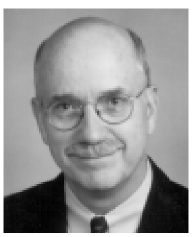
Using modularity to manage the interactions of technical and industrial design

by Ron Sanchez, PhD



Ron Sanchez, PhD,
Professor of Strategy and Technology Management
IMD—International Institute for Management Development

Introduction

Modularity, a design approach familiar to most designers, is now becoming an integral part of mainstream strategic management thinking. Growing numbers of global product firms are now not only adopting modular product designs, but are also adopting new kinds of product strategies and implementing new development processes that are explicitly focused on achieving a range of competitive advantages through modular product designs (Sanchez, 1999). As the experiences of these firms show, the systematic, strategic use of modularity concepts can significantly accelerate the product development process, increase the range of product variations a company can bring to market, enable more-rapid technological upgrading of products, *and* reduce costs of development and production (Sanchez and Collins, 2001; Sanchez, forthcoming).

As more companies around the world adopt modularity concepts in managing the technical development of new products, however, there is a growing need to develop approaches to integrating modular technical design and industrial design processes. This paper identifies some new priorities for industrial design in supporting modular product strategies and development processes, and describes some resulting key interactions of modular product strategies and the industrial design process. This paper also draws on a recent product design and development collaboration between Philips Design, in Hong Kong, and Philips Garment Care (PGC), in Singapore, to illustrate these new priorities and interactions.

Our discussion is organized in the following way. We first define the foundational concepts of *product architectures* and *modularity* and then summarize the main features of modular approaches to product development. We consider the new kinds of product strategy objectives being pursued through modular designs, as well as the new approaches to managing technical development processes now being used by companies with advanced modularity capabilities. With this overall perspective on the objectives and methods of modular design, we then identify some key strategic objectives for industrial design of modular products, and elaborate some important interactions between modular product development and industrial design processes. We then illustrate how these objectives and interactions were managed in the Philips Design-PGC development collaboration. We conclude by identifying some additional strategically important benefits for industrial designers that can result from collaborations with technical designers in modular development processes.

What are product architectures? What makes them modular?

Designs of all products—whether hardware, software, "process" goods, or services—have an architecture. The *architecture* of a product design (Sanchez, 1995; Sanchez and Mahoney, 1996) refers to

1. The way the overall functionality of a product design is decomposed into *functional components*[1]
2. The way the functional components are intended to interact in the product—that is, the specifications of the *component interfaces*

These two defining properties of a product architecture are illustrated in Figure 1.

The way a product design is decomposed into functional components is usually directly observable in a physical product. However, only some of the interfaces in a product architecture may be visible and of direct concern to industrial designers. Figure 2 lists the six kinds of interfaces that must be defined and managed in a product architecture. Industrial designers are usually primarily concerned with defining the *spatial interfaces* of components in a product architecture—in effect, the space a component will occupy in a product design—and with the *user interfaces* that define how a user will interact with a product (which usually includes interactions of users with certain components, as well). Technical designers, on the other hand, are commonly concerned with defining the attachment, transfer, control and communication, and environmental interfaces for components in a product architecture. Of course, alternative approaches used by technical designers to defining these more technical interfaces may have significant implications for the spatial and user interfaces in a product design, and thus may also be of concern to industrial designers. Similarly, the concerns of industrial designers for the form and user friendliness of a product design are also likely to have implications for feasible approaches to specifying technical interfaces.

A modular product architecture is one that has been designed to allow the "mixing and matching" of different "plug-and-play" component variations in the overall product design to configure product variations. This *configurability* of an overall product design is achieved by specifying component interfaces that allow the substitution of component variations into the product design, without having to change the designs of other components in the product architecture. Perhaps the most familiar

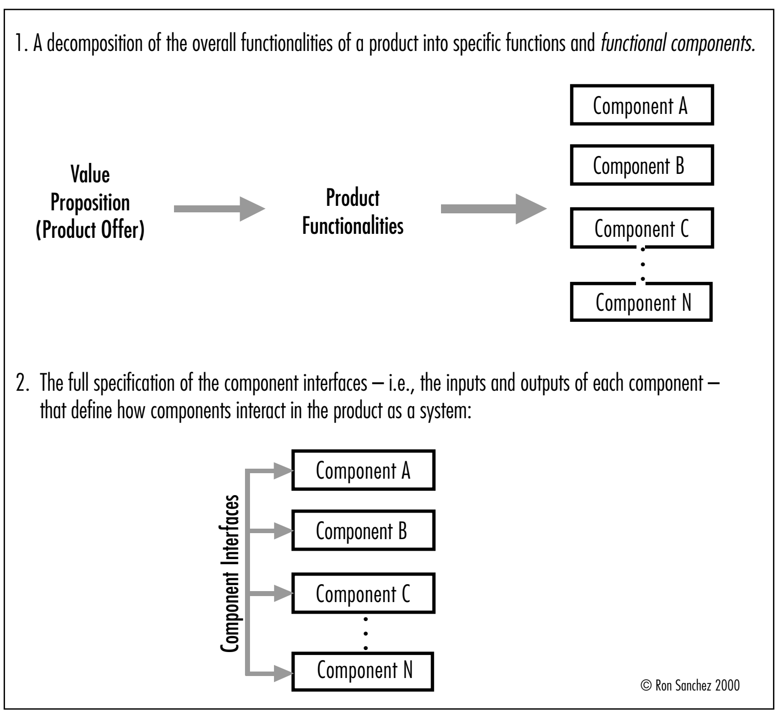


Figure 1. Definition of a product architecture.

1. In simple products, a product design may be decomposed directly into simple parts. Designs of complex products, however, may first be decomposed into systems, which are then successively decomposed into subsystems, components, and finally parts. For simplicity in this discussion, I use only the term *components* in referring to the design elements, or "building blocks," that result from the functional decomposition of a product design.

Fully specifying the interfaces between each component or activity requires specification of the the following kinds of interfaces:

1. **Attachment interfaces:**
   · How one component attaches to another
2. **Spatial (volumetric) interfaces:**
   · The space a given component occupies
3. **Transfer interfaces:**
   · What goes in (to be transformed) and comes out
4. **Control and Communication interfaces:**
   · How one component signals to another component what state it is in, and how the second component signals to the first component whether to stay in that state or change to another state
5. **User interfaces:**
   · How users interact with the product or a component (human interface)
   · How a product interacts with a user's "macro-system" context
6. **Environmental interfaces:**
   · How each component will interact with the intended ambient environment
   · How the functioning of one component affects the functioning of other components in a product in unintended ways

Figure 2.
Six kinds of interfaces in product architectures.

example of a modular product architecture is the desktop computer, in which a range of variations in microprocessors, memory cards, hard disks, monitors, keyboards, and other components can be freely combined to configure a nearly unlimited number of product variations. Growing numbers of firms are now using modular architectures to create highly configurable product designs (sometimes referred to as *platforms*) in product markets as diverse as automobiles, personal care products, financial services, food, software, industrial and consumer electronics, bicycles, home appliances, and professional services (Sanchez, 1999).

Strategic objectives of modular product development

Modularity is becoming an increasingly important part of strategic management thinking today because it enables firms to achieve at least four strategically important advantages in competing in product markets (Sanchez, forthcoming). Three of these advantages—greater product variety, faster technological upgrading of products, and cost reductions—result largely from the intrinsic characteristics of modular product architectures identified above. The fourth advantage—greater speed in developing new products—results from adopting a new kind of development process for modular products. Let us first consider the three advantages that can result from the nature of modular designs.

Greater product variety

The high degree of configurability of modular product architectures is now being used to increase the range of product variations that firms bring to market. In modular design strategies, an overall product design is *strategically partitioned* to achieve a "one-to-one mapping" between the benefits to be offered to users of a product and the technical structure of a product (Sanchez, 1999). In effect, a product design is partitioned technically so that each product functionality or feature thought to be a significant source of product differentiation in the eyes of users is contained in a single component or a subsystem of components. Variations in functional components (or subsystems) can then be substituted into the modular architecture to create product variations based on different combinations of component-based functionalities, features, and performance levels. In this way, a modular product architecture can be used as a configurable platform for leveraging a potentially large number of variations on a basic product concept. Sony and its Aiwa subsidiary, for example, used modular product architectures to introduce more than 250 variations of its Walkman-type products during a 10-year period in the US market.[2]

The ability to leverage significant numbers of product variations from a single modular product architecture makes it possible to explore consumer preferences more extensively and quickly through *real-time market research* (Sanchez and Sudharshan, 1993), a process in which small lots of product variations are introduced to markets to test consumers' reactions to various combinations of functions, features, and performance levels. Both Sony and Nike, for example, now operate "antenna shops" in major cities of the world, where they introduce a changing array of new modular product variations. Real-time sales figures combined with direct observation of consumer reactions provide fast feedback on consumer reactions to different product variations. The configurability of

2. See *Managing Product Families,* Susan Sanderson and Vic Uzumeri, Richard D. Irwin publishers (1997).

modular product architectures is also the basis for *mass-customized products* (Pine, 1992) that firms capable of creating modular product designs increasingly offer at prices that are competitive with mass-produced products.

Faster technological upgrading

Modular product architectures may also be designed to accommodate technologically improved components that are expected to become available during the commercial lifetime of a product architecture. When component interfaces are specified to support the introduction of improved components expected to be available in the future, technologically upgraded product variations may be brought to market as soon as improved components become available. For example, many personal computers today use motherboard (printed circuit board) designs with modular mounting sockets to support the substitution of technologically improved (that is, faster and/or functionally enhanced) microprocessors into the motherboard as soon as they become available. When designed in this way, modular product architectures can substantially accelerate the introduction of new technologies into products (in the form of new and improved components). In addition, periodic processes for renewing current product architectures or planning next-generation architectures provide a structured framework for defining the technologically improved components needed to introduce higher-performing products in the future (Sanchez, 2000).

When Sony introduced its first HandyCam 8mm-format video camera in the 1980s, for example, the firm first defined interfaces between components that anticipated a number of technological improvements in key components that were then under development. As higher performing components emerged from its development pipeline, Sony could plug-and-play technologically improved components directly into the HandyCam product architecture, without requiring extensive redesigns of other components. This modular strategy for rapidly upgrading product performance has enabled Sony to establish technology leadership in the market for 8mm-format video cameras and to maintain a dominant market position.

Cost reductions

A modular design strategy also commonly seeks to reduce product costs by partitioning some functions in a product architecture into component designs that will be used in common across product models (and perhaps even across product lines) or that will be reused in future architectures. Such *common or reusable components* generally provide technically necessary functions that are "transparent" to customers and thus are not sources of product differentiation (for example, a power supply in a personal computer). Using common components in product architectures lowers the development costs for new product variations. Production costs may also be reduced through increased economies of scale in producing components, extended economies of learning (experience-curve effects), and increased buying power for outsourced components. Greater use of common and reused components also reduces parts variety and resulting costs of carrying inventories of parts. The greater reliability of reused component designs that have been incrementally improved over time may also help to reduce service costs and claims costs associated with new product introductions.

> *Modular product architectures may also be designed to accommodate technologically improved components that are expected to become available during the commercial lifetime of a product architecture*

Recent research establishes that the strategic and systematic use of modular architectures to capture these forms of cost reduction may lower product realization costs by 40 percent or more for many common types of products (Sanchez, forthcoming).

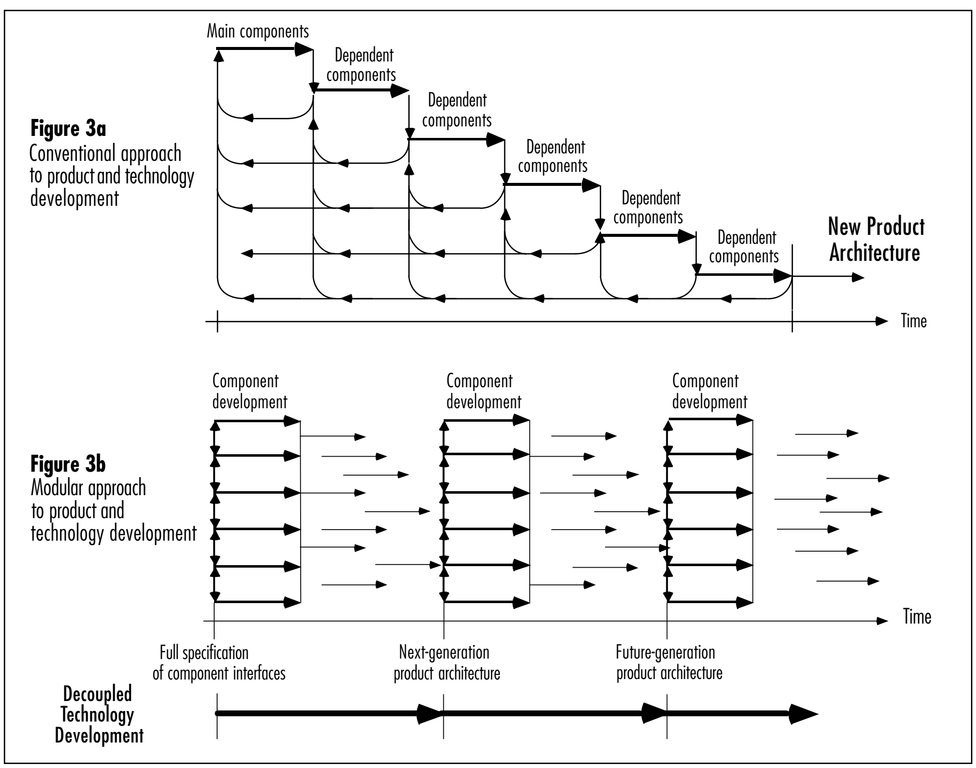
Modular development processes—Increasing speed to market

Modularity is also the key to achieving another critical strategic advantage—*speed* in bringing new products to market. Once a firm begins to adopt modular product architectures, it also becomes possible to adopt a new way of developing products that can radically reduce both development resource requirements and time to market.

The key to getting fast in creating new products is using modularity to reverse the priorities that firms have traditionally followed in product development. In the technical development of new products, most firms today focus on developing the key components needed for a new product, and only secondarily try to figure out exactly what interface specifications will be required to make all the components in a product work together as a system. However, as suggested in Figure 3a, recent research has established that letting component development precede the specification of component interfaces typically leads to frequent component redesigns throughout the development process. Such component redesigns can consume 50 percent or more of total development time and resources (Sanchez and Collins, 2001).

By contrast, the modular approach to product development begins by first working out the component interface specifications for a product architecture, then standardizing—that is, *freezing*—those interfaces, and subsequently constraining component development to conform to the established interface specifications, as suggested in Figure 3b. This reversal of traditional development priorities reduces overall development time and resource requirements by essentially eliminating the time-consuming redesigns of components that result when component interfaces are not fully defined and standardized during component development processes.

As long as all component development groups are disciplined in developing components that conform to the standardized interfaces of the product architecture, development of the components required for a new product design may be carried out through *concurrent development processes*. As some firms that have tried to implement concurrent engineering methods have realized, attempting to design components concurrently, without first standardizing component interfaces, quickly leads to "concurrent chaos," not concurrent design. Fully specifying and standardizing the component interfaces in modular product architectures, however, provides the essential information structure for coordinating concurrent development processes and is the key to radically



Figures 3a and 3b.
Comparison of conventional and modular development processes.

improving speed in bringing new products to market (Sanchez, 2000). GE Fanuc Automation, Philips' audio products business group, and other firms that have managed to implement this disciplined modular development process are now reporting an astounding *50 percent to 80 percent reduction* in total development time and development resource requirements (Sanchez and Collins, 2001).

Defining and standardizing component interface specifications as the first step in new product development is also the key to accessing the world of design and development capabilities outside one's own firm. Fully defined and standardized component interface specifications for modular architectures provide, in effect, the *system specifications* for the components of new products, which enable a distributed network of competent designers and developers around the world to develop new components that will plug-and-play in a new product architecture.

Strategic objectives for industrial design of modular products

Given these strategic objectives and new methods of modular design, we may now identify some important strategic objectives for industrial design in developing modular products. These objectives are, of course, in addition to the usual concerns of industrial designers to achieve design integrity, a cost-effective design solution, and so on.

Many industrial design firms now assist their clients in analyzing the strengths and weaknesses of competing products and in exploring new product concepts that will have maximum impact in the marketplace. Modular product strategies add some further dimensions to these tasks. When modular product strategies are used to increase product variety, industrial designers may need to develop design concepts for more-extensive product lines than has been the case in the past. In technologically mature modular products, for example, sets of core functional components are usually technologically stable, and product development will largely be focused on frequently refreshing product designs through styling changes in visible components. Many audio products, for example, have stable sets of common and reused technical components, and product development is largely a process of creating new case and user interface designs to be launched at the twice-a-year consumer electronics trade shows. In effect, many consumer electronics companies now manage their audio products like a fashion business, with frequent additions of new features and restyling of enclosures around stable sets of core functional components.

More generally, industrial designers can play an essential role in modular product strategies by creating styling variations that can effectively distinguish individual product models within modular product families, while also giving a distinctive and unifying design theme to the total product family. In product strategies that intend to leverage large numbers of product variations while using similar or identical sets of common components in various product models, industrial designers must create product forms that give a distinctive appearance to individual product models while providing spatial enclosures that conform to repeated sets of common components.

Defining and standardizing component interface specifications as the first step in new product development is also the key to accessing the world of design and development capabilities outside one's own firm

This design task is often made more challenging, however, because of spatial constraints commonly encountered in locating differentiating product features within modular product architectures. Varying levels of features often form the primary basis for differentiating product models, but in order to preserve a consistent physical arrangement of common components and their spatial interfaces with the common components used across product models, differentiating features must normally be constrained to a constant location in an overall product design. In effect, in modular product variations, the spatial interfaces between the components that provide various levels of featuring and the set of common functional components used across various product models are very likely to be standardized.

An illustration of the need to achieve

distinctive styling variations, a consistent design theme, and design solutions for standardized spatial interfaces in modular architectures is provided in Figure 4. The five shaver models shown in Figure 4 indicate how designers of Philips Quadra Action shavers created several attractive variations of the plastic case surrounding the set of common mechanical components used in the models while maintaining a readily recognizable design form for the total product line. At the same time, to preserve a constant spatial interface with the core mechanical components, the components providing the differentiating features (in this case, various styles of switches and charge-level indicators) were constrained to the same location on the plastic cases for the five different models in the product range.

When modular product strategies are intended to support rapid technological upgrading of products, industrial designers can play a further strategic role in helping to bring a series of technologically upgraded products to market, often in fairly rapid succession. Designers may be asked to create design concepts that can be used to distinguish the multiple generations of technologically upgraded products that will be leveraged from a modular architecture. Here, the essence of the design challenge is defining an overall design theme for a product family within which a number of styling variations can be generated to help differentiate successive generations of technologically upgraded product models as they are brought to market. In some cases, the technologically improved components in a

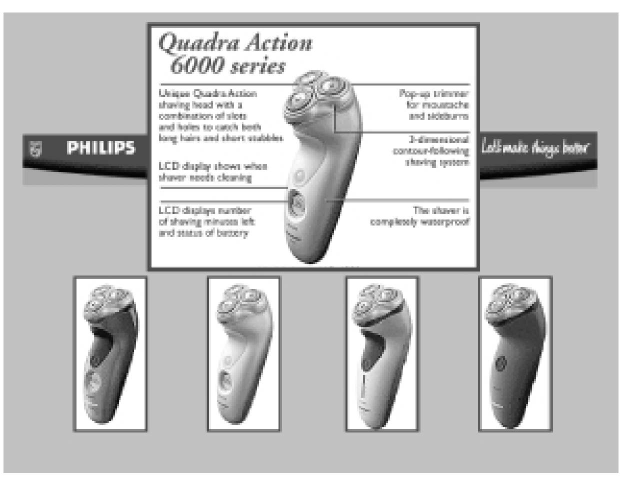


Figure 4.
Designs for Philips Quadra Action Shaver line.

new product model may not even be visible to users of a product (for example, a faster microprocessor for a laptop computer). Effective differentiation of new product models may then depend in important measure on the styling differentiators that industrial designers create to communicate visually the improved technical performance of a new product.

In other cases, technologically improved components may be larger or smaller than their predecessors, creating the opportunity—or sometimes the necessity—for creating new spatial interfaces and arrangements of components in product designs. As new, higher-performing components and resulting new product models are added to a product line, new spatial interfaces between components used in higher-performing models must usually be defined and executed in ways that preserve the essential design theme used to distinguish the overall product line.

Key interactions of modular product development and industrial design

Keeping in mind these common strategic objectives for industrial design in modular product strategies, we now elaborate some important interactions between modular product development and industrial design processes. We first consider the role of industrial designers in processes for deciding the specific strategic objectives for a new product architecture. We then discuss some of the critical interactions between technical designers and industrial designers in defining a product architecture that is capable of supporting the strategic objectives for the product architecture.

Strategic inputs from industrial designers

The first step in creating new modular architecture is defining the essential benefits to be delivered to users of the products that will be leveraged from the modular architecture (see Figure 1). The next steps are then focused on defining the variations in functions, features, and performance levels that will be the basis for the specific product variations to be leveraged from the modular architecture.

Many industrial designers contribute to the first step in this process by helping clients to define the best possible "bundle" of user benefits to be delivered by a new product architecture. In so doing, many designers increasingly act as marketing consultants, as well as product designers. The key question to be answered at this early stage is: What strategic benefits—and in what priority—are desired from a new modular architecture? Modular architectures are essentially a tool for achieving a range of potential benefits—greater product variety, faster technological upgrading, greater speed in bringing new products to market, and reducing product realization costs. But, inevitably, trade-offs must be made among these benefits. Product variety may be limited in favor of greater component commonality and resulting lower costs, for example, or expanding product variety through increased use of variations in plug-and-play components may be emphasized over cost reduction. Industrial designers can contribute greatly to making these strategic decisions by helping firms to understand the design implications, relative market impacts, and cost benefits of the various trade-offs that could be made in defining a new modular architecture, and by helping to define the specific product variations that could be leveraged from alternative modular product architectures a firm could develop.

Critical interactions among technical and industrial designers

Once the strategic objectives for a new modular product architecture are clarified, industrial designers can then interact with product line managers and technical developers to define the size, shapes, colors, textures, and other design elements that would most effectively communicate the key benefits of the product to the intended user. This interaction will usually result in the definition of a number of product design parameters that may then constrain technical development of components. For example, styling objectives may constrain development of components to a specified maximum size or weight or a specific shape that is important in communicating the benefits of the product. Alternatively, technical design considerations may dictate that some components must have specific physical characteristics, and industrial designers must sometimes "design around" such constraints in developing the overall product design. Interactions among industrial and technical designers to define styling objectives and technical constraints should, of course, take place at the earliest possible stage in the development of a new architecture to avoid conflicts between technical and industrial design criteria in downstream component development processes.

Industrial design also plays a critical role in conceptualizing a range of product variations in which each product variation is perceived as distinct from the other product models leveraged from a modular product architecture. This interaction involves defining the specific "bundles" of functions, features, and performance levels—as well as styling variations—that will be used to differentiate the product models in a product line. A critical interaction among industrial and technical designers in this process is the strategic partitioning of a product architecture into components that will be used in common across product models (or will be reused in future product-line extensions) and into components that will be sources of perceived variety in the product models to be offered. In this strategic partitioning of an architecture into stable versus varying components, the strategic objective is to find a design solution that achieves the optimal trade-off between the cost-reducing benefits of component commonality and reusability on the one hand, and the product positioning and differentiation benefits derived from varying components on the other hand.

Industrial design also plays a critical role in conceptualizing a range of product variations in which each product variation is perceived as distinct from the other product models leveraged from a modular product architecture

A further critical aspect of interactions among technical and industrial designers is understanding and honoring a defining principle of modular product development processes. Component interfaces, once fully specified and standardized, will not be changed during subsequent component development processes. Standardized component interfaces provide the essential information structure that serves, in effect, as the means to coordinate concurrent component development processes. Changing interface specifications midstream in a concurrent development process can therefore greatly disrupt the design work of component development groups, leading to redesigns of components and resulting additional development time and cost requirements.

Companies that have successfully implemented modular development practices have done so only after enshrining the principle of honoring standardized interfaces in their development processes. In Chrysler's vehicle development processes, for example, once interfaces between subsystems of a new vehicle architecture are defined, they become "hard points" that are not allowed to change during component development. In Philips' modular development processes, standardized interfaces are characterized as "holy" and, once fully specified, are not permitted to change during a development project. To help support this central principle in developing modular architectures, industrial designers must provide their strategic inputs early in the architecture development process, when the component interface specifications for a new architecture are being worked out—and then be prepared to work within those interface constraints throughout the design and development process.

Case study: The collaboration of Philips Design and Philips Garment Care

To illustrate how the interactions of industrial and technical design may be managed in developing a new modular product architecture, we turn now to a case study of a recent collaboration between Philips Design's Hong Kong office and Philips' Garment Care (PGC) business in Singapore. This collaboration was initiated in 2000 to develop a modular architecture to serve as a platform for two new lines of home irons, the Elance and the Mistral series (see Figures 5 and 6).

The first step in the collaboration was the use of Philips Design's "high design" methodology for analyzing the positioning of competitors' products and for defining the desired market positionings for the Elance and Mistral product lines.[3] After extensive market and competitive analysis, the Elance series was positioned as the "flagship" line for the Asia/Pacific region, with a benchmark retail price point in the range of 50 euros, while the Mistral series was positioned in the middle to upper end of main market demand, with benchmark retail prices in the range of 30 to 40 euros. Discussions with PGC's product line managers and product development staff then defined in detail the functions, features, performance levels, and price points for individual models that would be consistent with the desired market positionings for the Elance and Mistral product lines.

Since ironing is regarded as a necessary chore rather than as a source of enjoyment by most consumers, a central design theme of "radiating

3. For further discussion of the Philips Design's "high design" approach, see "Suffusing the Organization with Design Consciousness" by Stefano Marzano, now CEO and chief creative director of Philips Design, *Design Management Journal,* Winter 2000, pp. 22-27.)

Figure 5.
Example of Philips Garment Care Elance product line (photo courtesy of Philips Design).

Figure 6.
Example of Philips Garment Care Mistral product line (photo courtesy of Philips Design).

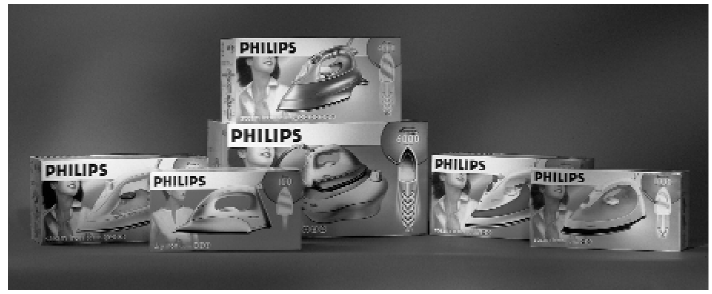


Figure 7.
Packaging Designs for Philips Garment Care irons (photo courtesy of Philips Design).

speed" in ironing was adopted to communicate to consumers the main benefit of fast ironing performance. In essence, the designs of the new irons would have to persuasively communicate a fast ironing capability even as consumers looked at the products in boxes on the shelf in shops, because that would be the context within which most consumers would make their purchase decision. The central theme of radiating speed was then developed through several aspects of the designs of the irons themselves and their packaging.

For example, to be consistent with the theme of radiating speed, the iron designs would have to suggest high levels of "autonomy time"—that is, the time available for active ironing between refills of the water reservoir used to generate the supply of steam during ironing. Impressions of significant autonomy time would be created by making a generous water reservoir a visible, colorful part of the product design. At the same time, a too-large water reservoir would suggest excessive weight and a need for physical exertion in ironing. Therefore, a part of the water reservoir capacity that is required to provide extended autonomy time would have to be shielded from view by embedding part of the water reservoir within the main plastic case of the iron. Such key aspects of the iron designs in communicating speed in ironing would then have to be clearly shown in the images used on the retail packaging for the irons (see Figure 7).

Workshops involving Philips Design and PGC staff were then held to determine any constraints on the overall product design that would be imposed by technical characteristics of key components and by manufacturing considerations. Experts from Philips CFT (Center for Industrial Technology) in Eindhoven, The Netherlands, also participated to help clarify important interrelationships among alternative designs for the new irons and alternative approaches to manufacturing the new products. The cost, speed to market, and reliability implications of several approaches to designing and manufacturing the new irons were assessed, ranging from maximizing reuse of existing components and current manufacturing capabilities to creating radically new product design concepts that would require significant changes in production equipment and processes. This evaluation was carried out for each major component in the product architecture of an iron. For example, existing manufacturing lines in PGC were set up for rapid, cost-efficient production and assembly of a "tear-drop" shaped sole plate, and analysis showed that continuation of that shape in the new product designs would bring a number of strategically important cost, reliability, and speed-to-market advantages.

The eventual outcome of this analysis was a strategic partitioning of the new product architecture into (1) a set of common components that would be standardized across all or most product models in the Elance and Mistral product lines, and (2) a set of components that would be varied to configure different product models for both lines. Figure 8 shows the resulting strategic partitioning of the new architecture, with sets of common components located below the dotted line and components that would be varied to generate different product models located above the dotted line. The strategic partitioning also resulted in full specification and standardization of the interfaces between the sets of common components and the sets of components that would be varied to create different models. The standardization of these interfaces then enabled technical development of common components to proceed independently of—and concurrently with—exploration of alternative styling and featuring concepts in the components that would be sources of perceived product variety. Moreover, a strategic decision to maintain these standardized interfaces in future product line renewals has enabled PGC to accelerate development of new varying components that will be used in future extensions of the Elance and Mistral product lines.

A clear definition of the components that would be used in common across all product models also enabled PGC to fully define early in

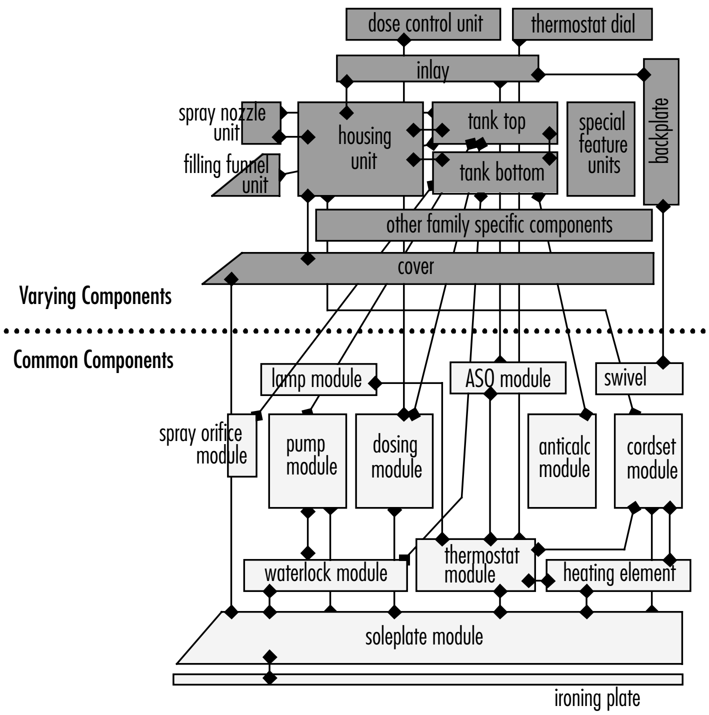


Figure 8.
Strategic partitioning of modular architecture for Philips' Elance and Mistral product lines.

the design process the manufacturing equipment and processes that would be required to produce the new products. Because many of the common components could be continued or reused from earlier iron designs, PGC was able to make extensive reuse of its existing production equipment and assembly processes. At the same time as overall design solutions were developed for the Elance and Mistral product lines, manufacturing development could be focused on analyzing and creating the capabilities needed to produce the new component variations that would distinguish each product line and the product models within each product line. Thus, development of many of the process capabilities for producing the new irons could be undertaken in an accelerated manner, even as overall product designs for the Elance and Mistral lines were being finalized.

Conclusions

We conclude now by identifying some additional, strategically important benefits that can be obtained through a well-executed collaboration of industrial and technical designers in a modular architecture development process.

Improved efficiency and effectiveness in using development resources

Careful, strategically motivated partitioning of a product architecture into stable sets of common components and well-defined sets of varying components enables both industrial designers and technical developers to focus their respective, complementary talents on creating product design variations that will have an impact in the marketplace—that is, to focus on creating those component variations that directly contribute to effective product differentiation. Using the modular design approach to define sets of common components that will be used in all or most product models prevents the wasteful use of development resources on creating variations in component designs that do not directly contribute to perceived differences in products. When the design and development resources available to a firm are focused on creating only those component variations that help to create value in the marketplace, industrial and technical designers can invest more time in finding the best possible design solutions for those components. The range of significant product variations that can be created by a given set of design and development resources can then be extended significantly.

Better integration of marketing and technical development objectives

One of the enduring challenges in product development is achieving a successful integration of market needs and technical possibilities in a new product design. The modular architectural approach to developing new products provides a powerful framework for translating market needs into a technical solution—that is, a system of components—that can deliver product functionalities capable of serving a defined set of market needs. The modular design principle of achieving a one-to-one mapping of specific user benefits into a technically distinct component or subsystem of components provides an explicit linkage between the technical composition of a product and the bundle of benefits a product is intended to bring to consumers. Once a product concept is explicitly represented as a system of components, the *strategic role* of each component within a product design in creating value for consumers can be made clear. In effect, the decomposition of a modular architecture into a well-defined system of components provides a framework for improved definition of the contribution of each technical element within a product design to the value proposition a new product is intended to provide to consumers.

Improving the creative design process through better technical definition

Compared with traditional product development processes, a modular architecture development process requires a much earlier specification of component interfaces in a new product design. While the early specification of technically required component interfaces may impose some constraints on subsequent industrial design freedom, doing so creates an important counterbalancing benefit for industrial designers. Early work on component interface specifications helps to make explicit the technical constraints that must eventually be recognized and dealt with in any product design process. In effect, working out component interface specifications early in a design process makes clear the degrees of freedom that industrial designers will actually have in a design process.

Clarifying these degrees of freedom helps designers to be more creative in developing product designs that are actually feasible—and helps to avoid investing time and energy in developing designs that will not function properly or that cannot be produced. As one designer who now works in a firm with modular design processes put it, the traditional design process the firm previously used now seems like "the dark ages," because designers never had enough understanding of the real-world constraints they would eventually have to contend with in a design process. By contrast, the higher technical definition of a product design in the modular process has brought to the firm a new "age of enlightenment" in which designers feel they are much more creative and productive because they now have good information about real constraints they face at the beginning of the industrial design process. In effect, once the technical limits in a design process are known, there are no limits on the creativity of industrial designers working within those limits. ■

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