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ROLES OF FUNCTION AND AFFORDANCE IN THE EVOLUTION OF ARTIFACTS

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ABSTRACT
The theory of affordances has been adapted by the authors into a comprehensive high-level approach to design known as affordance based design [1-6]. One of the features that distinguishes the affordance based approach from function based approaches is that a property of affordances is their *quality*, which is tied to the quality of the forms that embody an affordance, whereas functions, as form independent, are not characterizable in terms of quality. Since the quality of products tends to improve over time, the evolution of products can be understood in terms of the changing quality of affordances.
Using an idea borrowed from TRIZ (the Russian acronym for the Theory of Inventive Problem Solving) [7], the evolution of a product moves toward a hypothetical state called the "Ideal Final Result" (IFR) where, in terms of affordances, the quality of all positive affordances is maximized and all negative affordances are minimized or eliminated.
In this paper we contrast the changing quality of the affordances of house-hold vacuum cleaners with their relatively static set of functions since their invention. Our analysis of the quality of the affordances of vacuum cleaners over time supports the hypothesis that the quality of the affordances improves over time and approaches an idealized final state. Four vacuum cleaners are compared with an idealized vacuum cleaner.

Keywords: affordance based design, function based design

1 INTRODUCTION
The theory of affordances has been adapted by the authors into a comprehensive high-level approach to design known as affordance based design [1-6]. One of the features that distinguishes the affordance based approach from function based approaches is that a property of affordances is their quality, which is tied to the quality of the forms that embody an affordance, whereas functions, as form independent, are not characterizable in terms of quality. Since the quality of products tends to improve over time, the evolution of products can be understood in terms of the changing quality of affordances. In the next section we present an overview of affordance based design, followed by an overview of the history, strengths, and weaknesses of function based design. We then adopt the concept of the Ideal Final Result (IFR) from TRIZ to help explain the evolution of technical artifacts. Finally we apply these ideas to the history of the household vacuum cleaner.

2 OVERVIEW OF AFFORDANCE BASED DESIGN
The theory of affordances was originally proposed by the perceptual psychologist J.J. Gibson [8]. Since its introduction, the concept of affordance has been adopted as a useful formalism in diverse research areas including childhood development [cf., 9], artificial intelligence [cf., 10], industrial design [cf., 11], human-computer-interaction [cf., [14], and most recently engineering design in a series of papers by the authors [1-6]. Briefly stated, an affordance is what one system (say, an artifact) provides to another system (say, a user, or even another artifact). Simple examples of affordances are that knobs afford turning, keyboards afford typing, and iron affords casting. The concept of affordance thus allows us to describe a broad array of semantically rich relationships that exist in design; relationships in and between designers, artifacts, and users.
We distinguish between two broad classes of affordances, artifact-user affordances (AUA), and artifact-artifact affordances (AAA). Artifact-user affordances indicate what uses the artifact provides to the user. As in all affordances, AUA can be either positive or negative, depending upon whether

the potential behavior is beneficial or harmful to the user. Positive affordances must be designed into the artifact, while negative affordances must be designed against. Therefore, an important task for designers is to ascertain from users what positive affordances should be designed and what negative affordances must be designed against.

Relationships in-between artifact subsystems are described as artifact-artifact affordances (AAA). These affordances describe what artifact behaviors are possible depending upon the structure of the artifact subsystems. Five general properties of affordances have been identified: *complementarity*, which says that an affordance exists between two or more subsystems, not in isolation; *imperfection*, which says that there is no such thing as a perfect affordance; *polarity*, which says that affordances can be either positive or negative; *multiplicity*, which says that multiple affordances can be associated with a particular subsystem; and *quality*, which describes how well a particular behavior is afforded.

The central idea of Affordance Based Design is that design is the specification of a system structure that possesses certain desired affordances in order to support certain desired behaviors, but does not possess certain undesired affordances in order to avoid certain undesired behaviors. By changing the structure of a system, designers can change the system's affordances. The affordances, in turn, determine how the system can potentially behave. Designers define the structure of a system, and thus its affordances, and thus how not only the artifact will behave but also how the user will behave with the artifact.

3 OVERVIEW OF FUNCTION BASED DESIGN

3.1 History of Function in Design

According to Akiyama [12], the creation of the method of function analysis is credited to Lawrence D. Miles circa 1947 as part of his method for *Value Analysis* (VA). As part of this method, Miles also introduced the notion of expressing product functions as verb-object pairs. Later, in 1965, Charles W. Bytheway introduced his *Function Analysis System Technique* (FAST) as a method for systematizing functions according to a set of heuristic rules, accompanied by a resulting graphical chart, the FAST diagram. In the same year Arthur E. Mudge introduced a similar method involving the construction and use of a function chart in order to lower product costs. Then in Japan 1967 Masatosi Tamai published an expanded function analysis method based upon function family trees, which has become very popular in Japan.

Meanwhile, according to Pahl and Beitz [13], the use of *function structures* is first mentioned with respect to the work of Rodenacker in 1970 who used binary logic to formulate logical function structures. Also circa 1970 Koller began working on a design methodology, in which the "function synthesis" stage of the method centers around 12 "basic functions" derived from the flow of energy, matter, and signals; these functions are then combined into a function structure for the product. A few years later, in 1974, Richter proposed a "function-oriented design synthesis based on system dynamics." These function-oriented methods were later combined by Roth as early as 1982 as "function representing models." At about the same time, in 1981, the work of Gierse appeared wherein he formally applied Value Analysis as a general problem solving method with identification of functions and function structures at its heart. Then in 1984, Pahl and Beitz published the first edition of their influential book *Systematic Engineering Design*, in which function analysis, function structures, and the energy-matter-signal scheme are all fundamental. The use of function analysis by Pahl and Beitz has subsequently been referenced and incorporated into many popular English language design textbooks [14-17].

3.2 Strengths of the Function Based Approach

Akiyama [12] discusses several benefits of traditional function analysis, most of which are closely related to the goals of Value Analysis. In particular, using function analysis one can analyze to what extent previously set or recognized goals have been achieved. Similarly, a function analysis allows an objective evaluation of a design, at least insofar as the function analysis itself is performed objectively. And cutting to the heart of Value Analysis, using function analysis, designers can lower costs without compromising the essential role of the product.

Pahl and Beitz [13] discuss several more important benefits of function modeling, which are virtually inseparable from the systematic engineering methodology which functional modeling underlies. For instance, the determination of sub-functions facilitates the subsequent search for solutions by dividing a large difficult problem into many smaller more easily solved problems, each of which can be tackled separately. This also facilitates the development of modular systems.

In their recent work on function modeling, Stone and his collaborators [18-20] identify additional benefits of the function-based approach. By focusing on function independent of physical form, the designer can generate a functional layout of a product first, and then evaluate form solutions for each function later. A function based approach can also facilitate product architecture development because each component of the architecture can be identified by grouping functions. Finally, the generation of function structures, diagrams, and so forth facilitates archival and transmittal of design information.

With these benefits, it is easy to see how the function-based approach has become widespread. However, with popularity has also come criticism, as discussed in the next subsection.

3.3 Weaknesses of the Function Based Approach

Warell [21] identifies several weaknesses in traditional function analysis in engineering design. First, because of the input/output nature of the concept of function, the function based approach is not adequate for the design of products other than machine systems of transforming character. Second, a function based approach is not adequate for products where humans are involved as active users because functions model the workings of a product, not the interaction with people. Warell argues that focusing on just the workings of the product is improper because it neglects the product's use, which is very important. Third, a function based approach is not broad enough to describe many important aspects of the design beyond its technical functions, in particular life-cycle issues and human interaction, which are not functions in the usual sense. Similarly, Buur [22] argues that the traditional function based approach is not adequate for mechatronic systems, because of the complex logic functions introduced by electronics and software.

Another important weakness of function analysis has been known since its inception: the verb-object pair concept, while elegant, tends to be very difficult to use in practice. As VA's creator Lawrence D. Miles stated in his book *Techniques of Value Analysis*,

> While the naming of functions may appear simple, the exact opposite is the rule. In fact, naming them articulately is so difficult and requires such precision in thinking that real care must be taken to prevent abandonment of the task before it is accomplished (quoted in Akiyama [12], p. xxii).

Recent attempts at making this job easier by classifying functions have concentrated on mechanical functions [18, 20, 23], thus further demonstrating the difficulty of describing functions in general using the verb-object method. It also worth noting that the use of verb-object pairs lacks a fundamental basis itself; it is extremely compact, but that insistence on compactness is essentially arbitrary.

Meanwhile, Ahari [24] plainly states that "the most serious shortcoming of the conventional functional decomposition methods is that they are not based on any theory." Without a formal theoretical underpinning, designers do not know what the limitations of functional modeling are, what starting assumptions are, where it may be appropriately used, and where not. One approach to remedy this problem is to formulate the functional approach as its own theory, which the authors have not seen formally done. Usually authors just use the concept of function in a prescriptive methodological context, which is legitimate, rather than first discussing underlying theory.

4 PREDICTING TECHNICAL EVOLUTION

4.1 TRIZ: A Brief Introduction

TRIZ is a tool that designers and engineers can use to solve problems by looking at what the contradiction is between what needs to happen and what is preventing that from happening [7]. Once this contradiction is understood, the designer can look at the eight laws that Altshuller declares govern the evolution of engineering systems. Beyond these eight laws are 40 *inventive principles* that Altshuller found were common solutions to physical contradictions. A matrix of physical contradictions is provided and once the designer finds the contradiction with which they are dealing, a recommendation of which principles to consider is shown.

The foundation for TRIZ is based on a study of more than two million patents and therefore has a huge empirical base. "No other methodology is based on that kind of empirical base. This suggests that a comparison with [TRIZ] may be fruitful both as a source of ideas for improving the existing methodologies as well as for validating the design knowledge included in the methodologies" [25].

4.2 The Ideal Machine

In describing the evolution of *inventions*, Altshuller introduces the idea of an *Ideal Final Result* (IFR) also called an *Ideal Machine* [7]. This Ideal Machine is one of the eight laws described above and is the result of different lines of evolution that a machine takes, ultimately converging into an ideal result.

One of the most important characteristics of the Ideal Machine is "that all parts of the machine perform useful work with the greatest possible capacity" [7]. Malmqvist, Axelsson, and Johansson restate this by identifying the Ideal Machine as "one which the given function is realized but no resources are consumed" [25]. Furthermore, Altshuller makes the assertion that "only tendencies that bring a machine closer toward its ideal state will progress and remain active for a long time" [7].

The central idea of TRIZ is that technological contradictions can be overcome using the 40 inventive principles in order to push a design closer to the ideal state. In other words, TRIZ guides designs toward an ideal state while providing means to get there.

4.3 Affordance and the Ideal Machine

An Ideal Machine, in terms of affordances, would have maximum quality positive affordances and zero negative affordances. This extends Altshuller's proposition of the Ideal Machine (the machine performs the desired function without consuming resources) and says that it should not only perform the function desired, but must maximize the quality of all positive affordances (comfort, versatility, etc.). Also, not only must no resources be consumed, but *zero* negative affordances may be allowed.

As this is an *ideal* state, it will never exist for any artifact. In previous work, we have asserted that there is no such thing as a perfect design [1] because the affordances of the artifact depends on the perception of the user, and each user is different and has different requirements and expectations for the artifact.

5 VACUUM CLEANER CASE STUDY

5.1 History and functional evolution of vacuum cleaners

The history of the vaccum cleaner is discussed in many sources [cf., 26-32]. Sometime before the latter half of the 19th century, the phrase "spring cleaning" was coined as people began to clean their homes. For the wealthy, spring cleaning meant taking their large rugs out into the yard and beating the dirt out. This was a back-breaking process and was not seen as a pleasurable exercise by most, so inventors of the era began to come up with solutions and by 1858 the "carpet sweeper" had been introduced. Bissel, the company most people might associate with the "modern" carpet sweeper was issued a patent on their design in 1876. The function structure of the original carpet sweeper design is shown in Figure 1 below. The simple design calls for the user to control the device, moving it across the floor. This motion causes the wheels to rotate, which by some linkage rotates the brushes in the mechanism. By the contact between the moving brushes and the floor, dirt is lifted and resides in the air in the container until gravity causes it to settle into the base of the container.

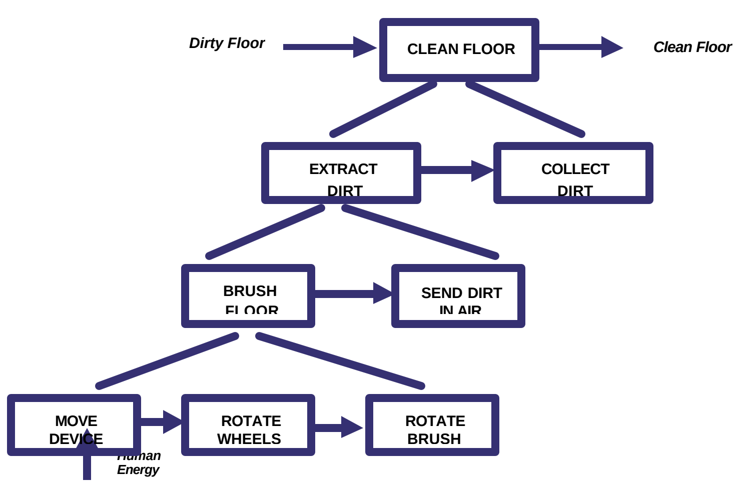

Figure 1. Original Carpet Sweeper Function Structure

One of the latest designs from Bissel, launched in November 2005, is the Perfect Sweep Turbo. This carpet sweeper boasts, however, a motorized brush roll and additional brushes on the forward corners of the sweeper. Nearly 150 years later, the function structure, and overall design, remains very much the same. The only change in the function structure, shown in Figure 2 is that the motion of the device no longer drives the rotation of the brush. This driving rotational motion is accomplished instead by a motor which uses electrical energy as input. So while there is no overall change in function, with the advancement and introduction of new technologies, the way in which functions are accomplished has the potential to change over time.

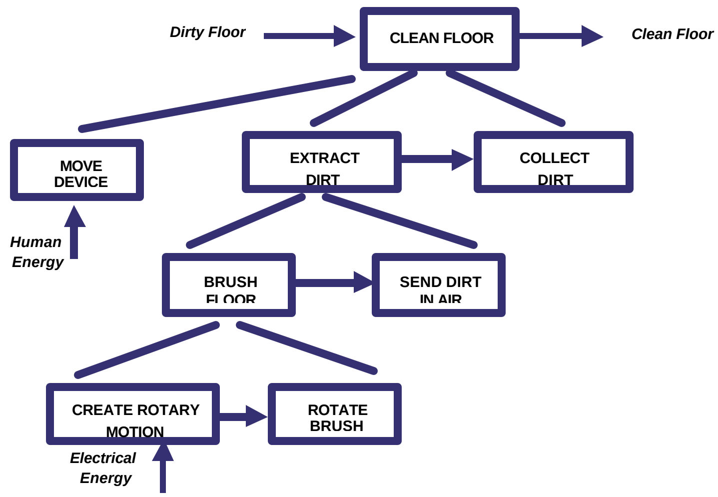

Figure 2. Bissel Perfect Sweep Turbo Function Structure

By 1869, the evolution of floor cleaning had reached a new paradigm. Ives W. McGaffey, of Chicago, devised an early version of the modern vacuum that became known as the "Whirlwind." McGaffey was issued a patent for his device on June 5, 1869. Shown below in Figure 3 is the patent for the Whirlwind. McGaffey's design looks incredibly similar to modern upright vacuum cleaner designs.

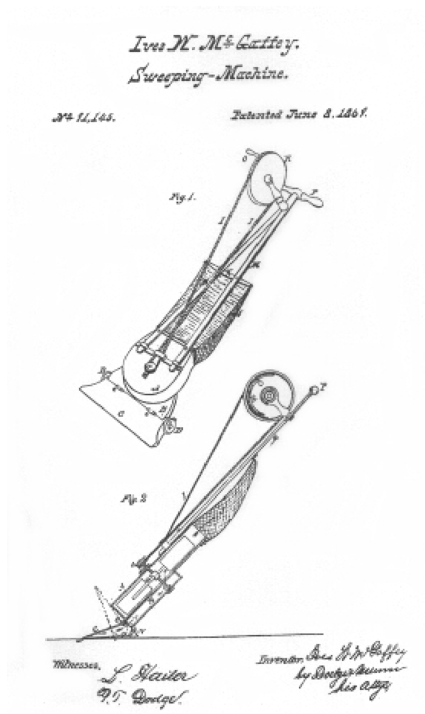

Figure 3. "Whirlwind" Sweeping Machine Patent

As shown in the patent, there is a long handle for support from the user, allowing him or her to control the motion of the machine. Mounted on the handle is a rotating crank that is connected via a belt system to an axle that drives the impeller, providing suction. This impeller allows for the conversion of rotary physical motion into translational motion of the fluid, which in this case is air. The motion of fluid is seen as an increase in velocity, simultaneously lowering its pressure, thus creating a vacuum. The floor surface, at ambient pressure, is exposed to this vacuum through the mouth of the device and the pressure drop from ambient to that pressure at the impeller creates suction. The other side of the impeller is connected to a cloth bag, which is permeable to air, but not to larger dirt and dust particles. Thus the bag acts as a filter, trapping and containing the dirt while allowing the air to be exhausted. Taking the description of each design parameter and its functional requirements above, the function structure can easily be laid out and is shown in Figure 4 below.

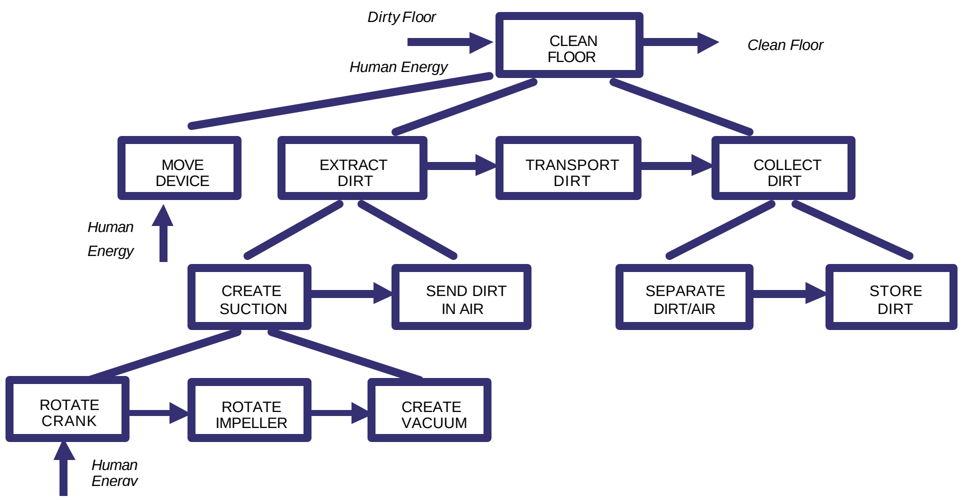

Figure 4. Whirlwind Function Structure

In 1875, the first combination of both carpet sweeper and vacuum suction appears. With carpet sweepers lacking a device to ensure the dirt is captured and collected, and McGaffey's Whirlwind not able to agitate carpets in order to loosen dirt, the addition of a brush roll to the vacuum seemed the perfect solution. A function structure was created by combining the structure of the carpet sweeper with that of the Whirlwind, as shown in Figure 5.

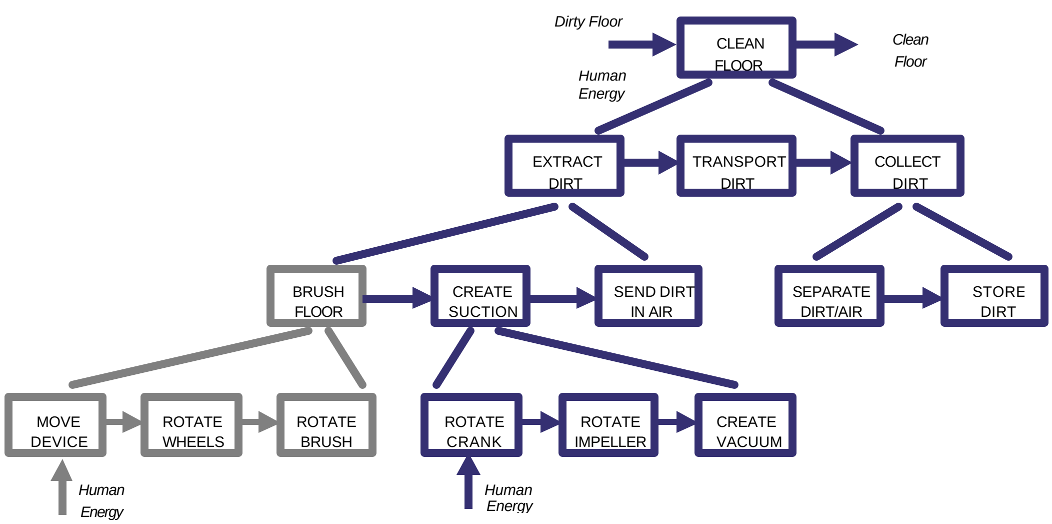

Figure 5. Combined Carpet Sweeper and Vacuum Function Structure

The combination of the two independent structures for the carpet sweeper and suction vacuum reveals what is almost identical to the function structure of a modern vacuum cleaner.

Between 1875 and the turn of the century the vacuum takes on many different forms, some large and some small, using differing floor cleaning technologies from sweeping/beating to suction. It takes some time for designers to allow the vacuum to take a dominant form.

One of the most important technological breakthroughs in history was the arrival of electrical power into homes. In 1907, James Murray Spangler, an asthmatic convinced that his carpet sweeper was putting dirt in the air and disturbing his allergies, decided to mount an electric fan in a soap box, attach a broom handle, and use a pillowcase as a filter. Spangler was granted a patent for his device as he quickly saw its market potential. Thus, he improved his design and formed the Electric Suction Sweeper Company. Soon thereafter, one of Spangler's cousins, William H. Hoover bought the patent and improved the design even further, ultimately introducing the Hoover Model O in 1908. The first "single operator upright," the Model O was a huge advancement in floor cleaning technology.

The Model O had the first commercial use of a cloth filter bag, weighed only 5 pounds, and introduced the use of cleaning attachments allowing the user not only to vacuum the floor, but also the couch, curtains, and other places previously unable to be cleaned by vacuum suction. Over previous vacuum designs, the Model O added versatility, improved filtration with the integration of the filtration and collection system, and greatly reduced the amount of human effort required to operate it by being lightweight and incorporating the use of electric energy. However, if we look at the function structure, shown in Figure 6 below, there are minimal changes from the function structure of the combined system shown above. These changes can be noted as the addition of electrical energy as input for the motors, replacing the need for human power, hand cranks, and the need for the wheels to rotate the brush roll.

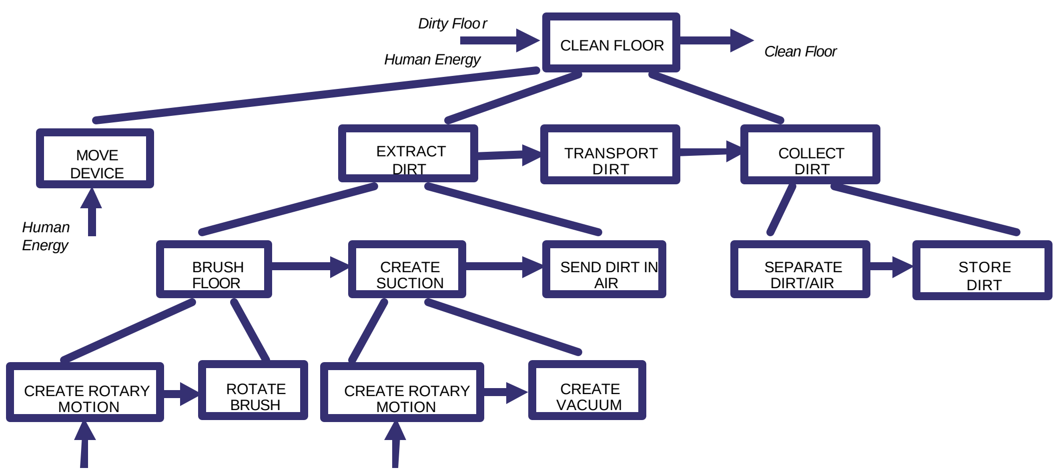

Figure 6. Hoover Model O Function Structure

After the introduction and commercial success of the Model O, many companies followed with similar competing designs. However in 1915, the Swedish company Electrolux, with the help of Axel Wenner-Gren, introduced the first canister cleaner. Called the Electrolux V, the canister is a cylinder that remains on the ground and houses the impeller and filtration system while the vacuum head is connected by a flexible hose. Along with being the first to introduce the cylinder vacuum, Electrolux was also one of the first companies to associate a more hygienic image with vacuuming by its "air-purifying filter pad" [27].

Throughout the 20th century canister vacuums are introduced. Plastic vacuums with "headlights" begin to appear. In the 1960s the first handheld vacuum hits the market and even self-propelled vacuums arrive.

In 1993 though, James Dyson introduces a new technology to vacuuming. The Dyson DC01 vacuum used patented "Dual Cyclone" technology that was created by Dyson himself, which allows the vacuum to have a bagless filtration system. The Dual Cyclone passes the air and dirt through a series of cones and cylinders that create a cyclonic flow of air. While the air spins in a cyclone, centrifugal forces pull the dirt to the edges and out of the airflow, where the dirt and dust then falls into a plastic container. The advantage of this system is that a filter never gets clogged with dirt and dust and allows the vacuum constant suction over the course of cleaning.

Though the vacuum cleaner at this point has evolved over the better part of a century, if we look at the function structure for the Dyson DC01, as shown in Figure 7, it has not changed since Hoover first introduced the Model O. The way in which the functions are accomplished have changed, but at this level, while there is clearly change in form and technology, it is not reflected in the function structure. So is function an appropriate means of describing the design of an artifact?

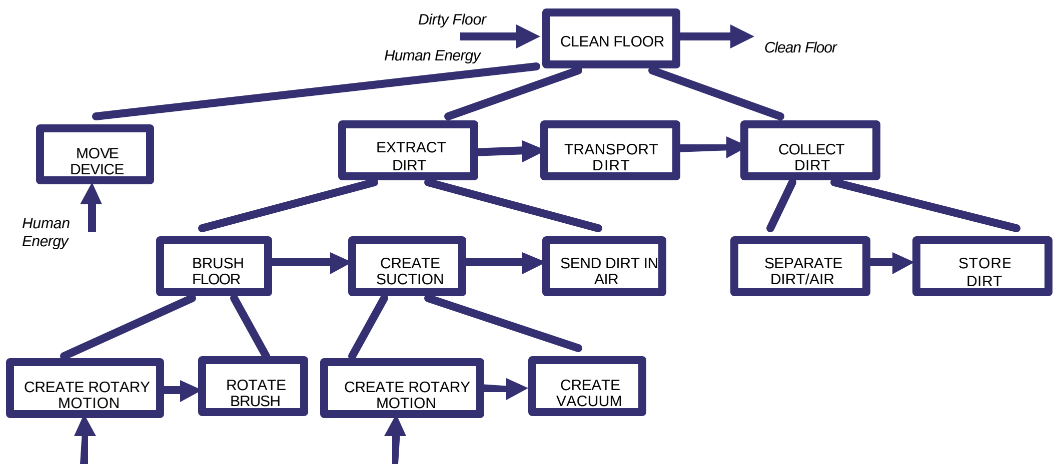

Figure 7. Dyson DC01 Function Structure

The form has changed while the function has not. New technologies have allowed the functions to be performed in different ways, however the functions themselves still remain the same. But should function change? Function tells you what you are trying to do. Without some goal, it is nearly impossible to know how to get there. Therefore understanding the function *is* important, but function should not be the only means by which designers describe an artifact.

5.2 Roles of function and affordance in the evolution of the vacuum cleaner

Looking back over the 150-year evolution of the vacuum there are few major changes in the function structure of the "floor cleaning" mechanism. The top-level function is, and will always remain, "clean floor". However, exactly *how* that occurs changes slightly over time. Initially, with the carpet sweeper the second-tier sub-functions are "extract dirt" and "collect dirt". Then with the introduction of the Whirlwind, the "transport dirt" sub-function becomes important, where the dust and dirt are transported away from the floor and into a filtration system, which is a new sub-function to the "collect dirt" function.

So the function structure of what ultimately becomes the modern vacuum slowly begins to take shape. In 1875 the first combination of the two technologies, sweeping and suction, arrives and this is really where functions stop changing. Just over a quarter of a century later, James Murray Spangler makes the last all important leap from manual human power to electrical power, which is less a change of function, and more a change of how the same function is accomplished.

While the function structure is taking shape, the affordances of the floor cleaning devices are also changing. The original carpet sweeper has the positive affordance of beating the carpet and general ease of use, but also has the negative affordances of allowing dirt to fall back onto the floor and expelling dirt into the air. Then the Whirlwind arrives and has the positive affordance of removing dirt from the floor and filtering that dirt into a collection system, but also has the negative affordances of removing a very limited amount of dirt while not able to agitate the carpet and loosen the dirt, as well as requiring serious human effort. The introduction of Booth's horse-drawn, petrol-driven vacuum sees the positive affordances of reduced human effort, adds versatility with the use of long hoses, and powerful suction is generated by the petrol-driven engine. However, this vacuum also brings on the negative affordances of incredible noise disturbance, high cost, and again is not able to beat the carpet and effectively remove dirt.

Finally, the two floor cleaning technologies are married and when Spangler adds the electric motor we arrive at the modern vacuum cleaner design. Positive affordances include beating dirt out of the carpet, providing powerful suction with the electric motor, and transporting and filtering the dirt out of the air. Negative affordances of noise and high cost from earlier gas-powered models are reduced.

As TRIZ points out, the evolution of the vacuum took many different paths with people experimenting with different sized machines and cleaning methods, ultimately converging into a design that best fit to solve the design problem at hand, from which point minor technological improvements are seen over the better part of a century. These improvements can be seen, however, as reduced human effort through the reduction of weight and the introduction of self-propelled and robotic vacuums; advances in filtration technology, allowing lossless suction; and added versatility with an assortment of attachments.

While the function structure is constantly being reorganized initially, once the product becomes "mature" and the different designs have converged into a best solution, the function structure becomes static. Meanwhile, affordances of the designs continue to improve. Affordance can be used to describe the changing form, enhancements in filtration technology, better maneuverability and accessibility to dirt, etc. All of these things can be described as designers searching for better ways to reinforce positive affordances, while removing negative affordances.

5.3 Predicting the evolution of the vacuum cleaner

With the vacuum cleaner case study, in terms of TRIZ, the system contradiction must be identified. The user desires a clean floor, for the purpose not merely of cleanliness, but also appearance (which may play a cultural/societal role as people are expected to have clean, neat homes) and health and physical wellbeing, among potential other reasons. However, the floor collects dirt and dust. Herein lays the contradiction. Note that if the user did not desire a clean floor, there would be no contradiction.

Now that the system contradiction is understood, an ideal machine can be considered. Because we want a clean floor, but do not want to expend any resources nor deal with any negative affordances, the ideal system would be a "self-cleaning floor" with the associated positive affordances of a carpeted floor. A list of positive and negative affordances for this ideal system is shown in Figure 8.

If we then try to compare the ideal system affordances with those of our current designs it is difficult to draw any conclusions. The two systems are actually quite different. The ideal system would not require the use of a vacuum in order for the floor to be clean. This very clearly tells the designer that there may be some other solution for solving the problem of a dirty floor.

Positive Affordances (improve)	***Negative Affordances (avoid)***
Allow use of carpet	Dirt collection
Dirt removal	Weight
Dirt disposal	Allow dirt in air
Quiet	Require user interaction
Ergonomic	Require replacement
	Require maintenance
	Require control
	Power consumption

Figure 8. "Self-Cleaning Floor" Affordances

This provides clues to the designer that one day we may not need a vacuum to keep our carpets clean. The solution may be an electrostatically charged carpet whose ions have the same charge as those of dust and dirt, preventing the dust and dirt from coming in contact with the carpet. While in the air the dust is then circulated through an existing air filtering system, removing it from the air. What is more useful, however, in predicting the evolution of the current design is to compare its affordances with those of the Ideal Machine, as shown in Figure 9 below. This may not be a complete list.

Positive Affordances (improve)	Negative Affordances (avoid)
Dirt removal	Allow dirt in air
Dirt collection	Emit noise
Dirt disposal	Require control
Versatility/Accessibility	Weight
Storability	Loss of suction over time
Mobility	Clog-ability
Dirt visualization	Power consumption

Figure 9. Ideal Machine Affordances

Now with the list of positive and negative affordances for the Ideal Machine, we can compare these to what was seen at different stages in the evolution of the vacuum cleaner. Note that the affordances for the Ideal Machine are shown as of today, with current knowledge of what technologies are in existence now. Table 1 shows a list of five items by which three different upright vacuums were compared along with the iRobot Roomba. A 10 is the best and a 1 is the worst.

Table 1. Comparison of Upright Evolution with Ideal Machine

	Whirlwind	Hoover Model O	Dyson DC01	iRobot Roomba	Ideal Machine
Accessibility	4	2	9	5	10
Agitation	1	6	8	6	10
Filtration	3	5	9	7	10
Human Effort	2	5	6	9	10
Noise	7	4	5	7	10
Sum	17	22	37	34	50

The vacuums on the horizontal grid are in order of evolution, oldest to newest, left to right, with the exception of the Ideal Machine, which stands as a tool for comparison. Looking at the sum of each column the trend is increasing from left to right. As the vacuum evolves it becomes closer to the Ideal Machine. The exception to the rule is the iRobot Roomba, whose value lowers slightly from that of the Dyson DC01 because it is designed for the more specific affordance of reduced human effort and lacks in accessibility because it only cleans floors.

In attempting to predict the next step in the evolution of the vacuum, it would appear from Table 1 that the high scoring affordances of the Dyson DC01 should somehow be combined with those of the iRobot Roomba. The result may be a Roomba with a Dual Cyclone filtering system, an improved agitator, and a more powerful, yet quiet, motor. However, then the user is still forced to clean his or her curtains and couch with a separate vacuum. The function is, after all, to simply "clean floor".

Let us not also forget that the design problem is still being solved by means already established; those of a machine to remove dirt from the floor, when the problem could be addressed in a totally new manner from looking at the ideal system, as previously described.

Table 2, below, tells a slightly different story. This table looks at not merely the evolution of a single design, but the impact special-purpose designs have. Again evolution is shown from left to right, but there is a less distinct evolution of technology. These different technologies are introduced, but they are designed to suit special purposes and therefore are very high scoring on one or two affordances, but typically low on all the others. All of the designs are around the same average value of 26.5. So while this idea of the Ideal Machine is there, each of the different designs, from upright to canister to handheld, etc., is ideal in its intended use for a particular user and the affordances that lend the design those qualities. There is no single Ideal Machine for any one user at any given time, but designs do exist for different purposes to serve different users' needs. This is why different designs with different qualities of affordances persist in the real marketplace.

Table 2. Comparison of Different Types of Vacuums with Ideal Machine

	Ideal Machine	Hoover Model O (upright)	Electrolux V (canister)	B&D Dustbuster (handheld)	iRobot Roomba (robotic)
Accessibility	10	2	7	8	5
Agitation	10	6	3	3	6
Filtration	10	5	6	4	5
Human Effort	10	5	5	5	9
Noise	10	4	5	5	7
Sum	50	22	27	25	32

6 CONCLUSION

In this paper we have contrasted the evolution of technical products in terms of affordance based design and function-based design using a case study of the evolution of vacuum cleaners.

The investigation of the vacuum cleaner showed that function is a valid means of describing the evolution of a design until the different product technologies, as described by TRIZ, converge into a dominant design and the product thus becomes "mature". However, once the product becomes mature there is still evidence that the design evolves, though the function structure, on the level presented, does not evolve.

While function describes the appropriate transformative technical character of the product, function cannot adequately encapsulate the post-convergent evolution of the product. Here affordances can more appropriately be used to describe the differing qualities of designs.

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