical terms this binomial of two views onto a product system and which is referred to as the *connector-based approach*.

4.2.2 Connector-based approach

The connector-based approach (Tseng & Li, 1999) in the realm of assembly design considers two abstract elements in an assembly: the connector and the associated components (together they form the connector based structure or CBS). Further, this approach utilizes the connector element in order to represent data of both geometric and non-geometric nature (connector based relational model CBRM) (Yin, Ding, Li, & Xiong, 2003).

This connector-based approach is a key method of relating the functional model of the product development with the actual model of the device itself. Identifying the connectors, one can employ them to annotate in a schematic way functions of components and of interactions between components that they connect. At the same time, the abstract element of the connector, when annotating functional aspects of the product, can subsequently be transformed into physical connections between actual components of the product. In such a case, the functional annotations become specifications and parameters for the product's design.

What this implies is that the connector, as an abstract element at the level of annotation, "knows" *which* components to connect and *how* to connect them. The connector, that is, contains the know-how regarding to the assembly[15]. This concept is not dissimilar to the idea of integrated user instructions discussed in section 3.6 regarding components produced with the help of rapid prototyping techniques (Sass, 2006). There it was the information regarding how to assemble parts in the form of distinct shape correspondence different for each connection in a product that is contained within the parts themselves.

It also refers to considerations of having identity information integrated into components themselves and read by technologies such as RFID from a distance. The Fraunhofer Institut, in its podcast "internet of things" (Fraunhofer Institut), in fact presents considerations of integrating into the components themselves all necessary information required for them to become connectors themselves and contribute to the constitution of products during production and distribution along the various systems of transport and distribution logistics until reaching the end user.

Applying the connector-based approach, the subdivision of the entire product into nodes of the components and connectors can be planned from the beginning of the product development process. In this way it is possible to assign these two types of elements more information than only geometric and physical properties. Instead it is possible to annotate in the product's representation all considerations and decisions from all development stages and all expert consultations that were involved in the development process. The connector-based approach allows in this way to capture more of the development group's design intent that emerges during different stages from what can usually be represented through geometric representations alone (Gui & Mäntylä, 1994).

4.2.3 Functional understanding of assembly modeling

From the above perspective, the question arises as to what exactly are *connectors*. According to (Ibid.), connectors put constraints onto the related components assuring in this way that they execute their function.

> The connector generated by designers is the medium between the functional level and actual level. A connector is also a basic thinking module engineers use in constructing product design, and it is the core block of providing component restriction. Furthermore, it also combines all components to satisfy the needed functions. A connector based product development system could be created through the following procedures (Tseng & Li, 1999):
>
> 1. Connector generation from functional description
> 2. Parts generation from connectors
> 3. Connector evaluation

[15]So called *ports* are used as a representation of connections on the level of part details as well as on the level of subassembly and are a useful tool during *design creation* and *design analysis*. *A port can be thought of as a marker placed at a specific location on a part or a subassembly, and endowed with a set of user-defined attributes* (Heisserman & Mattikalli, 1998).

The desire to develop a theoretical framework for the integrated annotation of functional and geometric-physical aspects of a product emerges with the attempt of implementing these capabilities in the form of two parallel perspectives within one unified CAD environment for product development, offering in this way a function-oriented view, in relation to the performance of the desired functions, and a module-oriented view, in terms of physical and geometric structure of a product (Ibid.). This aspiration is further strengthened by the awareness that while a "traditional CAD program grasps the geometric restraints of a component as well as a product, it misses the functional intent that stands behind them" (Heisserman & Mattikalli, 1998).

4.2.4 Design intent and product specifications

It is at this point interesting to consider the similarity between what in design for assembly is considered as the schematic notation of functions of a product and the notational system that can be identified in the context of functionalities of online software interfaces referred to as "notational procedures for complex systems". In that case, there is a similar subdivision of nodes and connections where the nodes contain annotations of intrinsic design characteristics while the connections show functional dynamics. Another parallel lies in the consideration of the interfaces between parts which will be discussed more in detail in the next section. Anticipating only one aspect I want to underline here that in the consideration of the connector-based approach, the interfaces of a product with which a user comes into contact are considered in a very similar way to those, material or not, through which parts that compose the product come into contact with each other and which affect both geometric and functional aspects.

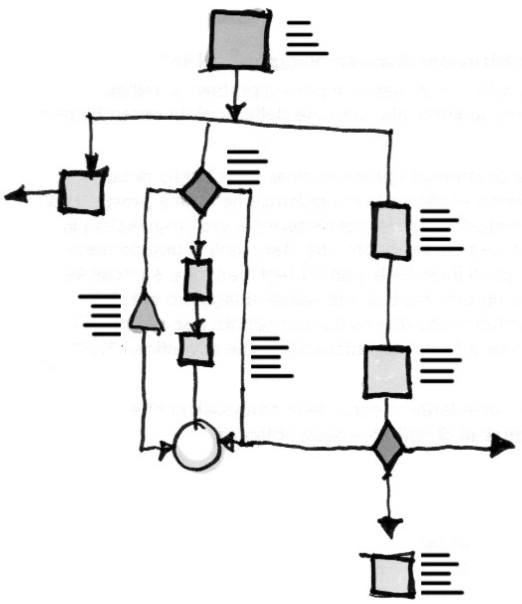


Figure 4.2: Connector based notation system

An often given example of notational system in product development is linked to the book of specifications of a product during the various stages of development. In the way that the notational scheme of nodes and connections succeeds to capture the design intent of the various stages and contributions, it becomes itself, besides being a formal and functional scheme, a combination of specifications which assures that the many modifications and evolutions that a product is subjected to before being completed happen not in an isolated way but in relation to all other aspects and prerequisites of a product. The various notes added to the components and connectors at the different stages become themselves a form of specification book for the product's evolution. In order to underline the significance of this approach:

> Using geometric relations, even a product degenerated to a single part can be treated using the concept of components and connectors. For instance, a spoon is modeled by two functional components, one for "containing matter" and the other for "handling". Both components are associated with surfaces as functional carriers; the connector between them constrains the surfaces to blend smoothly (Gui & Mäntylä, 1994).

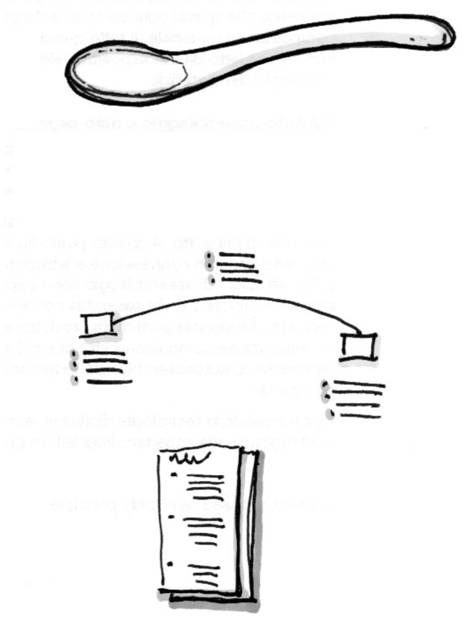


Figure 4.3: Spoon sketch and diagram suggesting the structure of the connector-based approach.

4.2.5 Partitioning

The scope of the abstraction of the whole of an assembly into components and connectors is in first place the creation of a representation to describe and put into relation the interfaces between the parts. In the same way that every system has an implicit interface with its surrounding environment, the subdivision into sub-elements, or *partitioning*, creates additional interfaces between the parts. These interfaces are similar to the interfaces between a system and its environment "except that the selection of interface relationships is largely at the discretion of the designer" (Wilson, 1980).

An interesting point of view is offered by D.K. Wilson through the case of connections within electrical systems. He offers a novel perspective in considering that "sub-assemblies are different kinds of interconnection networks rather than assemblies of components" (Ibid.). Given the difficulties in managing connections on an individual level when these increase in number to an extend such as is happening in modern electronic systems, Wilson suggests to manage the interconnections rather in groups of connections formed by a common pattern of signal distribution. In his paper he outlines a conceptual framework for designers to allow them to focus more on the interconnections and interfaces instead of the components and physical blocks.

On the basis of this consideration emerges the problem of evolution in time. The more separated and independent various parts of a system are, the easier they can be exchanged and substituted according to evolutionary dynamics and changes in the technological system of reference. The process of *partitioning* or subdivision into sub-assemblies offers a series of benefits for the product development:

- simplification of the design process
- support from consolidated knowledge for problems already resolved in part
- accommodation of change of parts in long and short-term
- dividing a complex design problem into more concrete and familiar ones
- division of labor, production and research on design problems and parts
- separating conflicting requirements

4.2.6 Adaptability for short and long term changes

The now resulting question is "how" to subdivide a whole into parts. According to (Ibid.), there can be the following three modalities:

1. *Functional* subdivision

   In this case a set of substructures is optimized to be as standalone and as separable as the problem definition allows.

2. *Modular* subdivision

   Goal is the search for substructures (patterns) that are repeated which allows to re-use building blocks and to capitalize on previous design experience that went into the development of specific modules developed for past applications.

3. *Hierarchical* subdivision

   This subdivision leads to more than one interface which are nested within each other. One objective of this is that higher level substructures can in this way change slowly in time while lower level substructures can accommodate more rapid change. In this way we can split-up long term and short term requirements and so this applies well for environments in frequent or constant change. A strict hierarchical division means that all sub-elements are linked directly to the higher level element and not through links between themselves.

In the section of (Simon, 1988) that deals with the description of complex systems and their hierarchical structures, Herbert Simon indicates how there exist different time references regarding changes *within* subsets and *between* subsets. This consideration is closely linked to the argument of assembly design which is concerned with the structuring of assemblies into subsets in order to allow for frequent changes of some parts without having to alter others or the structure that holds them together.

This stresses the importance of designing the *right* connections in order to provide a product system with the necessary adaptability towards a changing environment and the distinction in elements that respond in different ways towards short-term and long-term change.

4.3 Complex networks

4.3.1 Complex connections

The integration of a *module-oriented view* with the *function-oriented view* of an assembly enables us to look upon a multitude of intrinsic dynamics within any combination of parts. Since these dynamics work in parallel and generate directly the outcome of its internal interactions and those with aspects of its environment I suggest to look at them them as a manifestation of a complex system.

> Roughly, by a complex system I mean one made up of a large number of parts that interact in a non-simple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given properties of the parts and the laws of their interaction it is not a trivial matter to infer the properties of the whole (Simon, 1969, p. 86).

Before contemplating about how conceptual remarks on complex networks can be of interest in relation to connections in the field of industrial design, we shall take a look at what in fact are characteristics that make up complex systems. According to (Taylor, 2001, pp. 142-143) they are connotated by the following:

1. Presence of many different parts, connected in multiple ways.
2. Components interact in serial and in parallel to generate sequential and simultaneous effects and events.
3. Spontaneous self-organization; the separating line between interiority and exteriority becomes undecidable.
4. Structures emerging from self-organization are not necessarily reducible to components involved.
5. Generated locally, emergent properties tend to be global.
6. Complex systems need to be open and adaptive to develop and evolve through self-organization.

7. Emergence occurs between conditions that are too ordered and too disordered at what is called the tipping point or edge of chaos, which is always far from equilibrium.

In order to consider in a more concrete way such a system (many different parts, connected in multiple ways in an open system which allows for adaptive modification), apparently so far from the industrial design discipline, it should help to consider the following case:

Eric von Hippel in (von Hippel, 1988) describes in different examples the impact of user innovation on product development and one of his case studies of interest to us talks about the clinical chemistry auto-analyzer.

Von Hippel emphasizes how in this case the product design determines to a large extend how easy or difficult it is for the user to apply modifications to the product and in this way, to what extend user generated innovation can emerge around a product (Ibid.). In the case of a facilitation for modifications and therefore a product system with weaker internal connections and more open to outside dynamics, the user is encouraged and assisted in experimenting useful modifications of the product relating to his specific way of employing the product.

A similar case I observed is that of two distinct devices for the application of nano-structured surface treatments located at the CIVEN laboratory in Venice-Marghera. Both machines execute the same functional process. One however is a product with a closed system structure where it is difficult to apply any changes. The other device is structured as a more open system, enabling the researchers of the laboratory to modify, remove and add parts and other components in order to improve the functioning of the whole product on the basis of their experience and experimentation and adapt it to their specific requirements.

We can look at this example case also in terms of seeing how a product can position itself in different ways as a filter between the social context of its users and its technological potential, allowing for different dynamics to emerge or not, according to its systematic structural layout.

Figure 4.4: Two types of plasma sputtering machines at the laboratory at CIVEN nanotechnology research center, Venezia-Marghera, Italy. It is clearly visible how the machine type on the left can be seen as having a more closed system type structure making user changes hard, while the machine on the right incentives user adaptations, alterations and customizations because of a more open system type construction that consists of various possibilities of attachment with external parts.

A third example for a concrete case of illustrating dynamics of complexity in product development can be observed on a daily basis in the field of software development. There are ever more software applications that are developed on the basis of a strong contribution from the side of the users of that very application. Aspects as to how *open* a software application is, how many open connections it offers and the multitude of dynamics it manages to provoke impact directly on what type of characteristics will emerge within the program itself.

In the case of the outlining application Omnioutliner, for example, the creation of a long series of so called *plug-ins*, developed by a wide variety of developers, integrated the basic program with such a wide range of functionalities that the resulting system could potentially become in fact a very different product from its basic application. This dynamic as a consequence lead the manufacturer of the program to the decision to integrate a number of these functionalities enabled by *plug-ins* into a new separate product that was developed together with the developers that had initially enhanced the original program.

This example not only illustrates complexity of a development process on the basis of an open system with many connections and many parallel activities that lead to the emergence of new structures. It also shows another important point, namely that of the importance of the right balance between too much and too little order in a system to allow for emergence of new structures to occur and to then consolidate them: enough disorder to allow mutations to emerge but sufficient order to consolidate these mutations and make them become structural parts and in this way a foundation for subsequent dynamics of mutation.

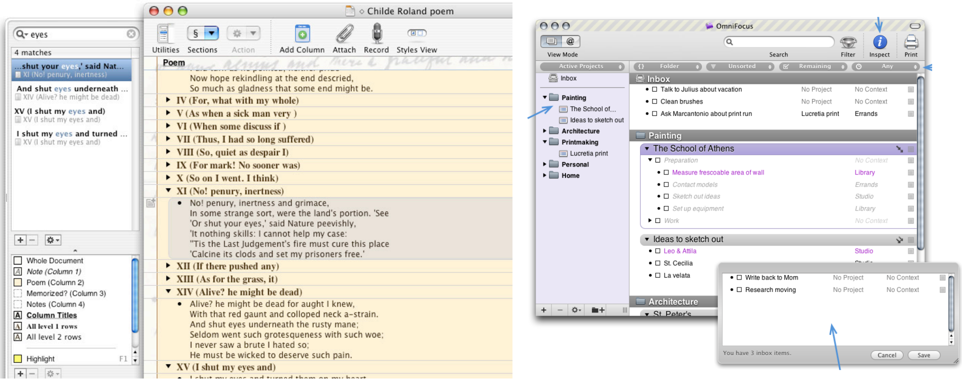


Figure 4.5: On the left the main program window of the program Omnioutliner and on the right that of Omnifocus, both developed by omnigroup software house. The latter emerges as a separate program after extensive dynamics of user innovation that first leads to the creation of numerous plug-ins before it gets embraced by the producer company and consolidated with the help of the plug-in developers into a separate program.

Following are a series of aspects of the research on complex networks I think of interest to this study on connections in design.

4.3.2 Emergence of structures and auto-organization

We commonly attribute to the designer of products the role of controlling through to every detail and preferably also with a strong hand the process of a products development and in part also the use modality of *his* product after its release into the environment. If not already before, certainly with the rise of the internet and the related impact it has on participation in remote dynamics, this can be sustained with increasing difficulty.

> Most of change take place through catastrophic events rather than following a smooth gradual path. The evolution of this very delicate state occurs without design from any outside agent. The state is established solely because of the dynamical interactions among individual elements of the system: the critical state is self-organized. Self-organized criticality is so far the only known general mechanism of complexity. […] Life is understood backward, but must be lived forwards (Bak, 1996).

A product is constituted on the basis of multiple contributions and it is difficult to foresee *ex-ante* what will happen to it after its release to market and into dynamics of use. But does this mean that the designer is losing his role in giving *form* to products? I sustain that it does not, however what changes is the meaning that this *giving form* assumes and at what point such a *form* is lost.

Considering a product as part of dynamics of a complex system, more than giving form, the designer arranges for modalities of interaction between parts that can lie both inside and outside of a product's boundaries. At every moment and at every stage of a product development process as well as use scenarios thereafter, this design intent, which we have seen annotated in ways such as the *connector-based approach* discussed in section 4.4.2, is part of complex dynamics that not only have an impact on it but also potentially alter it. Yet, it is clear that these alterations would not have occurred without the designer's arrangement in the first place and they do not happen independently from the way a designer lays out and designs a product.

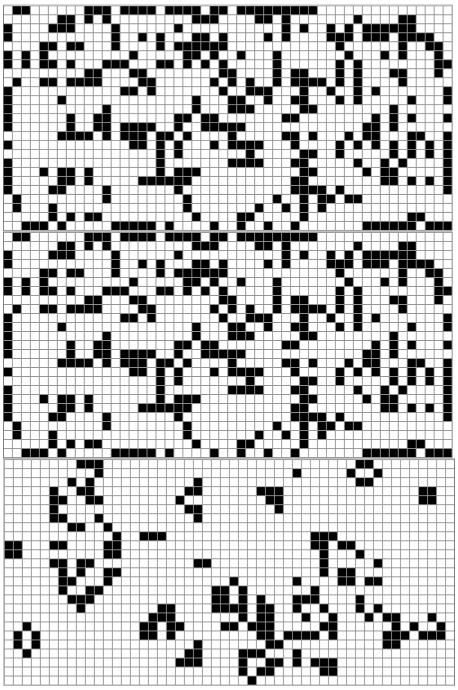


Figure 4.6: Three moments of a simulation of the Game of Life, a computer program written in 1968 by John Conway.

In the above figure three random moments of John Conway's Game of Life are shown. This piece of simulation software was first written in 1968 and was the first implementation of what Von Neuman in 1948 defined on a conceptual basis as a *cellular automata*. Computers and biological systems process data in analogous ways and cellular automata were devised to demonstrate this. They operate on themselves with iteratively recursive rules. Each cell is given the same set of rules which defines its behavior. Subsequently, on the basis of these rules of behavior, that are applied in a recursive manner, patterns emerge in unforeseeable ways.

The Game of Life is based on two states that any cell can find itself in, white or black, alive or dead. All eight surrounding cells of any one cell are checked each round to see if they are alive or dead. All alive cells are counted and the resulting number determines the fate of the central cell, leaving it in its current state or changing it's state, passing from dead to alive or vice versa or remaining dead or alive respectively.

Three rules apply:

1. Death: if the count is less than 2 or greater than 3, the current cell is switched off.
2. Survival: if (a) the count is exactly 2, or (b) the count is exactly 3 and the current cell is on, the current cell is left unchanged.
3. Birth: if the current cell is off and the count is exactly 3, the current cell is switched on.

Now, what do computational simulations have in common with the work of industrial designers and how can we see relevance for our research in these complex links between parts that lead to the emergence of patterns that were as such not determined by any one single participating part?

Two examples should illustrate well where this connection can be found and why I suggest that this field of study does and will increasingly impact on the design discipline.

The project developed by Andres Sevtsuk at MIT rotates about the problem of car traffic generated by people looking for empty road side parking spaces in city centers. From a 2005 study (Shoup, 2005), up to 30% of traffic in these areas is generated by the search for a parking space.

The question the project investigates is how this situation can be improved by communicating to drivers in search of parking where the nearest free spot is located. In this way, a car would know where to drive, avoiding cruising by trial and error. A first difficulty in this illustrates why the process of finding a solution to this problem is not straight forward and does benefit from simulating drivers' behavior. If three cars receive the same indication of a free parking spot, who would get there first? And how would the other drivers react?

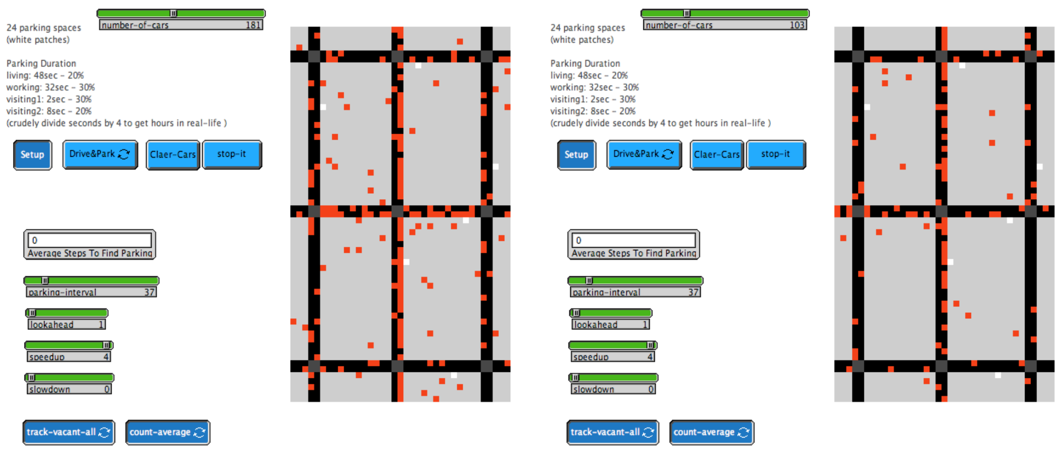


Figure 4.7: Two moments of the agent model based simulation of street parking behavior, Andres Sevtsuk

This then opens up different possibilities, some of which involve inter-car exchange of intent of taking a communicated parking space or not. In such a project it becomes clear how the simulation of the behavior of real world objects such as cars in search for a parking space can be integrated constructively with the actual behavior of these cars. A question of interest to design at this point is how the user, in this car the driver, gets in touch with such a system and how he interacts with it. On different levels, this system enables communications and connections between the user, the car, the cars of others and free parking spaces distributed in an urban environment. How can these different realities be present within the driver's compartment and how can these new instruments be integrated with the act of driving in a way that effectively improves the overall situation are new questions design is confronted with on the basis of these new potentials of networked technologies.

A second example in which the emergence of structures, on the basis of elements that interact in multiple ways, enters spheres of the design discipline is the way the interface for the WikiCity Rome[16] project was conceived.

Designers are used to developing the graphics of an interface by attributing forms and positions that are either static or follow predetermined transformations. Designing an interface that reflects real time data provided by large data networks, this is not anymore possible.

Rather, each interface element, representing a real world counterpart, needs to be thought of as a distinct personality of which the designer composes and structures certain rules of behavior. These rules of behavior determine how the data streams are translated into a visual representation through the interface element and how the different elements interact with other elements present on the screen estate and with context aspects of that screen such as the borders or static elements.

In this way, the designer does not anymore shape objects in a static way, but instead he predisposes, sets up and lays out contexts and behaviors that generate patterns and shapes unknown of during the process of product development.

4.3.3 Open and dynamic systems

The above discussion presents designers with a difficult situation: How open or how closed to design product systems?

> "If connections are too few, networks are frozen and no change occurs, and if connections are too many, there is no stability and networks remain chaotic. Along the margin between too little and too much connection, 'the spontaneous emergence of self-sustaining webs' occurs" (Kauffman, 1995).

[16] A more comprehensive description of the WikiCity project has been given in section 2.2.2.

Related to the activity of designing products, the three examples given in the first part of this chapter[17] illustrate well in what ways the possibility of a product to create new connections gives way to dynamics that are similar to those described as *emergence* and *auto-organization* in the field of complex networks.

Closed systems can be seen in conjunction with the aspect of stability in time while open systems can be associated with the possibility of modification and therefore adaptability. In the design of products therefore, a designer needs to consider what type of interaction with multiple parts in a product's surrounding contributes beneficially to the overall goal of the product, considering that the requirement of change and stability can also be present within one product at different moments in time.

4.4 New structures for new products

4.4.1 Stability and adaptability, design for re-assembly

In section 4.2 on assembly design I have illustrated how an adequate way of partitioning the whole of a product into parts can structure it adequately for having adaptation in an environment undergoing change. Considering how today's system of technology can be seen as sustaining an ever accelerating pace of change to an extend that some sources claim just this acceleration of change to be the specific characteristic of our times (Toffler, 1970).

> When programs are flexible and codes adaptable, noise can be processed in ways that allow novelty to emerge. In the open-ended revolution of information and noise, noise transforms the systems and structures that transform noise (Taylor, 2001, p. 122).

Now, if it is true that we live and design products in an environment associated with rapid change, what follows would be that our products should be arranged and designed in a way that would allow for and accommodate these changes through modifications that emerge during their use, get incorporated and altered in continuous ways thereafter.

This perspective is contrary to an approach towards the creation of objects with a perspective of *forever*,commonly the case in the past. Still, we do find ourselves in most cases in front of products that do correspond to this idea of *forever*, despite of the certainly limited and often short duration as products in use.

A design approach that stands in contrast to this and attempts to make up for such a situation in the context of closed system products is *design for disassembly*. I will be discussing this field more in detail in section 6.3 but taking it for now as an element of

[17]The three examples given earlier on relate to von Hippel's study of the clinical chemistry auto-analyzer, the two product structures of CIVEN's plasma sputtering machines and the emergence of Omnifocus as a new application on the basis of Omnioutliner.

reflection in combination with the perspectives and reasoning introduced so far leads me to envision a design approach that focuses on *design for re-assembly*.

Parts of a system would be capable of letting new structures emerge according to dynamics in continuous change. In this context we ought to consider the increasing diffusion of products which used to consist entirely of analog and components while now integrating digital technologies that allow for frequent change also due to the short the life span of such digital technologies proves to be.

In this regard, the concept of *embedded* opens up many new opportunities of structuring products in an adequate way but also do pose still open questions regarding the adaptability of product systems. What pattern of subdivision or partitioning will make sense to pursue in the growing fusion between material and virtual matter in products?

> It is becoming increasingly obvious that information is, in important ways, material, and matter is informational. From this expanded point of view, neither information nor materiality is what it seems to be when it is interpreted in simple oppositional terms. Thus, the movement into the Information Age should not be conceived in terms of growing abstraction and increasing dematerialization, but as the complication of the relation between information and the so-called material conditions of life (Ibid., p. 106).

Considering Gregory Bateson defining information as a difference which makes a difference, also the following assumes relevance in this discourse:

> Noise is not absolute but is relative to the systems it disrupts and reconfigures, and, conversely, information is not fixed and stable but is always forming and reforming in relation to noise (Ibid., p. 123).

4.4.2 Robustness and vulnerability - network hubs

I have already introduced aspects of robustness of a system when considering the point at which a product does or does not lose its *form* while still remaining open towards dynamics that occur in its environment and adapt to them. (Barabási, 2004) presents findings of his research group on complex networks which can be focused upon the characteristic that nodes in a complex network do not as a matter of fact follow a normal distribution with its characteristic bell shaped curve, as has been commonly assumed. According to such a normal distribution there would be many nodes with a medium number of links and very few nodes with very many or very few links. In consequence there would exist something like a typical node which would be by far the most recurrent node in the system.

Barabási's research instead shows that this is not the case in many networks where as networks he considers the molecular interactions of a cell or those within a social network as well as the entirety of web pages or links of citations in the realm of scientific publications. These networks, according to what has emerged from his research, follow a power law distribution showing the property of scale invariance.

The law of scale invariance takes its name from the fact that there is no such thing as a prevalent scale that expresses itself in the predomination of a mean. According to this law, nodes are distinguished by the fact that there are many nodes that have few links and few nodes that have many links, where however those few nodes that have many links do not tend to nearly zero as is the case with the normal distribution and its bell curve. Extremes, that is, do exist in this distribution.

For complex networks this means that they consist in so called hubs which are nodes that have a very large number of links with other nodes. Following one of Barabási's cases, within a cell only a few molecules are much more chemically active in comparison to most other molecules which are involved only in a small number of chemical reactions. In the connections of airborne traffic, there are only few airports that have flight connections with a large number of airports (which in this field are in fact referred to as hubs) while there are a large number of airports that have connections only with a few other airports.

This distribution attributes to the system an ambivalent characteristic regarding its robustness and its vulnerability. In short, such hub based networks reveal themselves as very resistant to accidents and errors, events that occur in a casual manner. In an ocean of nodes with only few hubs, it is very unlikely that a casual event does indeed hit one of those central nodes. Instead these networks are very vulnerable to targeted attacks. If purposefully one of the nodes that is a hub is assaulted, with one single hit a large number of interactions that happen within the network is blocked. These properties represent some of the strengths and weaknesses of internet and by having an increasing number of products interlinked with this type of network, also the design of such products ought to consider these dynamics.

4.4.3 Directed networks

In considering complex networks in diverse contexts, besides considering the links between nodes of the network it becomes crucial to reflect on the directionality of the links. Barabási has often illustrated this point with an example from the first complex network that his group did study extensively: internet. If webpage A contains a link towards webpage B, not necessarily this page B contains itself a link back to page A. While a linked path A-B-C-D, in which each letter represents a webpage, might be possible following links on these pages, the inverse path D-C-B-A might not be possible. This is the case because internet is a *directed* network.

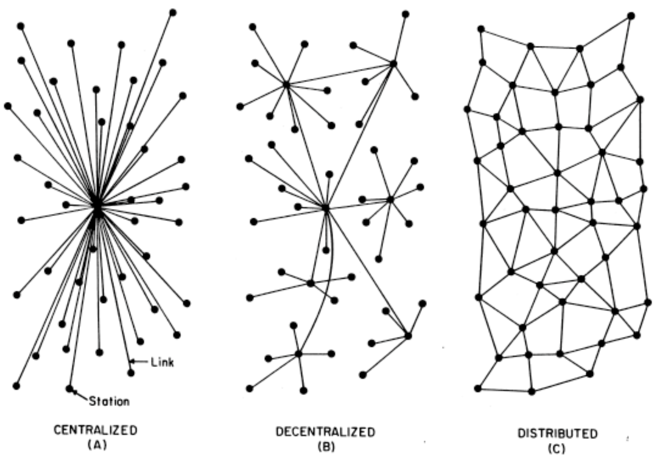


Figure 4.8: Experimental network schemes for military communication which later on developed into internet (Baran, 1964).

In the context of this research such a reflection is of interest when considering the modification of a connection of a product system that resembles structure of a directed network.

In a directed network, it is more likely that only one of the parts involved in a connection needs changing without having to adjust also the other parts involved. In the case of a non-directed network instead it is more unlikely to work without having to modify all involved parts or nodes on either side of a connection.

In the following concept of a library system based on RFID chips inserted in every book and signal readers distributed in the book shelves I have contemplated the effect that a transformation of a directed network into an non-directed one could have and found this a very effective approach.

In present library systems, the connection between the digital book catalog and the actual books in the bookshelves is of directional nature. The book catalog points at the location where the book can be found through a numeric code. The reverse is instead not possible. If the book is at a different location in the library, the book catalog does not reflect this change in location but continuous to point at a now irrelevant position which does not correspond to where the book is.

This situation in real word brings various disadvantages ranging from the library losing books within its own walls just because they are returned to wrong shelf locations to the inability of rearranging books flexibly according to temporary study focuses.

Now, creating a library system in which such a directed network were to be converted to a non-directed one implies to enable books to refer correctly to the book catalog even when their location changes. In this way, the catalog would always reflect the actual location of a book, reflecting its location within the library in dynamic terms.

To enable such a system RFID readers need to be positioned appropriately within the library and in the book shelves that allow for a triangulation of the RFID tags inserted in each book. Reading the distance between three RFID readers and one tag results in the location of a book within that space which would be the required data to update the catalog dynamically of the book's position.

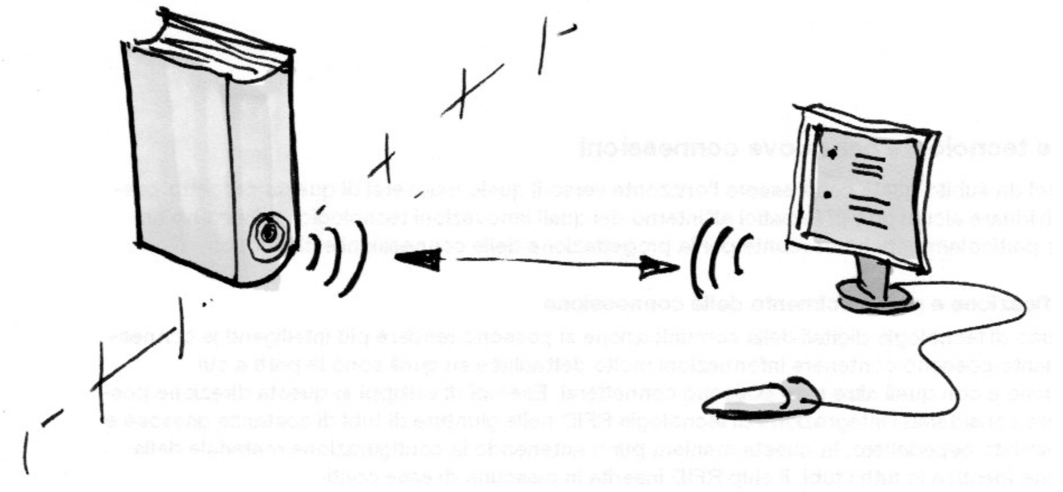


Figure 4.9: On the basis of RFID identification tags inserted into books and RFID readers positioned appropriately within the bookshelves the usually directed network between books, their physical location and the digital library catalog can assume the structure of a non-directed network.

All directions of investigation presented in this part on new structures for new products, have in common a view on products that ceases to see them as static in nature. Instead possibilities of adaptation and a more flexible and dynamic behavior are considered in order to allow for products that can respond in a more synchronous way to the constant mutations of the context they find themselves to operate in.

I believe that for this goal, for this structuring and articulating of ways in which parts and products connect, assuming the perspective of products as networks holds tremendous promises and the design discipline is only at the beginning of harnessing the full potential that this shit of viewpoint can represent.

5. Seamlessness

5.1 The fascination of concealed connections

Having identified with the example of the prehistoric spearhead mounted onto a wooden branch a first act of assembling it is implicit that there is an alternative to the assembly of multiple parts into products. This alternative consists in the creation of objects without the joining of parts but instead by elaborating one single part, one single piece without interruption, without a break of any kind that would need connections. A mono-materic piece that is adequately elaborated into zones of different configuration and functionality. Examples would be objects obtained by manufacturing methods such as the working with clay, wood carving, stonemasonry or the forging of a blacksmith. These methods start with one piece consisting in one material and *fleshing out* the various parts and protrusions by taking away and reshaping but always remaining at the level of one-piece object that fulfills all required functions.

While connections in objects enable constructive dynamics, many of which I am addressing in this research, there is an undeniable fascination about not having such connections at all or at least, not letting them be perceived by the user.

While only connections allow for many fundamental interactions between objects and parts to occur and in this way determine critical characteristics of products and systems as a whole one still has to acknowledge that there seems to be a perceived value in avoiding breaks of continuity in products at all.

Seamlessness, on a material level, consists in not having interruptions between components of a product. A seamless object taken to the extreme is a mono-bloc, a monocoque or monolithic object, a one-piece object. This fascination and appraisal of an object without interruptions and a therefore resulting absence of connections is reflected also by idiomatic expressions in both Italian and German language where both "un oggetto tutto d'un colpo"[18] and "wie aus einem Guss"[19] or "wie aus einem Stück gegossen"[20] are used to describe an object that is considered *just right*, *complete*, *perfectly coherent or consistent* and with an overall *integrity* which in English would be referred to as a *well rounded piece of work*; all reflecting robustness and a hint at eternal duration.

This fascination of a one-piece, unity as opposed to multiple parts dates back a long way and in the history of philosophy we find several traces that support this fascination when considering discourses about monism as opposed to dualism and pluralism, the related arguments of Plato and the Presocratics and the law of non-contradiction.

[18]Translation: "an objects made of one throw"

[19]Translation: "as made of one cast"

[20]Translation: "as cast out of one piece"

Perhaps this fascination of one-piece can be related also to its non-divisibility, its non-separability. A seamless object in this respect represents a less complex whole in the sense that it conceals its internal connections and together with them, its internal interfaces. Resulting as *one*, a user confronted with the product has no doubt and uncertainty about inner divisions of the object and incomprehension that may result from them.

Seamless connections can also be seen as a way to focus the perception of a product not on its single parts but on larger units, by this obtaining a specific effect in terms of composition and product aesthetics. To give some examples of seamless connections I want to recall glass facades in buildings that avoid interruption between the glass panels by abandoning the use of window frames; glass panels in buildings are held in recessed slots of concrete walls to create an immediate passage between the wall and the transparent panels; doors are inserted into walls without visible door frames; high precision manufacture of ceramic tiles allows for their posing without interspaces, resulting in seemingly continuous flooring surface ;techniques of textile production have been devised to produce pieces of cloth without visible seams.

Figure 5.1: Advertising poster for Boston Logan Airport, 2008. "Connect without the connections." In this case, a direct flight connection is made equivalent to no connections at all, considering connections as an additional airport node between the advertised airport and that of the destination.

In the design of objects, the interruption of continuity on various levels has opened up a vast amount of new potentials outlined in other parts of this study and the connections themselves have become integral part not only of the functioning of products but also of the aesthetic considerations and solutions.

However, the intrigue of seamlessness persists and this to an extend that beyond functional reasons which we shall soon see, it leads to a certain obsession and expression of rather personal ambition of actors involved in the product development process. Connecting without connections, joining without leaving traces of the joints to be identified creates a magical aura. It expresses a high level of professional and technical ability on the part of the designer since he connects to realize his goal but conceals the way he did it. He resolves a perhaps difficult transition in a way that makes it seem easy since hardly perceived. Like a magician he leaves the person confronted with his creation in wonder as to how what is held in front has been achieved, how the parts composing it were joined, creating mystery around an ability to connect.

Concealing the connections that make up a product is also a technique of protecting a product in terms secrecy over a professional ability, safeguarding it from being copied or reproduced.

From another perspective instead, seamlessness leaves the user in the dark, not letting him become aware that in fact there is a connection that composes the product he is confronted with. Seamless connections hide from the user fundamental aspects of how the product works, they conceal the interruption between one element an another and by this cover up the modality of transition between the parts. While this can be seen as a design technique of focusing the user's attention on larger units of the product – instead of perceiving single windows, a seamless glass facade for example – this creates also a situation in which the user can not bring himself in by reconfiguring a product, integrating it with new parts or extending its functionality by experimenting novel connections.

5.2 Seamlessness and the design of products

5.2.1 Why seamless and how seamless

Besides the above mentioned ambivalent appeal of seamless connections in products a question arises as to *why* designers would consider the hiding of joints in the products they develop. In the following list and diagram I have identified and subdivided these motivations in the three main areas:

1. *Aesthetic reasons for seamlessness*

   Connections are concealed in order to achieve a continuity of a larger shape or surface structure or in cases in which the perception of seams would interfere with a different visual composition the designer wants to prevail in the perception of the product. For example, if a horizontal band of windows is composed of single glass panels, creating seamless connections between these panels avoiding frames o supports this larger compositional figure.

2. *Functional reasons for seamlessness*

   Connections are not only critical zones of encounter between parts, they can also be very delicate zones and prone to damage or intrusion of elements that compromise the functioning of the connection itself. Functional reasons to conceal seams can be motivated by attempts to avoid the intrusion of alien elements between the connected parts and by avoiding that the connection through its very structure and composition interferes with other functional dynamics of the product.

   As already hinted at above, seamless connections can contribute to the usability of a product by blending out product aspects that are not inherent to interactions interesting to the user.

3. *Permanence in seamless connections*

   By concealing the seams of connections and giving a product a monolithic appearance, the aspect of permanence in time and robustness against dismantling of the parts plays a critical role. Seamless connections can be motivated by attempts to avoid disconnection of parts in terms of users not being aware of this possibility. Within assemblies, the hiding of some of the connections that links a product's parts allows for maintaining the integrity of subassemblies while letting users interfere with sets of components only.

   At last, considering permanence of time I can not help but allude to the above mentioned mysterious aspect of a designer's ability to conceal connections where instead connections are and to how such an achievement without doubt represents to a certain degree an autonomous aspect of professional ambition.

In this context of a research on connections, when discussing seamlessness, it is necessary to stress that a real absence of joints is not intended in absolute terms since the focus remains on products that consist in more than one piece. It is an aspect of gradual character, ranging from connections with apparent seams to those completely hidden from a user's awareness. In this continuous range I suggest to identify three zones or ranges within which seamlessness can be achieved in the design of products:

1. *No seams*

   No seams mean indeed no connections. Seamlessness of this kind means that there are no connections where they instead used to be in previous solutions. An example would be hinges integrated in plastic parts produced by injection moulding. Such hinges are integral parts of the two product parts which they join by consisting in a thinner cross section that allows bending.

2. *Partial continuity*

   This is the large area of seamless connections where joints exist but the designer achieves a level of continuity between the parts. When glass panels are inserted directly into concrete groves of windows without a frame, when two wooden panels are joined in a way that the wood grain maintains a continuity between the two plates, when floor tiles are posed without spaces in between or when a button is flush with its surrounding surface level, in all these cases one can speak of seamless connections of multiple parts because there is at least one aspect of continuity that bridges the gap, the seam of the connection.

It is this zone and modality of seamlessness in product connections most interesting to a designers contribution since it depends to a high degree on *how* material and form are used in the design of a product. This approach to concealing seams allows to identify weak points of a connection and single them out by creating a continuity in this respect between the parts.

3. *Hidden seams*

This last zone of seamlessness regards all these elaborations of connections in which the seams are in fact not perceived by the user. When parting lines of injection moulded parts are hidden within groves, when the seam of a connection is part of a larger design structure, when connections are covered up by parts altogether, we can speak of a seamlessness that is achieved by the hiding of seams from the user.

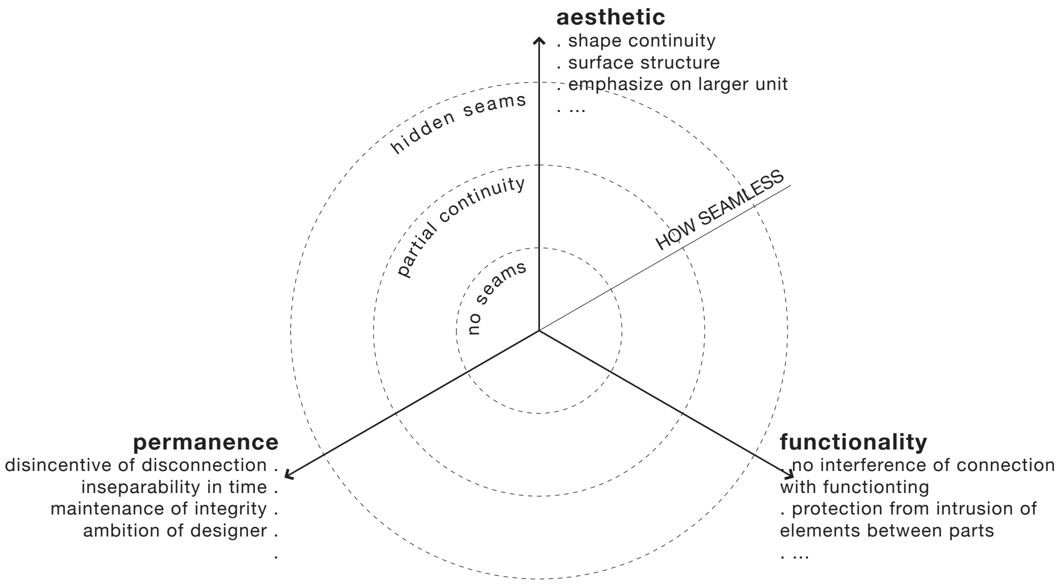


Figure 5.2: Why and How seamless? Illustration of three orientations of motivation for the design of seamless connections in terms of aesthetics, functionality and permanence together with three zones of modalities to achieve such seamlessness in terms of overall avoidance of seems, partial continuity between connected parts and the hiding of seams from the user.

5.2.2 Opportunities for new seamless connections

For the industrial designer several interesting ways emerge to make use of seamless connections considering potentials offered by new technologies of which I want to outline those directions that I deem particularly promising:

- *Zoning*

  Assembling multiple parts into one object often results in specific functionalities being associated with distinct parts. Being able to structure the material qualities of one part in different ways within various zones of that single part. I have mentioned above how one single piece of injection moulded plastic can comprise at the same time two functional elements such as a container and its cover as well as a hinge included in the mould and that allows bending because of a thinner cross section. In such a case I suggest to speak of creating distinct functional zones within one single piece.

Now, considering recent developments in nanotechnology, this approach widens its horizons; interfering with the nanostructure of different areas of a single component can characterize these areas as functional zones having distinct characteristics. In this way and with the help of nanotechnology, it is becoming possible to resolve functionalities that used to be addressed on a macro level on a nano level instead. The industrial designer plays a critical role in this by promoting the integration of functionalities into the materials themselves while maintaining the focus on how the user is able to harness these functionalities even though they manifest themselves at a scale far from his perception.

- *Differential transparencies and layering*

  Working with a seamless surface in the design of a product, the designer can articulate the functionalities of such a coherent and continuous surface by creating functional transparencies at different points. Such transparencies consist in the passage of magnetic force, radio-magnetic waves, light or heat and can become elements of functionalities.

  This approach I suggest to refer to as functional layering consists in two steps a designer ought to consider: addressing the differential structuring of transparency and passage of the surface of a product and deconstructing the functionalities into functional elements that lie beneath and pass across the product's skin.

Examples for this functional layering resulting in seamless connections are the recent BMW concept car Gina, that changes geometry without interrupting the surface skin and integrates various functional layers beneath this skin; touchscreen or touch-sensitive surfaces in products; or contactless sensors behind surfaces, registering heat, light or other parameters.

- *Continuities*

  The observations made under the term *partial continuity* in the diagram in figure 5.2 reveal a very compelling strategy industrial designers can follow to obtain seamlessness under the presence of connections. Creating at least one aspect of continuity between connected parts that does not otherwise exist can create a situation that bridges that gap across a connection in terms of user perception.

  Take for instance two glass panels that are joined within the context of a glass facade. Not using frames to resolve their fixture but managing to put them at direct contact at their edges results in a continuity of transparency despite the fact that there still is a connection between them. Another instance would be the selection of two wooden panels at contact with each other in a way that the wooden grain continuous from one to the other. Even though there still is a connections between the two panels, the correspondence of the wood grain establishes a perception of continuity resulting in a perception of seamlessness.

This provides an intriguing basis for reflections when integrating new technologies into products. What are continuities in these new types of connections? How can there be seamless passages between physical and digital elements? Furthermore identifying seamlessness with elements that bridge the interruption between distinct parts, this also opens up considerations regarding seamless processes.

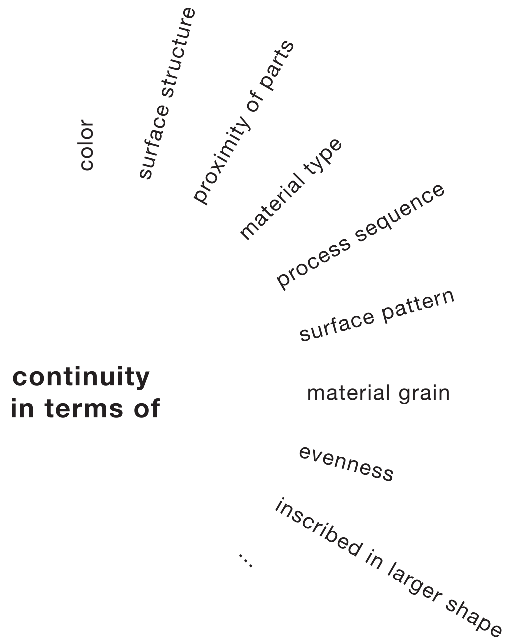


Figure 5.3: Possible aspects of continuity in products.

- *Seamless processes*

  A novel might have a seamless plot as well as a customer service might show a seamless performance and we might admire the seamless pictures of M.C. Escher where one contest passes into another one, such as for example the hand painting itself, seamlessly. What does one mean when referring to a seamless process such as a seamless experience in making use of a multi-trip within a public transport system or whether it has been a seamless process to reach a specific goal completing a series of tasks along the way?

  In the context of processes I suggest referring to seamless in terms of a number of steps that follow one after another without interruption. An interruption would break such a seamlessness and is something that comes unexpected, that has not been considered part of the process. If it was considered part of the process it would not be perceived as an interruption and as a consequence the process would continue to be considered as seamless.

This perspective on processes is similar to the way I described real time processes in section 2.4. There, I emphasized that a perspective on real time useful to industrial design is that which considers the transfer of information in relation to a sequence of events. If information is passed on in useful time for an event to happen that is beneficial of a larger mission, then we can speak of *real time*. In a similar way, a seamless process is one where elements both physical and digital are in place to be connected or to support connections without an interruption. If an element is not available in the right time and place, the interruption creates a break, a perceived seam in the process.

Alessandro Valli goes a step further in his description of seamlessness in the context of natural interaction, suggesting a "fluid information layout that (perceptually) removes the concept of event" (Valli), suggesting to move from distinct events that pass from one to another through breaks such as mouse clicks and on-screen page swaps to a more continuous environment in which all states are in continuous movement at different speeds (zoom in/out, panning,...).

In this case, he takes the continuity of time as the one element that overcomes the gaps in user experience of a process, making it seamless.

Seamlessness in processes thus indicate that within a goal oriented dynamic, there is a continuity between the different tasks that consists in the right steps at the right time. From a design point of view this is relevant in terms of users being able to focus on the given tasks of such a process without interruptions that provide distractions that can lead to risk and failure involved in the processes.

5.3 Drawing the product - intriguing seams

An approach to designing connections that is linked to their concealing consists in the careful integration of connecting elements in the aesthetic composition of a product. In this way, the parting lines of injection moulded polymer parts are laid out in a coordinated way with other aspects of shape composition or they are recessed in product groves to reduce their visual presence.

In an attempt to generate seamless compositions of parts, an attractive strategy lies in creating systems that allow for the adding of parts but without presenting open end connectors in the absence of some of these parts. In various fields of product design there are observable efforts to create such systems that appear finished but yet are open to receive components that extend or reformulate their functionality, shelving systems for the retail sector being just one of many examples.

Interesting considerations regarding this approach can be made by looking at one of the more classical ways of joining: knots. There exist different ways of bending and twisting ropes to create loops of attachment without having to access the ends of the rope. This allows for a connection to be formed leaving the other parts of the rope untouched. As an example for this modality of creating knots stands the alpine butterfly knot as shown in figure 5.4 which I want to give as an example in how very traditional ways of connecting can inspire the resolution of new connecting modalities.

Figure 5.4: Alpine butterfly knot allows for creating an attachment loop along a rope without having to use the ends of the rope during binding

While some connections are stronger than their parts such as those created by the process of welding, predetermined break points are used to design the programmed fragmentation of parts that originally do not consist in connections. In these cases invisible connections are created that determine a product's behavior of fracture.

Predetermined break points or break lines are often employed in emergency exits or instrumentations such as glass windows that break out of their frame by applying force at a certain location. Other examples can also be found in more everyday objects. Consider the opening mechanism of aluminum cans containing beverages, also in these cases the design of the implicit disconnections determines the way a one piece components divides and how the user can access a product through a programmed modality of interaction.

5.4 Continuity between physical and digital realms

5.4.1 Sensors and actuators

The development of the microprocessor in the early 1970's has introduced extremely sophisticated devices into many aspects of our daily lives, opening up entirely new perspectives as to what functionalities products can be comprised of. I have at different points of this study[21] emphasized how and why I feel it necessary to consider connections not only between physical elements but also those established with the digital realm. Many once purely physical connections now involve the exchange of digital information and numerous connection dynamics inexistent before have been enabled by the linkage of the physical and the digital realm.

[21] When illustrating the aspect of responsiveness of connections I have already pointed out how the moving of dynamics of connectivity into the digital realm represents the substitution of what used to be tangible matter with immaterial flow of digital information.

In 1991, Mark Weiser wrote about "the idea of integrating computers seamlessly into the world [...]", emphasizing that "if anything, the transparent connections that they offer between different locations and times may tend to bring communities closer together"(Weiser, 1991).

These types of connections and the passage between physical and digital elements is a highly complex issue not only in technical terms but also in terms of usability of the resulting product dynamics that involve the user. A seamless transition between one realm and the other is commonly considered one in which the user does not encounter difficulties along this process. Integrating both worlds seamlessly aims at letting the user perceive one, rather than two separate contexts or processes with which he is confronted.

How can such a seamlessness be achieved by the industrial designer in developing products and processes and how important is it at all, that this passage occurs in a seamless manner? What are the seams in this passage that industrial design needs to consider in order to reflect upon the aspect of seamlessness in this context and what types of continuity can we talk about when connecting physical objects with digital elements?

From the perspective of the digital domain, the connections between physical and digital elements is based on the basic concept of input and output. In one way, data is collected in the actual environment and transformed into digital information while on the other hand that data is elaborated and generates an output back into the physical realm in the form of visualizations or commands that trigger physical objects. The two elements that support most of these two dynamics are the classes of sensors and actuators.

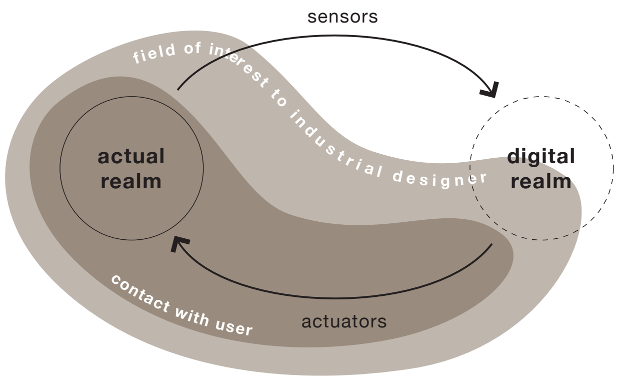


Figure 5.5: Sensors and actuators as intermediaries between the actual and the digital realm. Users commonly only come into contact with elements with the manifestation of the actuators in the actual realm. Industrial designers ought to also act upon parts of the digital realm and the disposition of sensors in the design of products in order to achieve their goals.

Sensors measure physical quantities, transforming them into signals which in the case of electronic sensors consist in digital data. There is now a large variety of sensors and they are integrated into an increasing number of different products.

Motion sensors register if an object is moved or stands still, orientation sensors register the way an object is positioned, GPS (global positioning system) modules integrated into objects generate data on its global location. Sensors can measure temperature, light intensity, sound levels or pressure, and the list could go on for long. The key aspect of sensors to consider in the context of this research is that they describe, in quantitative terms, specific aspects of a user's or an object's context.

> Microprocessors are digital devices that manipulate binary codes generally represented by electric signals. Yet, we live in an analog world where these devices function among objects that are mostly not digital. [...]
>
> Digital systems, however complex and intelligent they might be, must receive information from the outside world. Sensors are interface devices between various physical values and electronic circuits who "understand" only a language of moving electrical charges. In other words, sensors are the eyes, ears, and noses of silicon chips (Fraden, 2004, p. VII).

In order to connect the digital realm back with its material counterpart, actuators are the general class of elements most commonly used.

> An actuator may be described as opposite to a sensor - it converts electrical signal into generally non-electrical energy (Ibid., p. 3).

In engineering terms an actuator is therefore any element that transforms an electrical signal into a different kind of energy like motion, force, light or sound. In our context, I want to suggest to consider the actuator rather as a conceptual element that is key to transforming digital data to any sort of output that is perceivable to a human and that can consist in visual and audio signals or the physical (re-)configuration of parts or entire objects.

In the industrial design context, the connection of digital data and its actual manifestation happens always through the combination of different elements and components and this adequate combination is exactly the essence of the process designers have to address in this type of link.

Examples for actuators are traffic lights or digital road signs whose functioning is instructed by data about the present traffic situation of their context; a lamp that adapts in intensity of illumination to the environment's light condition, a bus stop that displays the real time to arrival of busses as opposed to a static time table. In general I suggest to distinguish between all those digital/physical connections that result in the visualization of data and those that lead to a three dimensional reconfiguration of a product, its shape and its location or that of its parts.

5.4.2 From real to digital and back

The two delicate passages to consider in linking real and digital elements are the generation of data from physical phenomena and the manifestation of digital data in a perceivable phenomenon.

When designing products or systems that integrate sensors it is essential to be aware of the limits of how sensors represent any environment and its dynamics in quantitative data. Commonly the following points are associated more with the role that a system engineer would cover in a development team. However, I want to underline in the following points why and in what ways it is fundamental to involve an industrial designer in this process to make sure that a sensor does not only function to its technical specification but provides meaningful measurements within the specific product context, its real user interaction and its proper usage within the product's functioning:

1. No sensor does grasp events in its totality. Sensors perceive a certain type of physical parameter and of those only a very specific subset of values that lies in the range of its specifications.

2. A sensor can measure a physical value if it occurs in its range of perception. This is not trivial and is perhaps a point most directly of concern to the industrial designer. If a sensor is supposed to register proximity of the user's hand but is positioned in a way that gets bypassed by the way the user grasps the product, the data generated by the sensor system will not be of much use and if the product's functioning depends in key terms on this data, the product will not work well.

   The integration of sensors into products offers industrial designers new ways in applying their understanding of real world use scenarios and interaction modalities between users and products. This understanding how a product is used by different use groups, in what environments and with what other products, has always been a key attention of industrial design.

3. Once the sensor picks up measurements from its environment generating streams of data, it is not obvious what the values reflect. Intervals of measurement can skip important events and thus not pick them up, measurements can be influenced by fringe events not relevant to those that are intended to be registered and the technical construction of the product system can impact the measurement values and distort them.

   Before elaborating the data it is crucial to understand what the measurements of a specific product setup really mean in order to consequently interpret them in a meaningful way that can lead to its integration in the product's functioning.

Once a set of quantitative data is acquired and elaborated on the digital side of a product, the following aspects are critical in utilizing them to act upon the environment:

1. At the moment that a sensor provides a data stream, this data has to be elaborated in order to be used to actuate physical elements according to a product's program. This involves the identification and extrapolation of parts of data deemed relevant for the envisioned application, the cross linking with other data from different sources to generate finally the output data in the desired format. The reason why this data process requires the attention of the industrial designer is that *what* data is used to act upon the system elements is directly related to *how* to make the data manifest itself in the actual world and in order to design a coherent product behavior a de-

signer must involve himself in determining the data that drives a product's visualization, its appearance and the behavior of its components; aspects he is more commonly involved in.

2. A second delicate step is the design of a coherent modality in which the visualization or materialization of data is reflected in the interface with which the user comes into contact. The designer on one side has to make digital information tangible, visible and audible in a way that makes sense to the user. On the other side, this process of creating a meaningful connection between data and perceivable correlation extends also backwards to how the data was originally collected and with what other data it might have been combined. It is in designing the manifestation of digital information in a product that a designer has the possibility to create a coherent and seamless whole which leads from sensors picking up physical values, to the data elaboration and finally to the actuators that reconnect the digital with the physical realm.

5.4.3 Dual realities

The project "Dual Reality: An Emerging Medium" by Joshua Harlan Lifton provides a good example of now possible projects based on the continuous connection between digital and physical spheres attempting seamless passages that result in one comprehensive experience.

The project aims at sensing certain values about how the rooms in a building are used and reflect that data in a virtual reality context such as Second Life[22], in which the real building is reconstructed virtually and enhanced with so called data ponds that reflect the real world dynamics of the building in the virtual context visually. For the projects' application, the MIT Media Lab building is used and the key input element is constructed around a standard plug socket of which many are distributed throughout the building. These sockets are equipped with various sensors that collect data about the consumption of electrical energy, temperature, light and the presence of people through movement and sound.

[22]Second Life from Linden Research, Inc., launched in 2003 and is an online social network platform that consists in a 3D virtual world in which users are represented by a human like avatar of their choice. Users can not only design and modify their own avatar but also large parts of the 3D virtual environment, they can buy virtual land and construct virtual buildings in which their own and other users' avatars can move and interact with each other.

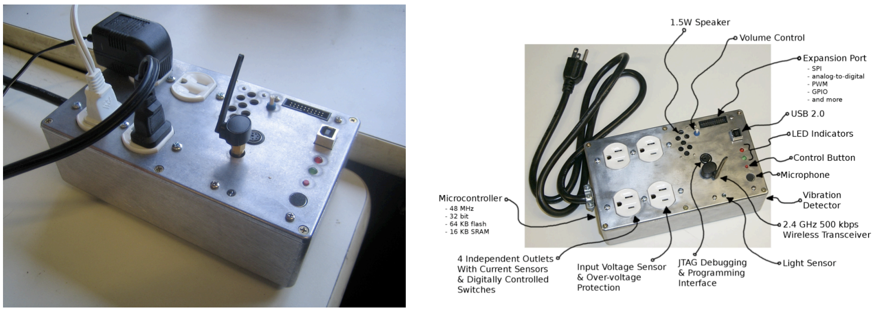


Figure 5.6: Plug sensor node of the "Dual Reality" project.

Subsequently, the data collected through the plug sensor nodes are elaborated and reflected within the virtual 3D model of the Media Lab building situated in the Second Life context. As Lifton says,

> […] obtaining the sensor data from which to generate content is only a part of the process of media creation – the actual embodiment of the sensor data-derived content and the mapping between raw data streams and the final embodiment are equally critical (Lifton, 2007, p. 17).

This embodiment of the digital data streams happens in the form of so called data ponds. "A single data pond is meant to be an easily distinguishable, locally confined representation of the sensor data from a single Plug node" (Ibid., p. 64). Data ponds are visual representations of the sensor data collected at the socket nodes. With change of color and configuration of 3D virtual elements, these ponds for each socket node within the virtual building convey information about the presence of people, light and temperature levels and the energy consumption. The result is a virtual model of a building that represents in real time the behavior of every room within.

Figure 5.7: Screen shot of the Second Life visualization of one floor of the Media Lab building with so called data ponds conveying visually the information collected by the sensor nodes in the real building.

Beyond the visual representation in a virtual world, Lifton takes his project a step further and proposes physical counterparts of the data ponds that consist in a computer controlled fan that blows up plastic color coded bags to determined heights. The color corresponds to the type of value while the size of the bag corresponds to the quantitative value.

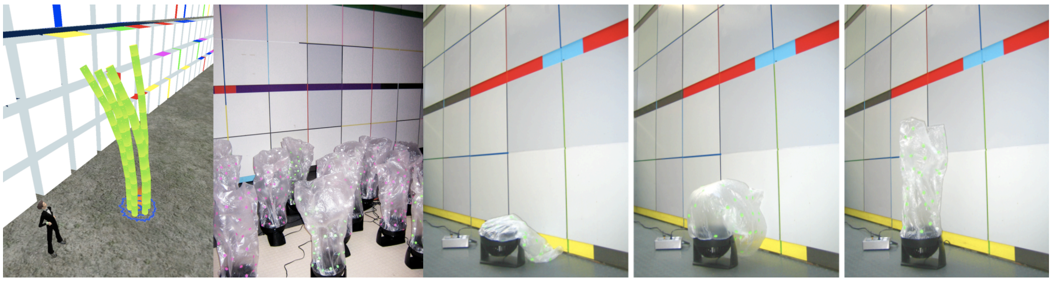


Figure 5.8: Data ponds reflecting the data captured at the socket sensors in both virtual (left) and real (right) environments.

The Dual Realities project illustrates well how to seamlessly bridge the gap between physical environments and a digital data layer. It does this by harnessing the potential of 3D visualizations of buildings in virtual space to represent these physical values that are not perceivable to users in the real world. Connecting physical and digital layers in this way allows effectively to grasp the dynamics of a building in real time and from an overall perspective both while inside or outside of that building.

The aspect of the project I find inconsistent is the physical version of the data ponds as shown in the photograph of figure 5.8. The plug sensor node that caters for the gathering of quantitative information from the environment by sensors is a good example of seamless connection between the physical and the digital realm since it provides a continuity between the two being based on an everyday object that already resides in the environment and with which people are familiar. No extra effort and no extra attention is required to enable the passage of information from the physical to the digital realm.

Also the first step of the subsequent actuation of the physical realm, the visualization of a 3D virtual environment indicating graphically the values from the sensor nodes, happens in a way I would call seamless since it proposes a convincing analogy between the physical space and its virtual 3D representation. This modality proves effective in making users comprehend a represented space.

What interrupts this process of enhancing a physical environment with an elaboration of digital data that is exchanged between both realms, is the final step of materializing the data ponds in the space where the data is collected in the way the project proposes. Unlike the input elements in the form of enhanced electrical plugs, Lifton proposes a completely alien element that is added to the physical space and which has no link with the environment familiar to the user nor does it have a function apart from representing the data collected from the plug nodes.

While I agree with the attempt to re-propose the digital data once collected to that very same physical space, the path chosen can not be considered sustainable for future developments along the same line. Imagine if more similar objects would be digitally enhanced, filling the physical space with additional objects to reflect digital information. This would both fill up real space and it would also create continuous distractions for people using this space. It would require users of the space to learn the code of these various data ponds in order to understand their meaning and it would request their attention as the data would continuously alter their appearance.

I propose to consider some of the elements that I have outlined in the diagram in figure 5.2 at the beginning of this chapter, and that was constructed on the basis of observations of entirely physical connections, to identify possibilities to create seamlessness also in this link through aspects of continuity.

This would mean designing ways to make users of a physical space aware of the energy consumed, the very moment the user is in that space. In the entrance hall, users would be made aware of the energy consumed in different parts of the building.

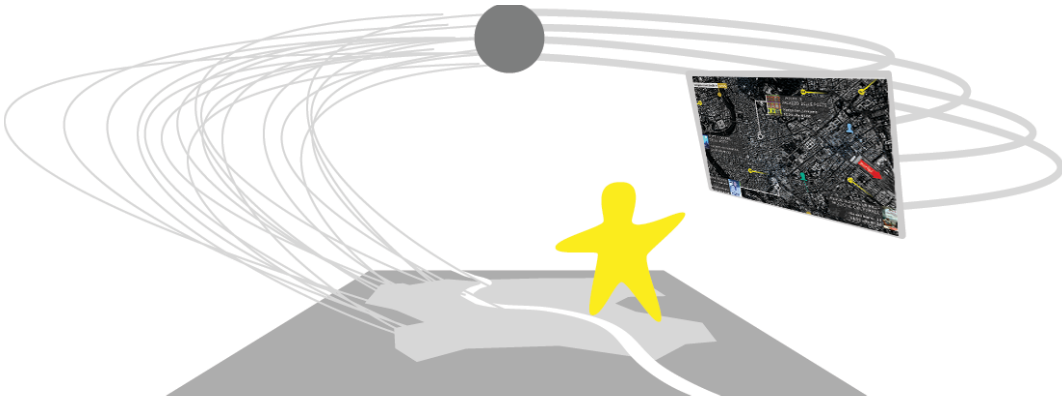


Figure 5.9: Sketch showing the passage from a real world context of urban space into a virtual model visualizing real time dynamics about the physical space, where the data is collected

5.5 Critical seams

Seamlessness has some clear functional benefits linked to the operation of the product and it can become a powerful instrument for the visual structuring of products and in this also contributing to a better legibility of the product. Concealing some of a product's connections allows the user to focus on higher level composition and functionality of which other connections are only supportive.

However, in its aspect of concealing the modality of how parts are joined and putting disincentive on the comprehension and intervention on connecting modalities seamlessness can be seen as counterproductive towards some of the more promising dynamics of innovation in product development that involve user participation and unexpected interaction with parts.

Seamless connections stand in clear contrast with observations made in chapter 4 on articulation and chapter 3 on compatibility that emphasize how connections enable products to adapt to a changing environment and how, through the existence of *hooks*, users can bring themselves into the process of creating and modifying products. For these dynamics, seamlessness as a design approach to connections can be considered as unfit for today's requirements.

Different is the situation in links between digital and physical elements of a product in the sense that these connections are intangible and intelligible to users. Concealing part of their seams allows for them to become usable, allows to focus the user attention on those elements that matter for his part of interaction with a product.

Doing this, however, industrial designers need to create *hooks* in this process of concealing. Links ought to be artificially created in order for users to participate in the connecting process and to allow unexpected combinations. While seamless transitions between physical and digital realms are fundamental of a design brief to enable a product bridging these two spheres to function well, it ought to become a new quest for the design discipline to understand in what way, this unified experience of such a product does still open up possibilities of detecting the links that allow creative user participation to innovate these very products.

6. Reversibility

6.1 Disconnections enabling to connect

Reversibility as an aspect of connections has to do with the restoration of a previous state, a situation that existed prior to an established link. Any connection is undeniably a phenomena related to a time dependent dynamic. It implies that there are at least two possible states in which parts can be in relation to each other, connected or disconnected. And it implies that these different stages occur at different points in time, a connection cannot be both connected and disconnected at the same moment.

For these basic considerations any connection present in a product's structure or configuration also a potential disconnection is present, both as a possibility or an impossibility. For the user, this leads to the question as to whether a developed connection can be disconnected at a later point after being joined.

This question determines to a large extend how a user poses himself in front of a connection he recognizes. Once connected, will he be able to disconnect again? And after that, is reconnecting still a possibility? To the user, it matters whether he will be able to detach one part from the other for reasons I have subdivided into three groups:

1. *Trial and error*

   Being able to connect and disconnect allows for experimenting with different relationships between parts without risking a situation of no-return.

2. *Reconfiguration of parts*

   There might be different possible connections between parts and different situations might request different configurations of parts. Being able to disconnect and reconnect parts allows the user to adapt a product to specific requirements.

3. *Short term decision*

   Connecting without being able to disconnect creates a long term commitment often beyond the users willingness. As a user, a connection might be desirable for a foreseeable timeframe, and in this way reversibility of connections encounters a user's time perspective more realistically.

The aspect of reversibility in connections thus comes close to the now ubiquitous "undo" functionality in many software applications where a mouse-click on a specific interface button returns any situation to its previous state annihilating a precedent action taken by the user and the effects that it has caused.

Being able to reverse a connection to its unconnected state however does also suggest a lesser degree of robustness and permanence. Being able to disconnect excludes a perspective of "forever" regarding artifacts and suggests proneness also to undesired disconnections that might impact the product's benefit for the user negatively.

6.2 Reversibility in product connections

6.2.1 User recognition of disconnections

Any connecting dynamic is a time based phenomenon of distinct states between the extremes *connected* and *disconnected*. However, even though these states cannot occur at the same time, they can be present for the user in actuating his choice of joining two parts. An industrial designer, in developing product connections, needs to pay attention to the fact that a user's attitude towards a possible connection changes according to whether re can tell whether and how it will be possible to disconnect. This information needs to be conveyed to the user before or in the moment of connection for it to be present in taking a decision. Two examples illustrate this point: connections established by screw mechanisms and those by a snap-fits.

In the case of a screw mechanism, the user understands that the reverse action of connecting will allow him to disconnect. The turning movement is gradual, establishing an increasingly tighter link between parts. While connecting by turning a screw, the user can try to test reversibility as a part of the connecting process. To the user, these conditions make it clear that a screw-connection can be undone and he understands that either no tools are required or the same tools that he uses for connecting will suffice.

Figure 6.1: Screw connection

Different instead is the case for snap-fit connections. This type of connection happens suddenly when one part of the attachment is inserted into its hosting bracket and an elastic indent snaps into its locking position. Snap-fit attachments can be designed to be reversible or not, depending on how the designer structures the parts, on how he allows the user access to the release mechanism and how he communicates this to the user. Since the movement to unlock a snap-fit attachment is different from the locking movement, visual clues in the connector's structure need to be designed to make the user understand beforehand that there is a way of disconnecting the link and how this would have to happen.

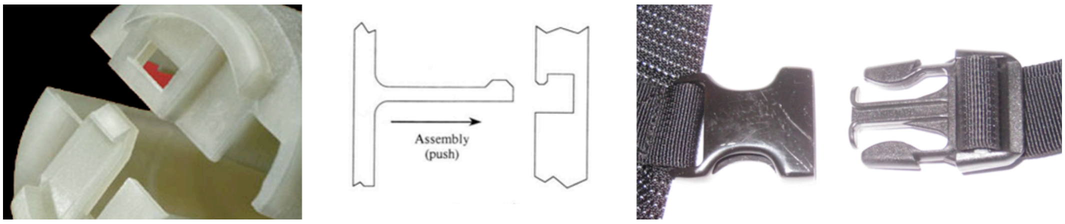
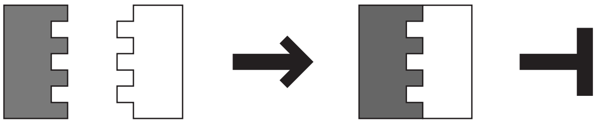


Figure 6.2: Snap-fit connections

This reflection takes up a stream of analysis started in the chapter on responsiveness, but it goes beyond what I have discussed there since reversibility is an aspect that needs to be communicated to the user not during but before the connecting process in order to allow for benefitting from the connection-disconnection potential of parts.

I suggest to make a distinction between three large connection groups that need to be treated diversely regarding their design and the modality of user feedback concerning their reversibility:

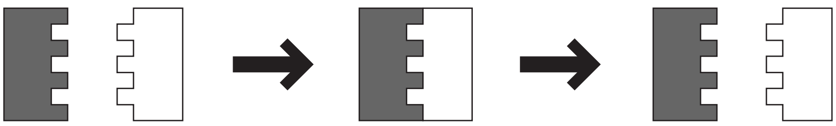
1. *Connections that do not allow for disconnecting*



This group of connections regards those that can be established by the user and which result in a permanent link between parts. It also includes connections which, if disconnected, leave an undesirable damage to either the parts or the connector and thus can only be disconnected in a destructive manner.

Often such a permanent characteristic of a connection is not communicated to the user through specific design clues of a product or part. Permanent connections such as super-glue, staples or rivets are understood as such through separate instructions or past experience but it is difficult to find cases in which the irreversibility of the connection is communicated to the user by the design of the connection. This can be considered a still open field for design exploration.

2. *Reversible connections involving the same or inverse movement*



This case is probably the most common of reversible connections. Links that work though geometric interlocking are unlocked through the same or inverse movement. Screws, hooks, zips and similar are examples of this group. For the industrial designer this means that little has to be done in terms of user guidance specifically for the stage of disconnecting as long as the connection process is intelligible to the user and it is easily understood that the reverse motion leads back to the disconnected state.

3. *Reversible connections involving a different disconnecting movement*

As I have discussed on the example of the reversible snap-fit connection, this group of reversible connections poses a very concrete task for the design of connections. How to communicate the ability and process of disconnection in the moment that the user contemplates the connection of parts.

The difficulty is bifold: it lies in the fact of having to find a way to communicate a user action which is not immediately going to be actuated and this communication of how to disconnect must not overshadow or confuse the user regarding the modality of connecting at first.

Having acknowledged that the design elements that would clarify to the user the first group of connections are rarely observable and that the second group is less problematic since already covered by the modality of connection, the third group is of particular interest to the design of connections since the disconnection process follows a movement and modality different from the process of connecting. The design of connections in this case requires that the parts indicate a user action, through touch zones or similar, that is inaccessible and therefore in-confutable with the connecting process. Elements that hint at how to disconnect need to be present in a user's perception of the connection during the process of joining but these elements must not interfere with the actual process of joining itself.

Examples of such an articulation of the joints can be fund in cable connectors such as those present for USB computer peripherals which have visible pull-groves in the connector that indicate a way to un-plug the cable already during the connection phase. Reversible snap-fit connectors such as those used often in backpack closures indicate by an open window how a user can subsequently undo the connection by pressing the interlocking parts inside.

6.2.2 Disconnections as product function

Having analyzed some of the principle dynamics of how users can recognize the possibility of reversing a connection and what impact this has on the design approach, I want to focus now on the role of disconnecting within a product's function and which I have summarized and illustrated in figure 6.3.

Two large parameters intersect to create distinct groups of connections once we reason on the re-usability of their parts offered through the reversing of connections. On one hand, I suggest to distinguish between connections that can be undone in a *non-destructive* way, maintaining the integrity of parts and connectors and on the other hand there are those connections that only allow for a *destructive* disassembly of parts[23].

Subsequently, I identify three groups of connections according the re-usability of connections: The first group regards connections which connect once without conceding reversibility if not in a destructive way. The second group of connections allows for the connection and a subsequent disconnection after which no further connecting modality is possible. Both, destructive and non-destructive modalities shall be contemplated for this case. In the third and last group multiple cycles of connecting, disconnecting and reconnecting are possible.

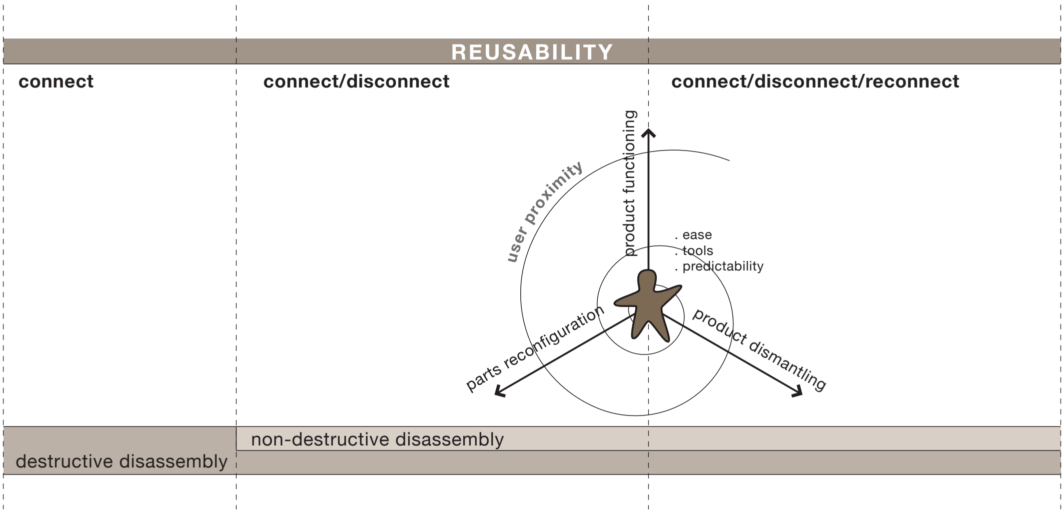


Figure 6.3: Aspects of reversibility of connections in products

Within the two groups that consider the possibility of disconnecting and re-connecting, a further subdivision can be applied which determines the functional role that the reversibility of connections plays within a product:

Reversibility of connections can be part of the product's very functioning. In these cases the multiple connecting and disconnecting of parts contributes to the functionality the product is meant to perform in regard to who uses it. Closures of containers that are opened and closed frequently might be an example as well as electrical plugs or sliding mechanisms for drawers.

The reconfiguration of parts into different objects is a second group in which the

[23]This is a distinction also applied in the context of design for disassembly such as in (Güngör, 2006; Tseng, Chang, & Li, 2008).

distinct identity and character of parts is maintained but disconnecting allows for reconnecting with different elements that creates various product configurations according to different requirements.

In the third group, disconnections are possible with the purpose of the product's dismantling in view of recycling or re-use of parts. This is an aspect generally studied within the framework of sustainable design and more specifically in terms of design for disassembly which I will discuss in the upcoming section 6.3.

Finally, as illustrated in figure 6.3, the functional role of the reversibility of connections varies in terms of the proximity to the user. This proximity can differ in the extent that the user is or is not directly involved in the connecting/disconnecting process of parts. Some aspects of reversibility might be present only in limited areas of product use such as during maintenance or repair, while others are actuated by the user himself[24]. The proximity between a user and the reversibility process of a product's connections can also be determined by distinguishing whether a user interacts directly and manually with the connecting parts or whether he necessitates a tool to accomplish both or either the connection and disconnection. The ease of disconnection is a hard to establish but fundamental aspect to consider in this context and refers to both the recognition of reversibility modality and the implementation of such a reverse action itself.

6.2.3 Rhythm of connecting

Considering the reversibility in connections I have tried to plot graphically in what way the repeated joining and undoing of a link modality is part of a product's functioning.

Figure 6.4: Six traditional connections to be employed for the graphical plotting of the repeated joining and undoing as part of a its common functioning

[24]People coming into contact with a product in different ways such as during repair or maintenance can be considered users in terms of obviously considering their interaction with a product related to its design. In this context however I refer to the *user*, meaning the actor that benefits from the product's actual functionality.

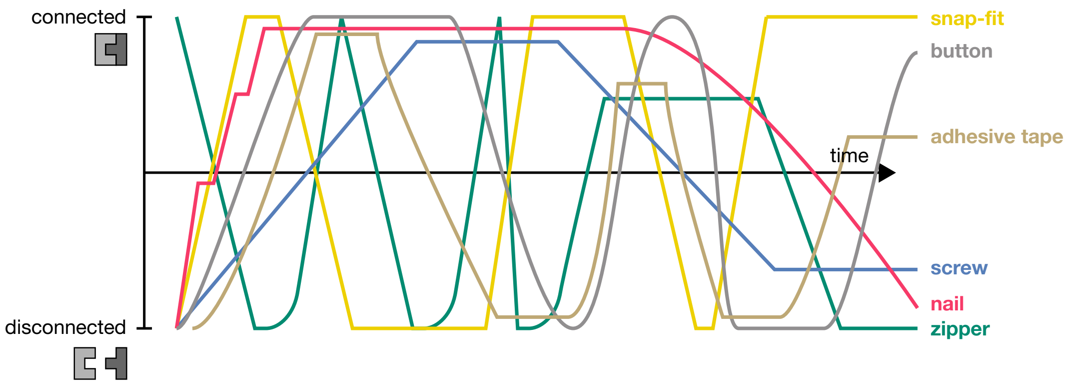


Figure 6.5: Overlay of mapping the dynamics of connection and disconnection cycles in a product's functioning for the example cases snap-fit, button, adhesive tape, screw, nail and zipper

The aim of these graphs is to illustrate how connections alternate between the two states connected and disconnected during their normal functioning, to compare these modalities and to understand how these graphic representations can contribute to the process of designing new types of connections. Some apparent benefits of these mappings can be seen in these aspects:

- In designing new connections, traditional modalities that correspond in frequency of intermittance with the requirements for the new connection can be identified and taken as a reference. Characteristics that enable that type of intermittence can be studied for a possible reinterpretation in new connecting modalities.

- Strong and week points of new as well as traditional connections, related to their ability to repeatedly connect and disconnect, can be understood quickly because of the visual traces.

- Facilitated identification of different connection types that show different patterns of connectivity to consider for combination within one product.

A difficulty encountered in plotting the connection dynamic of such diverse connections such as snap-fit, button, adhesive tape, screw, nail and zipper is to establish a commonly relevant time scale. While a button might be done and undone multiple times a day, a nail is likely to be used to establish a connection that lasts for several days or even years.

6.3 Taking things apart - design for disassembly

Once the taking apart of things is considered already at the moment of their conception, this reversion of their assembly enters to form part of the design process itself. The field of study that occupies itself specifically with this aspect is known as *design for disassembly*.

> The history of disassembly cannot be considered in isolation without also considering the history of assembly, for both obviously represent two characteristics of the same product and the solutions to both problems have been influenced by comparable techniques.
>
> Disassembly is virtually as old as mankind and thus is even older than assembly! The oldest example of disassembly comes from the retrieval (or disassembly) of various parts of animals by human beings for meat. The industrial counterpart of this was the establishment of large-scale slaughterhouses during the later part of the 19th century, which at that time were known as disassembly lines (Lambert & Gupta, 2004, p. 3).

Design for disassembly is a field which, like the already discussed design for assembly, commonly considers connections to be actuated in the phases that are not directly at contact with the user of the product. However it is a rich field of analysis and considerations that in part lead to new perspectives for the design of products also in the light of user-product interaction.

The disassembly of a product is the reversion of several connections established between parts during the phase of the product's generation. Objective for such a taking apart of a product has for long been reasons of product updating, maintenance and repair while especially since the 1990's design for disassembly has started to receive continuous and increasing attention within the context of re-use and recycling in light of environmental sustainability. Counteracting against a continuous increase of products with a limited and often short life time at which end they commonly are disposed of in landfills, the recycling and reuse of parts or products attempts to prolong the life cycle of materials and parts involved in the creation of all types of products.

Disassembly can be *partial*, in which case a product is decomposed into some of its subassemblies, or it can be *complete* in which case parts of a product are separated in a way that does not maintain their key characteristics. While many artifacts are reaching increasingly higher levels of inner complexity, "frequent variation of product specification causes the assembly and disassembly of components and modules to become more and more complicated." (Tseng et al., 2008, p. 2524) This fact has a particularly critical impact on the time it takes to disassemble a product and subsequently on the level of efficiency at which this process can happen.

In the example of the two clockmakers in (Simon, 1969) this time aspect is emphasized and analyzed in the phase of assembly. Demonstrating the benefit of partitioning a product's assembly, Simon presents one clockmaker that produces his clock by adding one part after the other until his clock is complete, having to restart the assembly at every unexpected interruption since only the completed product holds all parts in place. The other clockmaker instead approaches the assembly task by subdividing his clock into subassemblies that each consist in few parts that hold together on their own. In this way he proceeds by preparing all subassemblies before joining them together into larger subsets until the finished product is formed, the advantage being the at any interruption in this process, he only loses the subassembly he currently works on instead of the entire product thus far assembled.

Also in the perspective of disassembly, such a product modular approach becomes relevant, allowing for parts of products in disuse to be re-integrated into new products while maintaining their identity in this process. Also from the product cost perspective, this process of disassembly for re-use proves promising since the life-cycle cost estimation enables designers to bring product cost under control. (Tseng et al., 2008)

In extrapolating some of the concerns regarding the disassembly process from (Güngör, 2006), the following points should be of interest also to industrial designers:

- *Non-destructiveness of disassembly* and *possibility for reuse*

  When during disassembly the separation of parts leads to damaged elements, the cause of this can realistically be attributed to two distinct moments. Parts may get damaged already at the point of assembly without this being noticed or having any impact on the assembled state of the product, it only becomes evident in case of disassembly. An example would be nailed connections or parts linked by metal clips tacked through them.

  Other connections might damage parts only when being disassembled which is a situation that emerges in the case that connections are not conceived to be disconnected at a later point such is often the case with adhesives or types of energy bonding such as welding, brazing or soldering.

  Destructive modalities of disassembly can be useful even within the context of disassembly. Considering the recycling of the materials of a product as opposed to whole parts, the integrity of the latter is of minor interest since the components, both damaged or not will be reduced to material particles in any case.

  Non-destructive disassembly on the other hand is of interest if parts or subassemblies shall be reused in their integrity. When considering the life time of a product as a whole, we do not consider that individual parts of that product might have a useful time of utilization that exceeds that of the assembled product for multiple reasons ranging from technical functionality to the quality of appearance and dynamics of fashion or user preference. One company that has a very convincing track record on this behalf is Xerox, which has integrated re-use, recycling and remanufacturing of parts of its products into most of its products by heavily structuring the design process around these aspects.

  > Xerox maximizes the end-of-life potential of products and components by considering reuse in the design process. Machines are designed for easy disassembly and contain fewer parts. Parts are durable – designed for multiple product life cycles. Coded with instructions on how to dispose, the parts are also easy to reuse or recycle. As a result, equipment returned to Xerox at end of life can be rebuilt to as-new performance specifications, reusing 70–90% of machine components (by weight), while meeting performance specifications for equipment with parts that are all new.
  >
  > Xerox also designs product families around modular product architectures and a common set of core-components. […] A returned machine can be rebuilt as the same model through remanufacture, converted to a new model within the same product family,or used as a source of parts for next-generation models. (Xerox, 2007, p. 42)

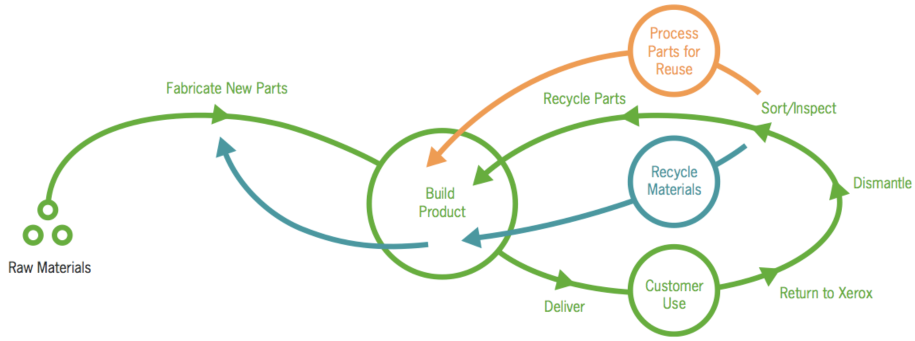


Figure 6.6: Xerox Equipment recovery and parts reuse/recycle process. (Xerox, 2007)

Design for disassembly linked to arguments of recycle or re-use of parts is commonly linked to manufacturing environments while I have mentioned already how recent studies into innovation dynamics[25] bring the end users of products closer to these processes. This is one reason for which an emerging question for industrial design is to understand to what extend users will benefit from being able to disassemble parts of products for reuse in different ways by obtaining integral and undamaged connectors and parts.

The other reason why I believe nondestructive disassembly enacted by the user will play an increasingly important role is the double velocity of products' aging and change to which I have referred to in section 3.3.2. Embedded electronic components become obsolete in their functionalities long before the physical components of the products they are integrated in. In order to avoid that such partial aging leads to the disposal of the entire product, nondestructive partial disassembly by the user can be one promising approach.

This however poses a determined requirement on the design of connections involved, guaranteeing that the process is easy enough for users to handle and that it does not comprise the integrity of the product as a whole.

Advancing this perspective a step further, I want to recall the process of re-assembly discussed in section 4.4.1. Not only does connection design need to contemplate the efficient disassembly of parts by the user but it further needs to pay close attention to the structure of connecting zones in a way that allows for possibly wide ranges of connectivity with other parts the industrial designer might not even be aware of at the point of product development.

A reflection shall also be made about new potentials of destructive modalities of disassembly. Industrial design often analyzes user behavior in order to understand how to design interaction modalities that are effortless since they involve familiar actions. Referring to the quote from (Lambert & Gupta, 2004) at the beginning of this part,

[25] As I have already discussed above, (von Hippel, 1988) makes a very compelling case for user based innovation processes which is further developed in (von Hippel, 2005).

about the origins of disassembly reaching back further in time than assembly, I suggest to reconsider the simple act of destructive shattering of parts as a constructive way of disassembling a product.

Perhaps the most intuitive way of taking an object apart can be considered that of simply throwing it to the ground or hitting it with another object as is done at a promising moment with the classic piggy bank. What may sound like a superficial provocation does, as a matter of fact have at least three references that stress its potential.

First, engineers have long ago developed the concept of planned break-points[26]. Implementations of this can be found in aircraft bodies that break at specific points in case of emergency landing or also different kinds of emergency exits or emergency tool coverings which only necessitate a slight but well positioned impact in order to fracture enough to make way for the intended passage. This means that a careful design of break points in products would enable to leverage this break-potential only when disassembly is desired.

Secondly, the increasing deployment of sensors in very diverse kinds of products can already register acceleration, orientation, speed or impact. These informations are subsequently used to trigger various product functions, at the moment mostly within the digital realm. I see this as a promising field of investigation to understand how this data could work together with planned breaking-points to give novel potentials to the act of destructive disassembly.

The third reference that could give destructive disassembly a new role in the design of connections relates to newly developed self-healing materials which at present have been developed mainly in the field of polymers. When fractured, these materials release nano-structured substances capable of binding the break-points, reforming the integrity of the parts.

- *Complexity of disassembly motion*

In the process of taking a product apart and divide it into some of its components or subassemblies two distinct types of disassembly motion exist: Disassembly of parts can occur in the same or reverse movement as assembly, or it can require a different movement.

Connections can be designed in a way so that the disassembly movements of different parts or subassemblies differs in type and complexity of motion so as to differentiate between groups of users coming into contact with the product. In moments of maintenance or repair, more complex motions can be designed to dismantle parts of a product since these steps are carried out by staff that deals with the product at an expert level and can be specifically instructed for disassembly modalities.

Instead, other connections can be characterized by easily accessible disassembly motions so that end users also with little experience with the product can master

[26]The German term "Sollbruchstelle" is even more telling, translating literally as the *place of intended breakage*.

these and take advantage of this sphere of taking parts out of a product to substitute it with different components or change the overall configuration.

- *Tool complexity*

  I have already described some dynamics that involve tools for establishing connections when referring to the long term compatibility of the Ikea mounting tool in section 3.3.4. While there are connections that a user can establish or dissolve manually, in other cases using a tool helps or might be indispensable to operate the connection. In case of a tool being necessary for a given connection, the designer has to choose between different options to provide the user with this requirement:

  One approach is to rely on standard connections depending on the user to *bring his own tool* or procure a tool which is easily found.

  A second approach is that operated by Ikea and consists in adding the tool required for operating the connection. This leads to the critical point of the user having to work out ways that ensure that he has access to the tool in the moment he needs it, not losing it while not using it instead. Various approaches of attaching the tool to the product in more or less practical ways can be observed in products.

  A third strategy is to integrate tool bits into parts of the product which have other functions but can, if necessary, be employed to actuate the connection or disconnection. This approach has the potential of providing the user with a connecting tool without adding an additional object that is often not used and that can be lost. It requires however at the same time a careful design that ensures the recognition of the tool bit as such, even if it is integrated in a part connotated by another function. Furthermore it requires that the tool bit does not obstruct the original functionality of that part.

  Besides these aspects of articulation of the tool, the modality of usage that involves a sequence of motions that lead to the desired connection or disconnection are constrained by the accessibility of the connection that needs to be acted upon and the specific hand or arm position a user needs to assume while operating the tool.

- *Disassembly time*

  In the context of manufacturing site disassembly, the disassembly time is critical in simple quantitative terms in order to evaluate the economic efficiency of the process with the overall life cycle of the product. The three points above are in fact all set up in view of this aspect and the connections of products designed for disassembly are developed in order to allow for quick disassembly by ensuring an adequate complexity in tool usage and disconnecting motion and non-destructive disassembly in case of reuse of product parts.

  The time aspect does however also play a critical role in taking products apart in regards to the user of a product and it does so also not only in purely quantitative terms but also related to correlation of events and intervals in the disconnecting process. In this regard I want to only briefly hint at the design of appropriate sequences in which connections can be undone and opportunities to link disassembly actions to specific events that occur in the user interaction with the product.

6.4 New dis-connections

Following are some aspects I deem of particular interest to the design of connections in products:

Disconnections in the form of disassembly are moving from distinct stages far from the actual product use towards intermediate stages involving also the user in order to update the product and to adapt it to a continuously changing context. By reversing connections that were established previously, users can in this way create new product configurations. In the case of products that combine physical elements with embedded electronic parts dealign with digital information at the core of a product's function, the possibility to disconnect these components for update reasons represents a potential for increasing the longevity of products that would otherwise risk obsolesce due to the fast turn over cycle of digital devices.

At present, contactless connections are being used successfully in applications in which users identify themselves or one product with a larger network. Not requiring physical interaction in fact renders these connections an easier task for the user and many difficulties present in repeated physical connection/disconnection cycles can be overcome in this way. A consideration I want to pose is how such contactless connections can be harnessed between the components of a product. This would introduce new possibilities of updating product components in a much simplified manner for the user.

Another consideration of reversibility and contactless connections such as between an RFID card and a reader regards the modality of which the design of this process enables the user to understand before establishing the connection whether the effect can be undone. I have raised the question for physical connections in this chapter, pointing out how the user understanding of possibilities of future disconnections influences his willingness to experiment connections in first place. How does this work for contactless connections? Design will have to introduce new feedback modalities so that users know up front, for example, whether an RFID ticket registered erroneously will be recoverable or not.

As a matter of fact, while it is clear what it means in physical terms to bring back a connection into its previous state, this is not the case for digital connections. A relevant discussion is introduced in (Rhodes & Maes, 2000), which poses the question whether systems that memorize digital information should, like humans, forget information, returning, that is, to a state previous of established connections. While this seems odd at first since to a large extend, the benefit of digital information systems is perceived just in the way large amounts of data can be stored without time limits, this approach would address in a charming way some of the problems surrounding aspects of data privacy.

Finally, there are promising outlooks in the combination of efforts of tagging objects with digital information like is happening today in the form of RFID tags or barcodes, and research in nanotechnology. In fact, attempts are to continuously shrink the size of identification tags so that not only objects but even components can be individually characterized. Nano-tags on product components would open up intriguing possibilities of establishing sophisticated systems of disassembly based on the distant reading of identification tags associated with all of a product's parts severely enhancing recycling and re-use logistics of products.

7. Scale

7.1 Scale issues in products

How big or how small, how many or how little are criteria that quickly come to mind when considering the combination of elements, parts that are joined. These questions concern aspects that can be approached through units of size that can be objectively measured. More than approaching these questions with absolute numbers in terms of size and measures however, I want to stress the size relations for which this chapter confronts the aspect of *scale* in connections.

In designing connections three reference elements ought to be considered in relation to the scale aspect:

1. *The user*

   The relationship between the user and any product connection determines the intelligibility of the connection by the user and the possibility and modality of interaction with the connecting zones. Even though there are no absolute size ranges in terms of measurement units that can reasonably established, this relationship does exist and determines consequences such as whether a user would need to use a tool in order to operate a connection, whether he could without an instrument perceive and interpret correctly the connection and similar aspects.

2. *The size of parts*

   When dealing with physical connections, any link is necessarily related to the size of the parts it does connect. This has a series of implications for the design process: relatively small size connections can be integrated in larger parts while users can be facilitated in focusing on a connection or not perceive it. In connecting objects a designer can chose to connect two parts with many relatively small or few large connections.

3. *The size of the whole*

   Connections in relation to the size of the product they constitute result visually a prime element or hardly perceivable allowing for a seamless appearance. The number of connections in relation to the whole instead determines how restrained this larger unit is.

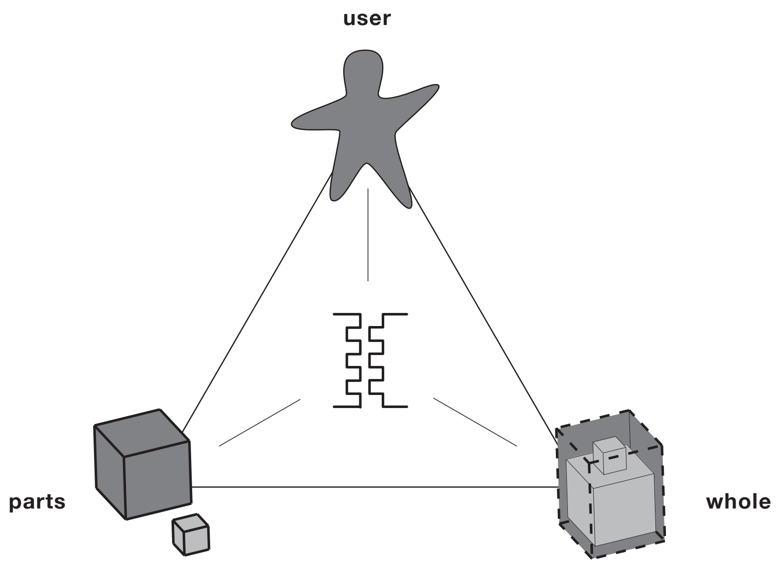


Figure 7.1: Scale aspect in connections in relation to the user, the parts and the whole

The role of scale in the design of connections can subsequently tackled from three distinct perspectives:

1. *The scale of connections*

   This aspect regards the scale at which the connection between two parts is actually formulated and can range from molecular cohesion and chemical bonding such as is the case in adhesives up to geometric interlocking at sizes perceivable and operable to a human user.

2. *Size of combination*

   Joining two or more parts necessarily results in a larger combined unit. Vice versa, introducing connections in parts allows for these parts to be reduced in size at specific moments of product life.

3. *Extension of connections*

   Increasingly, specific types of connections allow for large numbers of elements to be joined into one unitary whole. The extension of networks refers to both the number of parts and distance that lie between the elements.

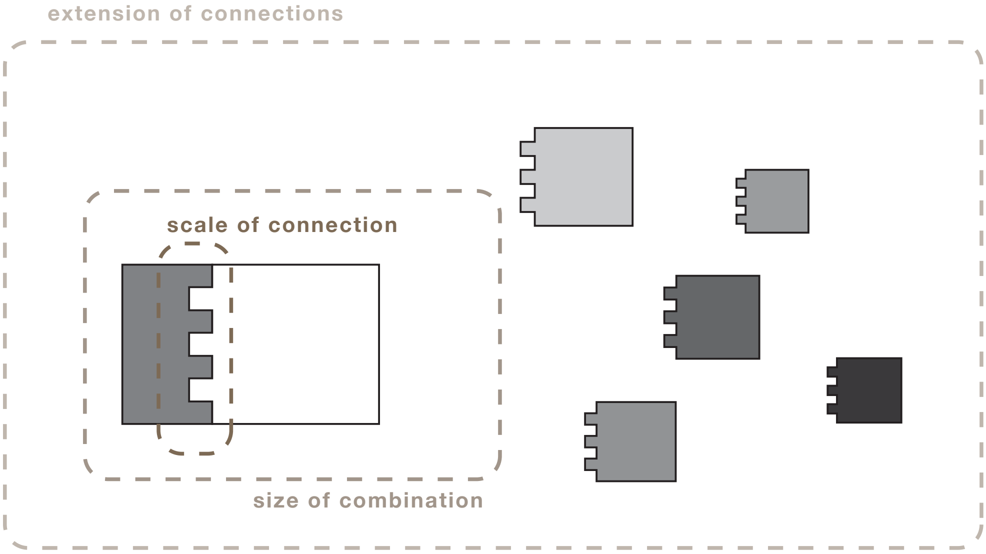


Figure 7.2: Scale aspects in product connections

7.2 Connecting to enlarge and shrink objects

Manufacturing technologies can have technical restraints that limit the maximum size an object can be produced at. In order to compose objects of larger dimension, necessarily multiple parts produced in such a process have to be joined to larger units.

A telling example is the case described in (Sass, 2008) which focuses on the production method of layered manufacturing, commonly known as rapid prototyping.

> […] the outcomes produced by layered manufacturing are limited by factors associated with the machine tool (e.g., machine size), materials, and physical behaviors—issues that become clear post model production. (Ibid., p. 692)

and further:

> Most machines are limited in the maximum size of model manufacture; the maximum length for a common layered manufacturing device is less than 25.8 cm. Architects, however, would benefit from a variety of size models that can be manufactured from the same machine with software functions that subdivide a model into parts with attachments. (Ibid., p. 693)

Sass approaches this task by subdividing product parts to be produced with the rapid prototyping process into smaller components. Key in this process is the shape grammar language he devises in order to structure computationally the interface zones of these components in a way so that each part interlocks with its neighboring parts through connectors that are integrated in the components. Every connection interface between two parts is unique, allowing for one only assembly composition. The result is thus a series of components with integrated connections that contain the assembly instructions within their connections and that can be composed to form the larger desired shape.

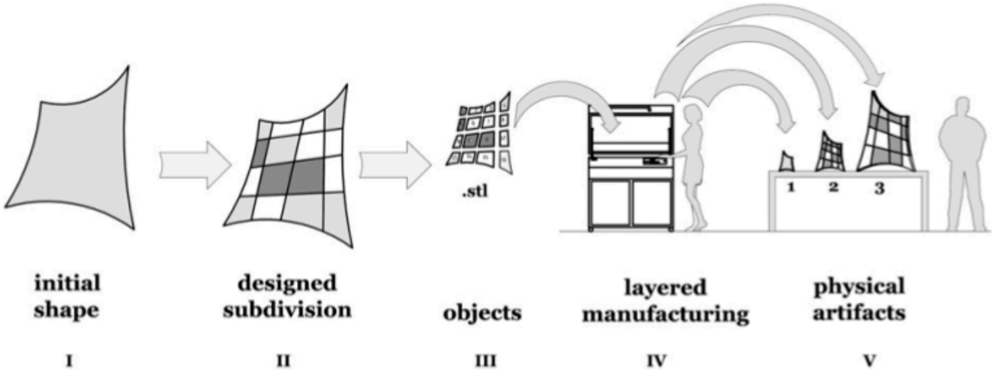


Figure 7.3: From (Sass, 2008): Materializing process, starting with an initial shape to the finished artifact.

A critical aspect in connecting differently sized parts with equal connectors is that the relation between the connector and the parts vary, making it difficult to simulate and calculate the behavior of each of the connections separately. In fact, while the simulation of material behavior has reached high levels of maturity, it remains difficult to calculate the behavior of connections. The critical aspect in this remains the passage from one component to another, from one material to another by way of a connector.

For this reason Sass, in his research has worked with scaled integrated connectors. Instead of devising a single sized connector for all parts of different dimension, his approach is based on forming the connectors in proportion to the size of the interfaces of the parts to be connected. The aim of this is to allow for a coherent calculation, simulation and behavior of all connections within one assembled object despite different sized parts.

Figure 7.4: Model Assembly of a Curved Wall (Digital Design Fabrication Group, Massachusetts Institute of Technology)

Figure 7.4 shows a manual assembly process involving parts manufactured by rapid processing. The parts are shaped in a way so that there is only one fitting position, avoiding doubt concerning the assembly location and orientation. At the same time, the interlocking surfaces are in proportion to the size of interface, resulting a more coherent whole in terms of force transmission between parts, required resistance of the connecting zones and possibility of computer simulation of the connections behavior.

A compelling analogy is presented in (Mihaly, 1989) between building puzzles and the design of objects constructed by smaller components. By connecting "between tiling problems and the design of construction parts of prefabricated building systems"(Ibid.) the emphasize is put on the combinatorial nature of the problem to conceive systems capable of creating wholes characterized by a small number of distinct elements that allow for a large number of arrangements.

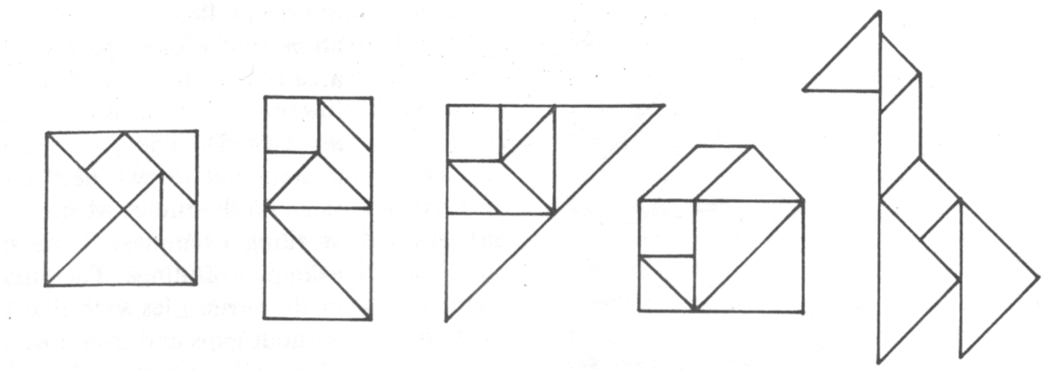


Figure 7.5: Tiling examples of the Chinese tangram puzzle (Mihaly, 1989)

The analysis of traditional building puzzles such as the Soma Cubes invented by Danish puzzle expert Piet Hein, the Z-blocks or the Chinese Tangram puzzle are studied to suggest methodologies of structuring prefabricated components such as has been done in the past by Walter Gropius and Konrad Wachsmann with their General Panel System (Wachsmann, 1961) or by Max Mengeringhausen in form of the Mero universal connector.

Mihaly considers the bit-like elaboration of parts' interface in a similar way as Sass has done nearly a decade later, disposing of a much more effective support of computers to structure a shape grammar language regarding the connection zones of parts. The continuing development of manufacturing technologies such as rapid prototyping and the increasing diffusion of such machinery leads to expect this connecting matter to enter gradually the realm of the end user. This would then introduce a new field for design in making the approaches experimented by both Mihaly and Sass accessible to a non-expert audience and use group.

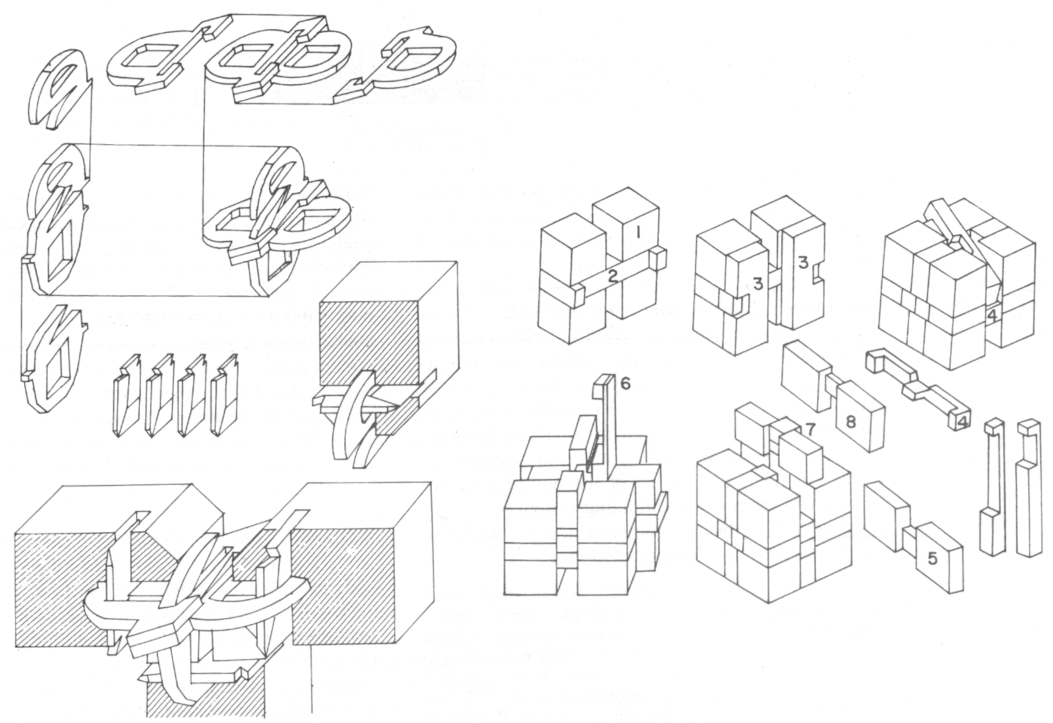


Figure 7.6: Comparison of the connection parts of the General Panel System by Walter Gropius and Konrad Wachsmann (left) and the interlocking wood pieces of a Japanese puzzle (right)

Assembling objects by connecting smaller components allows vice versa for the reduction in size by the disassembly of parts, as long as the connections allow or the reversibility to the previous state, a topic discussed in the previous chapter 6. Beyond the disassembly of an object by disconnecting its components, another dynamic has always been of particular interest to industrial design: foldables.

Being able to fold an object is never the main functionality of a product it rather serves the secondary purpose to reduce the size or volume of things in perspective of transportation, storage or adaptation to a changed use context. The emphasize on mobility in recent years has given new attention to foldables, allowing for objects to be carried by the user that would originally occupy too large a volume to be taken on the move. Miniaturization has long been the prime strategy for this purpose but having reached apparent limits of usability, the folding of objects that can be brought back to original size when in use offers advantage over the permanent reduction in component dimension.

The design of connections involved in foldable items assumes a particular importance since the entire aspect of foldability depends on them both in terms of ease of use, reliability and endurance. Similar but at the same time distinct from the argument made in chapter 2 on responsiveness, the design of foldable objects does not need to consider the user comprehension of how to connect different parts of a product but rather how to maneuver already connected elements in an appropriate way to obtain the desired product structure. This is particularly difficult since besides the two distinct states of the product *folded* and *unfolded*, there are an infinite number of gradual steps of product configuration in between that the product can assume and which the user needs to interpret correctly in order to achieve his goal.

Recent investigations have been experimenting with aspects of self-assembly or auto-configuration of parts. The former is one of the fascinating possibilities that are opened up by research into the nanoscale of matter, allowing for the self-assembly of molecules on the basis of a program that is devised by the scientist. Automatic reconfiguration instead is a modality closer to the folding of objects. Components are already in place but can reconfigure to turn into diverse combinations of the parts, again following design programs devised upfront.

It is in fact the aspect of programming the behavior between reconfigurable parts that opens up fascinating new possibilities since it sees the designer not in the role of giving one determined shape to objects but to set groups of parts up for possible behaviors, altering the designers role by having him focus on the layout of possibilities rather than on formulating one of them in particular. (Yoshida et al., 2001) discusses investigations in one such case of a reconfigurable robot capable of structuring its parts on the basis of a behavioral program.

It is still an open question as to in what way such assembly automation could be considered in products at contact with end users. However, having hinted at the difficulty of maneuvering complex foldable objects above, one approach could be that such an objects supports the user in bending and turning the parts in the right way in order to change it from one state to the other. Similar to some sports exercise equipment, the parts would not move themselves, but would in their movement assist the user towards the right direction.

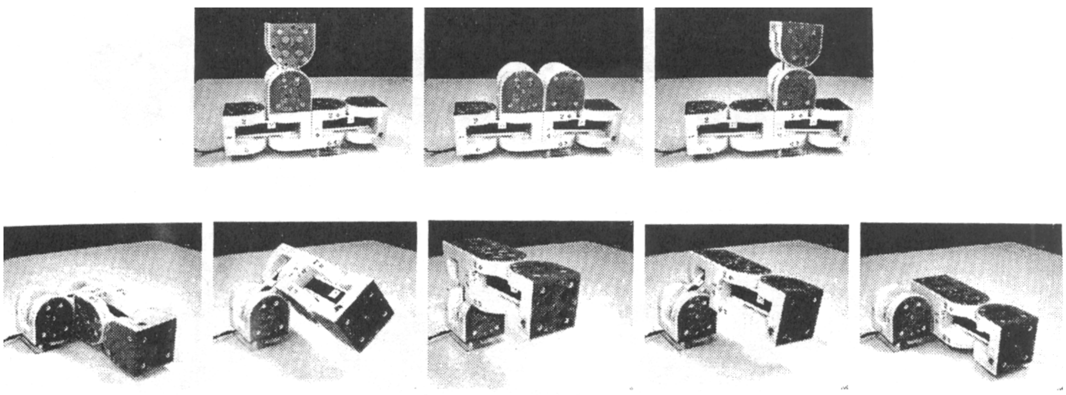


Figure 7.7: Experiment with self-assembling modular robot (Yoshida et al., 2001)

7.3 Designing very small and very large connections

Over the past decades an increase in complexity in the construction of many types of products could be observed. This is happening especially on the basis of the ongoing introduction of electronic components in ever new types of also traditional kinds of products that use to not contain these in the past. Today's automobiles contain a multitude of microprocessors, sensors and micro-motors for different kinds of functionalities previously resolved by mechanics alone or absent altogether. In the construction of airplanes, the problem of wiring and electrical connection within a product of these dimensions has reached impressive dimensions, consisting in no less than 530 km of cables, 100.000 wires and 40.300 connectors in the case of the Airbus A380 (Wong, 2006).

For the industrial designer this means an increase in the number of connections to be managed both in terms of component contact as well as product-user interaction. How to manage hundreds or thousands of connections within a product in a way that is meaningful in keeping control over the larger design goals?

An important viewpoint shift is proposed in (Wilson, 1980). Instead of seeing interconnections as "point-to-point connections between single elements" Wilson suggests "considering the distribution aspect of interconnection design", similar to other distribution systems such as railroads, highways or pipelines. The paper describes a conceptual framework for the designer to focus on interconnections and interfaces rather than components and physical building blocks. The result is an approach that is based on patterns of distribution of interconnections rather than building blocks of point to point wiring.

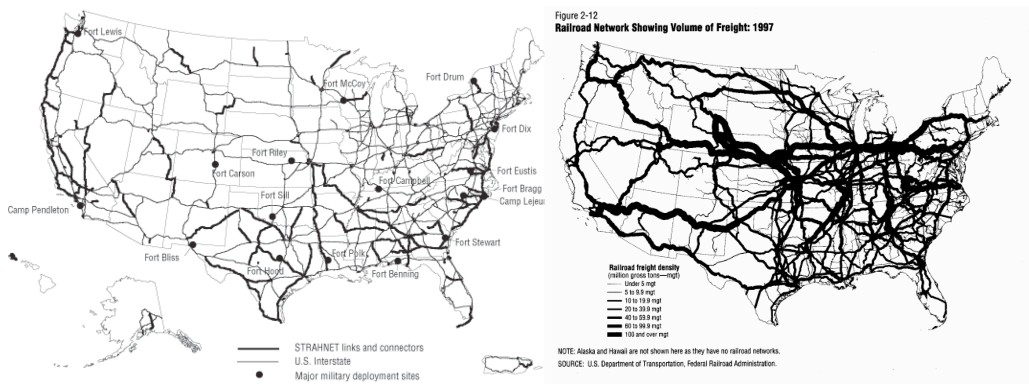


Figure 7.8: Highway and railway network of the United States, U.S. Department of Transportation, 1999.

The result of such a shift in viewpoint towards reading patterns of interconnections is finally an emphasize on the networks of connections as opposed to a series of individual links. Industrial designers are increasingly challenged to approach the design of products on a multitude of scales.

> "Far from being only a zoom of the map, it represents the first step for the process of interpreting information. The setting of the scale level consists in an operation that aligns the distance from the observed systems to the communicative goals pursued, as determined by the observer cognitive and perceptive capacity" (Scagnetti, Ricci, Baule, & Ciuccarelli, 2007).

In this sense, designers gain knowledge by considering different levels of scale in the product systems they are conceiving. At the same time, this consideration of large network connections that involve many individual products is necessary not only for understanding but for the optimization of the final functionality of a product within an ever more connected context.

In the case of the WikiCity project that I have been directing at the SENSEable City Laboratory at MIT this multiple scales become very evident. Through the design of a dynamic interface projected on a public square in Rome, various urban dynamics were represented in real time that were extrapolated from data collected in various technology systems such as the public transportation system, the cellphone network and different online databases. Two scale aspects are of particular interest in this operation:

First, as a designer, the difficulty lies in creating an interface that is comprehensible to the non-technical user in which these enormous amounts of live data are represented in a meaningful way. Large systems tend to be incomprehensible to the user of products. In fact, this assumption is at the basis of the difficulty of actuating choices of sustainable nature. A user has difficulty in understanding what impact his action will have on a larger system in the moment he is confronted with choice. Having such kind of networked data about the state of larger systems connected to products and being able to present this information to the user at the moment of decision making in a meaningful way opens up an entirely new perspective in what it means to take better informed decisions in a daily context.

Second, in order for such detailed data to exist, a multitude of objects need to contain electronic elements that allow for the collection of digital information regarding their specific context and the modality in which they are used. This data needs to be collected, networked and continuously updated. What this means is that public busses, street lights, sign posts and many many other objects are designed today with these requirements in mind. When designing them, these considerations and functionalities for networked applications need to be part of the development process. In this way, they become instrumental for such novel applications.

Figure 7.9: The WikiCity project installed in a public square in Rome during the Notte Bianca on September 8th 2008

Another project I was able to develop at the SENSEable City Laboratory is the *New York Talk Exchange* project presented at the 2008 exhibition *Design and the Elastic Mind* at the Museum of Modern Art of New York. A key essence of this project is the revealing of hidden connections within and between global cities (Rojas, Kloeckl, & Ratti, 2008).

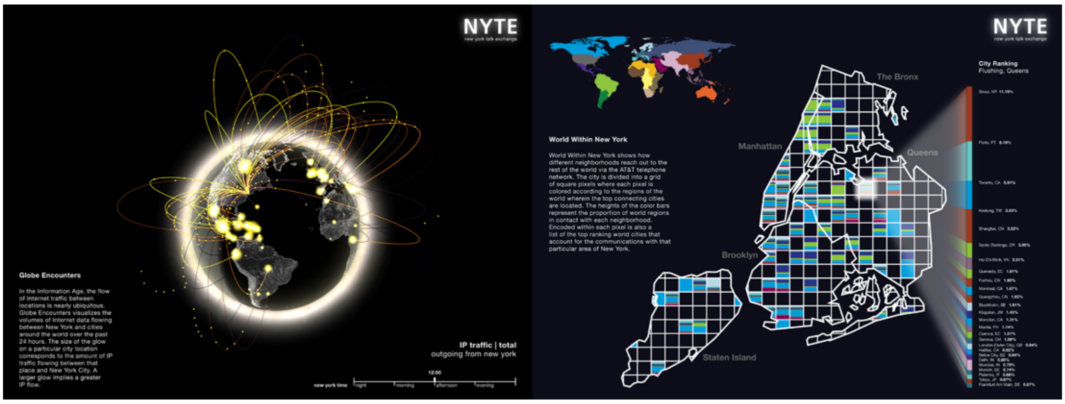


Figure 7.10: Two of the three visualizations elaborated for the New York Talk Exchange project showing telecommunication connections between New York and the rest of the world, SENSEable City Lab, MIT, Boston

Data visualizations such as NYTE can bring to the surface connection patterns of a system with which users interact but commonly do not become aware of due to the extension of the system.

After looking at how design is confronted with considerations of very large networks even when designing human scale objects with which users interact individually, the other scale that poses novel quests is the very small one: nanoscale.

Nanotechnology today is capable of creating materials with radically new characteristics unlike any material that has existed previously. This is so because changing matter at the scale of atoms and molecules means introducing change at a scale at which the ration between surface and volume is much larger than at the scale matter used to be modified. At this small a scale, the laws that govern behavior, more than Newton's are those of Einstein's relativity. How then can designers apply themselves at this small scale and further, how can users benefit from it?

I see various ways in which nanotechnology provides a potential for the application of the design discipline. There is a surprising similarity between geometric studies of volume packing designers are familiar from different common tasks and the packing of molecules in newly conceived material typologies, it is not a coincidence, that one such new molecule was named after design pioneer Buckminster Fuller[27].

A second way in which I see a fruitful encounter between the domain of industrial design and that of nanotechnology is in the development of real world applications for newly created materials and nanoscale technologies. Material scientists tend to do re-

[27] Fullerenes are carbon allotropes composed entirely of carbon, in the form of a hollow sphere and also called buckyballs.

search following only one idea of application which is often chosen arbitrarily. In fact, their focus is rightly put on discovering new characteristics in materials and new ways of creating them. Design on the other hand has much expertise in developing a variety of use scenarios and product concepts on the basis of a particular material specification. In this way, a collection of applications can be developed in collaboration while some of these applications might feedback to the realm of material science in terms of suggestions of modified material characteristics that ought to be created within that domain, orienting research on the level of nanotechnology in this case.

Finally, one of the very fascinating possibilities that emerged with the capability of manipulating matter on the nanoscale is the possibility to devise molecules that organize themselves according to an implicit program. Designers are confronted with this entirely new realm of matter capable of arranging itself to molecular structures that gradually form larger wholes. At present still there are few applications of this phenomenon but in future it might just be the joint forces between the realms of design and nanotechnology able to disclose these new potentials.

8. Conclusion

8.1 On methodology

An aspect which made itself very evident as the outcome of this research on connections in the design of products has been the breath of aspects related to what emerged upon closer examination of the topic. In line with Charles Eames' exclamation quoted in the introduction regarding connections as the details that give the products its life, I have encountered a multitude of ways and dynamics in which the design of these details determines the effects of the overall products and systems they make up.

Having recognized and developed this breadth as the core characteristic of this research, lead to embrace it throughout the entire analysis. Tackling these manifold arguments related to product connections, a methodology has been devised around the identification and subsequent structuring of the six factors (responsiveness, compatibility, articulation, seamlessness, reversibility and scale) that form the theme for each chapter. This strategy has revealed itself as a very fruitful approach to understanding the core dynamics involved in different connections and reflect how these change with the introduction of new technologies.

8.2 Traditional and novel types of connections: different levels of maturity

This research has been introduced with the claim of richness and wealth of traditional connections which could be read in opposition to the implicit counter-claim of scarcity and insufficiency of existing typologies of connections that harness recent technological innovations. The richness of traditional methods of joining has developed in the course of evolutionary processes over long periods of time and in close relation to the users and their capabilities to interact with them. This has resulted in connections between physical parts that contain a high degree of responsiveness towards the user regarding the characteristic of each specific modality of joining. In many cases, direct maneuverability by the user of modalities of connecting parts contributes in these processes of feedback as well as it allows for growing familiarity and mastery in the use of connections. The materiality of the involved parts and their static nature in traditional connections has contributed to the production of diverse forms as well as the clear dynamics of compatibility that can be attributed and in most cases perceived or discovered by the user through direct manipulation.

Is there poverty in novel types of connections? New connections involving digital technologies or new material characteristics break in many ways with connection dynamics intrinsically perceivable to the user and in most cases, they have not yet found mature material manifestations resulting in poor interaction modalities for the users.

On one side, the user is in many cases not aware of the functional modalities of such technologies that contribute to the joining of parts, while on the other side, the still dominant paradigms of connecting digital and physical realms are represented by the plug-in and the press-button dynamic, as well as the 2D visualization of graphic and numeric interpretations of digital data which are far from the variety of dynamics involved in traditional connection modalities.

8.3 Designing new perspectives

The richness in traditional connections is reflected by user actions involved in the connection process such as turning, hammering, zipping, hooking, knotting, sewing, inserting, screwing, leveraging, clipping, tacking and all those other manifold user actions that lead to the combination of parts of particular characteristics due to the way they are being joined. The analysis of this variety of traditional connecting dynamics has proven very valuable in identifying deficiencies in new connection dynamics and has allowed to take clues on how to approach the design of new ones. As an example, a very detailed analysis of the traditional connection process between tickets and ticket stampers involved in public transport systems have been confronted with novel dynamics involving contactless chip-cards and digital readers. It has been shown how this jump from one to another technological system has lead to the break of many aspects of user responsiveness significant to the successful operation of this product system in its specific context. Subsequently, these deficiencies were confronted with technological opportunities to overcome them and to further harness new possibilities to disclose entirely new product functionalities that contribute favorably to the comprehensive connection process involved.

In a similar way also other cases have been identified in which it was possible to open up intriguing ways of enriching the spectrum of dynamics to be introduced in the design of connection applications for new technologies. These investigations have furthermore enabled the identification of limits in traditional connections that offer new perspectives for the design discipline to harness the potential of new technologies of which follows a brief summary of some of the most relevant findings that emerged throughout the six streams of analysis linked to the thematic chapters.

8.3.1 Very small and very large

I see some of the particularly promising directions in the design of new connections focus on the very small and the very large connections. Traditional methods of joining are a useful guide in the ways new technologies can be integrated at the human scale level of products. However on the extremely small and the extremely large scale of connections, there is little to no precedents in the design of connectivity, opening up an immense new field for the design of the manifestations of this potential.

Being able to modify materials on the scale of atoms and molecules opens up completely new spheres in terms of compatibility and interaction on a material level. Components that could not be fit together because of material incompatibility can be adapted to form stable wholes while at the same time the material behavior can be designed in dynamic terms in relation to the use modality and environment.

Designers can determine functionalities on the invisible nano-scale that used to be developed on macro scales and the question of how users can interface with such functionalities that are not perceivable to them is one of the new territories for industrial design to address in this circumstance.

On the other extreme of the dimension scale, the connections between large numbers of parts and products distributed over huge geographic distances find an unprecedented manifestation in digital data that can register and track multiple parameters and identify patterns of this connectivity. Again, this data and these links between artifacts on such a large scale do not have precedents in traditional connections and the design discipline can be one of the prime actors in mediating this new potential with applications that are meaningful to users in various contexts.

8.3.2 Re-connect

The immaterial nature of digital elements involved in connection dynamics has introduced an entirely new degree of flexibility and re-configurability in the way that parts connect and how such connections behave after a first link has been established. This today forms the basis for considerations on how to conceive products and services that are fit to withstand a fast changing environment through techniques such as adaptation and re-assembly by a combined effort from the users, the producers and with the ability to integrate direct sensing of ambient aspects into a product's functioning.

8.3.3 Inter-connect

The growth of numbers of connections within objects has also lead to new perspectives on the entirety of links within products and systems. Looking at links in products as networks facilitates observation of the complexity of their interrelations. Viewing product parts as nodes and links of complex networks has already lead to novel methods of structuring and annotating parts within the product development process. Industrial designers now have the opportunity to bring these innovative perspectives on products and their functioning in direct contact with the user to allow him a more immediate interaction with potentials of new connections that have remained so far at distance from the sphere of user action.

8.3.4 User connect

In fact, it is the role of the user in relation to connection dynamics that has emerged from this research as a more sophisticated one. The shortcomings of new types of connectivity mentioned above can be addressed by the design of the modalities in which the user comes into contact with connections and how he can bring himself into these dynamics.

At the intersection between physical and digital elements, the designer's future attention focuses on the creation of awareness of a systemwide connectivity and on providing this information to the user in the moment he acts upon the connections with which he is at direct contact. Subsequent possibilities of connecting, disconnecting and finally reconnecting and reassembling of parts to create products with new characteristics that better fit specific use contexts contribute not only to the longevity of products in a fast changing environment potentially enhancing environmental sustainability. This perspective dynamic also represents one of the emerging realms where innovation will be happening.

Whether this potential of a more sophisticated role of the user in connecting parts and products can be harnessed depends to an increasing extend on the designer and his ability to create products with appropriate *hooks* that enable user participation in continuously adopting products for their context.

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