INTEGRATING DESIGN AND ENGINEERING, II: PRODUCT ARCHITECTURE AND PRODUCT DESIGN

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ABSTRACT

Effective product design demands cross–functional teams comprised of industrial designers, engineers, marketers, and others who can effectively speak a common language. Here we show how conceptual tools adapted from the field of systems engineering can be used across disciplines to explain design decisions.

Keywords: design methods, systems thinking, multidisciplinary teams, product architecture

1 INTRODUCTION

Analytical tools typically associated with systems engineering are applicable to the realm of product design, whether the task is evaluating existing products or creating new product families. One of the most useful analysis tools in this field is the functional decomposition chart (FDC), which is an essential tool for systematically dissecting complex systems [1]. Starting at the top with a simple 'black box' model, this method iteratively decomposes the system into smaller and smaller functional elements, until the user is satisfied that the most basic functional level is reached. Naturally, different sets of constraints apply to each level in the hierarchy, and in some cases to each individual function. By examining functions and constraint sets at different levels in a system's hierarchy, the design team can expand the possibilities for innovation.

The problems with the functional decomposition charts stem from the fact that, by their nature they lead to thinking of products in isolation. The 'black box' (Figure 1), like every other visualization tool, is an abstraction of a real system. Unless an effort is made to resist, the user is tempted by the nature of the representation to ignore the wider context in which the system or product defined by the black box exists. As we will show, this can lead to designs that are optimized for specific tasks, while ignoring the total activity in which they are embedded.

Here we are interested in showing how the functional decomposition method can be used as an effective tool for teaching design by applying it to real products. To lessen the danger of isolating the product from the context, we embed the method in an activity sequence chart to show how the problem of isolation can be addressed. We begin by analyzing an existing design currently on the market, and infer how decisions made during the initial product definition stage, i.e., when the functional hierarchy was developed, determined the configuration of the final product and product family. We analyze and discuss alternative paths that could have been taken if the functional hierarchy and subsequent constraints were defined differently and demonstrate how the use of this method can enable a design team to effectively develop a range of possibilities.

2 THE DYSON VACUUMS

The product we have chosen to apply the method to is the well–known Dyson vacuum cleaner [2]. The impetus behind James Dyson's innovative technology came from identifying a problem with an air filter in a spray–painting booth: the filter was constantly clogging with powder particles. Dyson designed and built an industrial cyclone tower, which removed the debris from the air stream by the use of centrifugal forces. Realizing the commercial potential of his invention, he then identified a commercial product that experienced similar problems, the vacuum cleaner. By utilizing the same principle to solve the problem of clogging bags in a vacuum cleaner, he developed a new product that has had a significant impact in the industry and in the design community. Dyson's machines are the best-selling vacuum cleaners in Western Europe, Australia and New Zealand, and his market share in the United Stated is consistently growing. Dyson vacuum cleaners are included in the permanent collections of numerous museums, including the London Science Museum, the Metropolitan Museum of Art in New York City, and the Centre Georges Pompidou, Paris, and are often cited as examples of design excellence.

For the purposes of this paper, we wish to draw a clear distinction between the patented 'Cyclone' technology that is at the heart of every Dyson machine, and the Dyson vacuum cleaners themselves. In effect we are claiming that the Dyson can be analysed as two distinct entities: the vacuuming *technology*, which is quite different from other products on the market, and the various *configurations* of cleaning machines in which the technology is embedded, and which in many respects are very similar to other products already on the market. The 'black box' shown in Figure 1 can serve as a generic, high–level description of the technology required to remove dirt and debris from an air stream. While space limitations preclude a fully detailed function decomposition diagram, the top level shown here shows the inputs and outputs to the system. From an engineer's perspective, this is sufficient to explain the functional requirements of the technology.

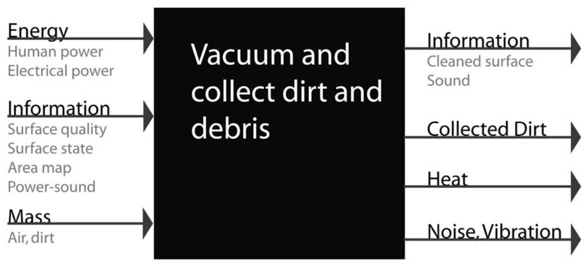

Figure 1 'Black box' description of the top–level function

James Dyson has been quoted as saying, 'Things should work properly'. What we hope to show here is that whether or not something 'works properly' often depends on where one chooses to draw the boundary of the black box. If one draws it around the core technology, it can be said to 'work properly'. If one expands the system boundary to include the user and the environment in which the user operates, a different answer may result. The original upright machine (DC07) does in fact remove and collect dirt and debris from carpets in a very efficient way. However, Dyson's marketing material claims equal success removing dirt from hardwood floors, furniture and stairs; in our opinion, this particular model does not perform these secondary tasks as well as the primary task of cleaning carpet on horizontal surfaces. Its failure to do so has nothing to do with the core technology, and everything to do with the product architecture.

3 EXPANDING THE SCOPE

As one would expect, the analytical tools developed over the past few decades to enable engineers to better understand and control highly complex systems are also readily applicable to understanding complex products. However, when one first begins to apply these tools to even relatively simple products, it quickly becomes clear that this is not a simple task. Understanding the complexities of systems and product architectures can be difficult due to the multiple levels of inter-related information, and to the multiple pathways by which mass, energy, and information find their way through systems. Several different representations of systems have been developed over the years, all of which represent efforts to make real complex systems comprehensible by abstracting essential features and characteristics. Functional decomposition, sequential flowcharts, and the Design Structure Matrix method [3] are all useful tools for representing functions, elements and relationships between components and activities.

Here we show how the function decomposition chart can be made more useful by embedding it in what we call an Activity Sequence Diagram. In Figure 2, we use a 'black box' functional model of a vacuum as a single part of an expanded representation of the total user activity around the Dyson DC07 machine. The inputs and outputs to the black box are now seen to be the consequences and causes of a larger system of functions and activities that impact the product's performance. Where previously the vacuum was seen essentially in isolation, now it is placed in the context of a user with specific needs in a typical scenario. Where the black box of Figure 1 is sufficient to represent the *technology*, in this case the Dyson Cyclone technology, the expanded diagram captures the characteristics and capabilities of the specific vacuum cleaner, i.e., the total product which *contains* that technology.

We believe that by embedding the function decomposition diagram in a contextual representation, it ceases to be merely a tool for engineers, and becomes a tool for product designers as well. All the complexity that was 'in the box' before is still there, but now additional demands are placed on it as well. This technique can reveal desired and undesired interactions between components, functions, related products and user needs. Equally importantly, the design team can use the diagram to acquire possible insights for designing products as part of larger systems.

For example, the diagram shows that the machine needs to be "un–powered" in order to switch from one surface to another. It also shows the cycles of re-configuration needed in order to adapt the machine to different surfaces. This particular activity can be quite cumbersome. The user is required to stop and make an assessment of the new surface, search for the correct attachment, and re-assemble the handle or wand. The machine is transformed from a standard upright configuration into a very awkward vertical barrel or canister configuration that does not easily support the user in performing these secondary activities.

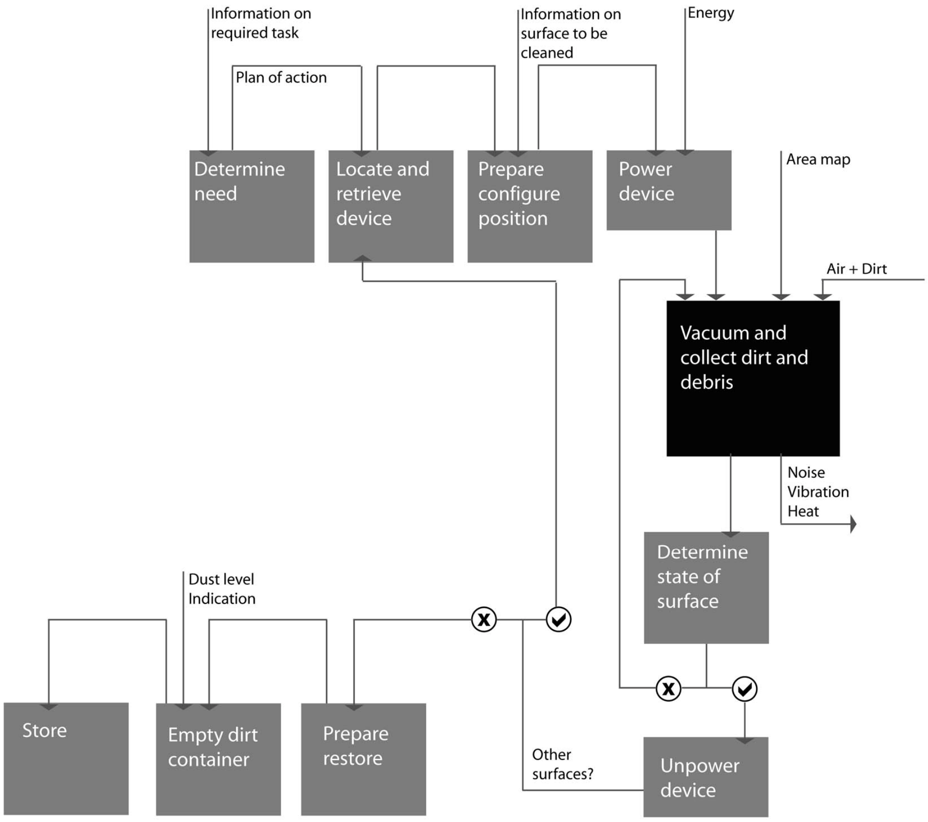

Figure 2 First level functional description of the user's activity

This discussion leads naturally to an assessment of the product architecture of the Dyson DC07. Coherent product architectures flow logically from well–designed system decomposition charts. Ideally, once the chart is completed down to the basic level, the design team decides on a strategy for mapping components to functions. A strategy that maps one function to one component naturally leads to a very modular design; a strategy that maps multiple functions to a single component, or multiple components to a single function, leads to a highly integrated design [4].

Quite often, products are designed without much thought being given to the architecture of the product, which leads to 'add ons' and product families that are not well thought–out. In the case of the Dyson DC07, the integration of the attachments into the basic upright vacuum cleaner appears at first to be quite clever: the handle detaches, the hose is extended, the handle is reversed and re–attached to the hose, and the attachments are fastened to the free end of the handle. Figure 3 shows how the system works in practice. While at first this method seems to fit well with the 'revolutionary' theme of the Dyson marketing campaign, in practice it presents several problems for the user.

Probably the most significant shortcoming of this cleaning system is the difficulty and tediousness of having to stop, remove the handle, completely reconfigure the device, and then proceed. A consumer using this machine to completely clean a living space, i.e., curtains and furniture as well as the floor and carpet, would be forced to adapt their cleaning strategy to the machine, since the machine is very clearly not readily adaptable to rapid and easy alteration.

Figure 3 Dyson DC07 attachments [2]

This is an example of designing a machine around a new technology, without giving due thought to the entire range of relevant activities. In effect, Dyson adapted his quite revolutionary Cyclone technology to a standard Hoover upright vacuum cleaner. As often happens with 'technology driven' products, the technology itself takes centre stage, and little thought is given to how well the product performs in practice. In effect, the product was optimized 'inside the black box', with lower priority given to the flow of activities that the typical user will encounter.

By way of contrast, consider the architecture of a more recent Dyson machine, the DC11 Telescope shown in Figure 4. Here, the overall product architecture is designed in such a way that affords much easier configuration changes during operation. While the primary task of vacuuming large, flat horizontal surfaces is still given precedence, the subsidiary actions of cleaning carpets, walls, furniture, and hard–to–reach places is also supported. While we do not claim that the Dyson designers used the methods we present here, the use of these methods as instructional tools can make the rationale behind the designs much clearer to students, and open new avenues for innovative ideas.

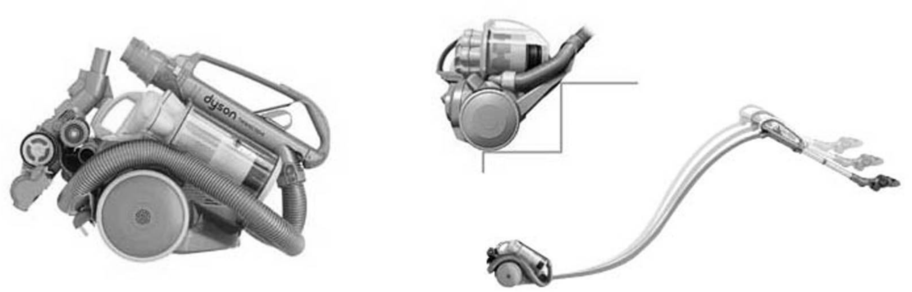

Figure 4 The Dyson DC11 Telescope [2]

4 CONCLUSIONS AND FUTURE WORK

Based on our close collaboration in teaching industrial design and engineering students over the past three years, we have concluded that some conceptual tools from systems engineering apply well in both teaching and practice. Because these representations of complex systems are essentially visual maps, they are useful for allowing practitioners and students in allied fields of design to communicate their ideas easily, and to better understand the context, constraints and complexities of the various design domains. The advantage of using these tools applies both across specialties and within them, as for example between mechanical and systems engineering.

While students at the undergraduate level often struggle with approaching design in this rather abstract way, we have had greater success to date in working with our team of graduate students. Our intent is to further develop our instructional methods with graduate students whose research is focused on product design, and only then apply these visualization tools in our undergraduate courses in industrial design, mechanical engineering, and systems engineering. We believe that by combining and expanding the scope of the current methods, we can reduce the tendency of engineers to focus on one narrow aspect of the problem; at the same time, we can make industrial design students more aware of the need to focus on the functional details of design which they often neglect. Going forward, our intent is to integrate other systems thinking tools, such as the Design Structure Matrix, into our product design curricula, and to develop more effective visual representations of systems information.

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