AN ANALYTICAL SURVEY ON CUSTOMIZATION AT MODULAR SYSTEMS IN THE CONTEXT OF INDUSTRIAL DESIGN

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**by
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ABSTRACT

Enterprises in all branches of industry are being required to become more user focused, yet, at the same time, increasing competitive pressure dictates that costs must also continue to decrease. Mass customization and modularity are strategies developed to address this challenge by producing goods and services meeting individual customer's needs with near mass production efficiency. However, while mass customization and modular systems have already been discussed in the literature, reports on practical implementation of the principles of mass customization in businesses can be found only within the last years.

It is a challenge of manufacturing to produce variety of products with limited resources. As corporations strive to rationalize their manufacturing facilities and to produce a large variety of products at lower cost, modularity is becoming a focus of attention. Modular products and reconfigurable processes are crucial to agile manufacturing and provide a way to produce a variety of products that satisfy various customer requirements in time. This modular approach promises the benefits of high volume production (that arises from producing standard modules) and at the same time, the ability to produce a wide variety of products that are customized for individual customers. Such modular product design has been stated as being a goal of good design.

Mass Customization target is the transformation of knowledge into "new" products or services, thus customizing and adapting first knowledge then the product itself. Customizing knowledge happens through instantiation and adaptation of design prototypes of the products or the component to fit the individual needs of the customer.

This thesis' emphasis is placed on mass customization and modularity which can be seen as key strategies for making firms more customer centric. Furthermore, provide an introduction into principles, concepts, and demarcations, for mass customization and modularity. As the case study Ayşe Birsel's resolve model for Herman Miller is a very good example for the relationship between mass customization and modularity.

ÖZET

Endüstrinin her alanındaki yatırımcılar artan rekabetin baskısı altında maliyetleri sürekli olarak düşürmek zorunda kalmışlar ve bunun sonucunda, giderek daha müşteri odaklı olmak ihtiyacı duymuşlardır. Kişiselleştirme ve modüler sistemler, eşyaların ve hizmetlerin üretiminin getirdiği bu rekabetle, seri üretimin verimliliğiyle müşterilerin kişisel ihtiyaçlarının başa çıkabilmesi için geliştirilmiş stratejilerdir. Her ne kadar kişiselleştirme ve modüler sistemler literatürde ve çalışmalarda ele alınsa da, son birkaç yıldır tam olarak yerine oturmuş kavramlardır.

Üretim sistemleri için sınırlı kaynaklarla çok çeşitli ürünler üretmek oldukça uğraştırıcı bir konudur. Şirketler düşük maliyetlere çok çeşitli ürünler üretmeye ve üretim tesislerini de buna uydurmaya çalışırken, modüler sistemler odak noktası olmaya başlamıştır. Modüler ürünler tekrar ayarlanabilen ve üretime kolayca uyum gösterdiğinden, çok çeşitli ürünlere olan müşteri isteklerini zamanında başarmanın bir yolu haline gelmişlerdir. Modüler yaklaşım yüksek verimde üretimin getirilerini garantiler aynı zamanda müşteriler için kişiselleştirilmiş çok çeşitli ürünler üretme yetisini kazandırır. Bütün bunların sonucu olarak da modüler ürün tasarımı iyi bir tasarım öğesi haline gelmiştir.

Kişiselleştirmenin hedefi bilgiyi yeni ürünlere veya hizmetlere dönüştürmektir, böylece kişiselleştirme ve uyum ürünün kendisinden önce daha önemli bir bilgi haline gelir. Kişiselleştirme bilgisi ürün prototiplerinin oluşturulması ve uyumunun sağlanması veya müşterilerin ihtiyaçlarına uyması için kullanılır.

Bu tez çalışmasındaki asıl vurgulanan nokta, kişiselleştirme ve modüler sistemlerin, firmaların tasarımlarında ve üretimlerinde daha müşteri odaklı olabilmesinde anahtar stratejiler olarak kabul edilmesidir. Daha fazlası, kişiselleştirme ve modüler sistemlerin temel prensipleri, uygulama metotları, çeşitleri ve konseptleri hakkında yararlı bilgiler vermektir. Hazırlanan örnek çalışma olarak Ayşe Birselin Herman Miller için tasarladığı Resolve ofis sitemlerinin incelemesi hem modüler sistemlere, hem de kişiselleştirmeye aynı zamanda da aralarındaki bağlantıya açıklık kazandırabilecek gerçekçi ve iyi bir örnektir.

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INTRODUCTION

1.1. Definition of the Problem

Within the next decade, people may find that any non-interactive objects or systems around them have been replaced by almost invisible, intelligent interactive systems-an 'Ambient Intelligence' that could soon form a natural part of their everyday lives.(Aarts 2003) Much of today's technology is still obtrusive at traditional and stable objects in homes and offices. In the traditional objects they have surrounded themselves with for millennia, such as tables, chairs, walls and ceilings. As technology becomes hidden within these static, unintelligent objects, they will become subjects, active and intelligent actors in their environment.

Much of today's world of products we expect more and more. We are beginning to see that negative environmental and social effects are not isolated but are related to our everyday pattern of production and consumption. People are beginning to see themselves as not only living in the present, but as being connected with both our predecessors and generations to come. This is leading to a radical reassessment of the old paradigm. People are searching for a better balance between material prosperity and frenzied activity on the one hand, and emotional well-being and harmony on the other- not only on a personal level, but also at a collective and global level.

It is increasingly possible both to design products that have the ability to be configured to meet the preferences of individual customers and to produce those products at costs that do not differ significantly from the cost of mass producing a single product design. In other words, in a number of businesses the economics of providing product variations for individual consumers on a large scale are approaching the economics of producing a single product for all consumers.

In an increasingly competitive and segmented global marketplace, the need to diversify is greater than ever before. Advances in production technologies has rendered out many of the differences in product quality, and thus changed the competitive environment companies find themselves in. Traditional mass production has in the past decade been replaced by the concept of mass customization, mass production of customized products. To overcome the great complexity that customization potentially creates in the manufacturing systems, modularization is used as a tool to break the product structure into smaller, manageable units (Ericsson 1999).

Modularity is a common but unexplored thread among all areas of life-cycle engineering. Modular products tend to have fewer components for assembly and are therefore cheaper to assemble. Modularity allows for the reduction of service costs by grouping components so those less reliable components are easily accessed. In addition, grouping components into modules by how they are recycled can greatly reduce product retirement costs.

Life-cycle modularity is a relative property. Products possess a higher or lower degree of modularity. A product with a higher degree of modularity either contains a larger percentage of components or subassemblies that are modular or contains components and subassemblies, which are, on average, more modular. Subassemblies, which are relatively modular in nature, are modules.

In conclusion, development of the technology affects people's lives in different ways. Emotionally changed people need to reflect their own personalities on the products they use. Manufacturers and designers tried to solve these needs in different methods. Modular systems are one of those methods. There are lots of benefits that modular systems provide.

- Component economies of scale,
- Ease of product updating,
- Increased product variety,
- Ease of design and testing,
- Excessive product similarity.

Modularity in product design impacts every stage of the product life-cycle. Supply chain factors influencing modularity include outsourcing strategy and postponed differentiation. Manufacturing considerations address assembly efficiency and component complexity. Modularity also affects serviceability and recyclability in terms of disassembly, separation, repair, and reprocessing. Manufacturers could benefit from a methodology that analyzes modular product architecture for overall life-cycle efficiency. The thesis should help designers in grouping subassemblies by identifying

(1) Core platforms,

(2) Flexible modules and

(3) Mating

As a result, designers should keep in small chunks the features that require flexibility and standardize other core functions. They should gauge the modular design against three evaluation charts that relate design attributes with life-cycle complexities. The modularity evaluation for manufacturing plots part commonality against lead time. Service modularity gauges service complexity vs. frequency. Recyclability chart plots sort complexity against material recovery.

1.2. Aims of the Study

Product design development is no longer about creating a product but about creating a platform, or more precisely a modular architecture. The notion of product architecture is a key concept in product development which is no longer just a technical issue. Creating appropriate modular architectures to support new kinds of product strategies is now central to business strategies. Businesses need to create product and process architectures that are capable of providing the flexibility to customize products for individuals and to upgrade them when better components come along.

The main purpose of this research is to guide the industrial designer for the modular systems and customization at modular systems. People's needs are changing towards upon recycle, reusable, qualified and customized products. So that, in order to design for high productivity and also to achieve high quality and controllable material cost, designer should consider the simplification and size reduction possible in product and the maximum reduction possible in the number of component parts. The approach embodied in mass customization is that customized products are produced to meet specific customer requirements and needs. In the future, body parts, cases, and other parts of a design could be stamped, pressed, cut, or molded to order. Efficient assembly lines could put together customized structures. The choice of alternatives could expand. Manufacturing techniques are making it possible to extend the range of customization.

This is the future. So that, designers should consider both modular systems and mass customization.

1.3. Method of the Study

The study is comprised of five chapters. In the first introductory chapter, the aims and means of the study are defined.

The second chapter is constituted from four sections. In the first section, modularity is defined and some examples of modular design are given placed. In the second section, advantages of modularity at industrial design are taken up in order to give place to benefits and costs and challenges of modularity. In the third section, concepts of modularity constituting of modularization and integration and their distinctions. At finally Modular design, as a special form of product design, aims to identify components with a high degree of interaction meaning its concept and types are defined. Modularity means customization.

The third chapter consists of six sections. In the first section mass customization and how it evolved is defined. Second section takes up benefits of mass customization. In the third section types of mass customization and in the fourth section advances are taken up. At last fifth and sixth sections are constituted from examples of mass customization and a link between both modularity and customization.

The fourth chapter consists of a case study showing both signs of modularity and mass customization and all explained through the thesis.

The last chapter comprises the conclusion of the thesis to find an answer to the question of how mass production and modular design systems affects the designer.

CHAPTER 2

MODULARITY

2.1. Overview of Modularity

During the development process of manufacturing, technology is more and more complex, the product system is more and more huge, the demand of market is more and more uncertain, the life cycle of product is more and more short, and the intension of competence is more and more furious. To respond the pressure imparted by this era, the manufacturing introduces technology and strategy of modularity, speeds up technology innovation, and is in leading position in modern industry. (Baldwin 1997). Modularity design theory and approach popularized rapidly in the seventies of the twentieth century. Now the modularity design and modularity manufacture of product had been used widely in aircraft, automobiles, consumer electrics, household appliances computers, software, test instruments and power tools (Sanchez 1996).

Development of modular product structures is often discussed for reducing cost in assembly and management of product families. From a viewpoint of manufacturing, it is inefficient to have multiple types of products with minor differences. Modular structures are used to reorganize product family. Sharing common modules in a product family can make production more efficient. In addition, products with modular structures could be more suitable for life cycle management than without them. Upgrade and maintenance are executed much easily if products are modularized functionally. Standardized modules with well designed structures will be reused as long as their quality is guaranteed.

Modularity systems have the properties of reconfiguration, reusability and scalability, and can realize multiplication and decentralization. Based on analysis of the concepts and characteristics of modularity, this paper analyzes the learning characteristics in knowledge management, the organizational construction of enterprises, and the co-operation and competition in modular-cluster firms. It is shown that modularity plays an important role in the speed and level of technology innovations and can give reasonable explanations on innovations of technologies and development of industries.

It is a challenge of manufacturing to produce variety of products with limited resources. As corporations strive to rationalize their manufacturing facilities and to produce a large variety of products at lower cost, modularity is becoming a focus of attention (Paul 1988). Modular products and reconfigurable processes are crucial to agile manufacturing and provide a way to produce a variety of products that satisfy various customer requirements in time (Kidd 1994). This modular approach promises the benefits of high volume production (that arises from producing standard modules) and at the same time, the ability to produce a wide variety of products that are customized for individual customers. Such modular product design has been stated as being a goal of good design practice in current engineering areas (Kidd 1994).

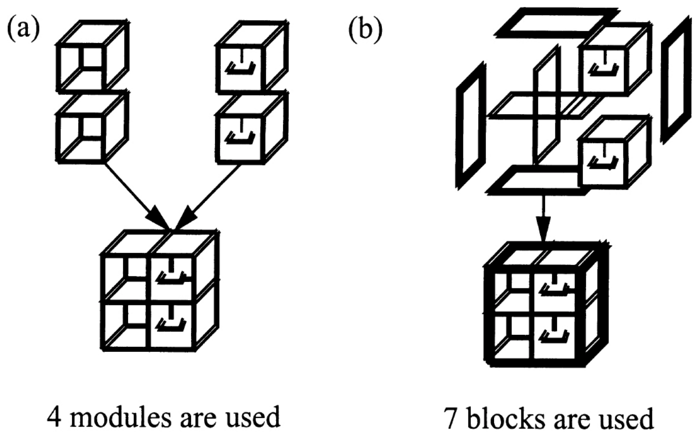

Figure 2.1. Two designs of a piece of domestic furniture.
(Huang 1998)

Integrated – Modular: Consider two different designs of a piece of domestic furniture shown in Figure 2.1. In the design shown in Figure 2.1.(a), two types of functions, the drawer and the open space, are allocated to separate modules, which in fact are mounted together and make up a piece of domestic furniture. The most modular architecture is the one where each functional element of the product is implemented by exactly one module, and in which there are a few well-defined interactions between the modules. Such a modular architecture allows a change to be made to one module without generally affecting other modules so that the product can function correctly. Each module may also be designed quite independently of other systems. The design shown in Figure 2.1.(b) is integrated, in this case motivated by ergonomic concerns. A product embodying an integrated architecture is often designed so as to maximize a certain performance measure; however, modifications to one component or feature may require extensive redesign of the product. Implementation of functional elements may be distributed across multiple blocks. Boundaries between the blocks may be difficult to identify or may not even exist.

An integrated product shares one or more of the following properties:

(1) The functional elements of the product are implemented using more than one block.

(2) A single block may implement many functional elements.

(3) The interactions between blocks are ill-defined and may be incidental to the primary function of the product.(Huang 1998)

Some of the motivators for product change are: upgrades, add-ons, adaptation, wear, consumption, use flexibility, and reuse. Modules allow changes to be made to a few isolated functional elements of a product without necessarily affecting the design of other elements. However, changing one block in an integrated product may influence many functional elements and require changes to several related blocks.

According to me, the design of modular products has recently become the focus of significant research in the area of design theory and methodology. This focus is the result of increased awareness of the potential power of modularity to achieve certain product objectives. However, there continues to be a gap between the results of academic research and industrial application. The refinement, consolidation, and extension of this academic research would help design teams who are charged with developing modular products to use these academic findings in real world, industrial applications. The research presented in this document focuses on developing design tools, based on past and present academic research, for use in industrial settings where the design of a modular product is the goal. In this chapter the many definitions and methods for classifying modular products are consolidated and refined.

As a result, modularity is a very important subject that it has been the focus of many researches. According to Baldwin and Kim B.Clark; humans interact with artifacts in three basic ways: they design them; produce them; and use them. In their articles they define three basic types of modularity: modularity-in-design, modularity-in-production, and modularity-in-use. A system of goods is modular-in-use if consumers can mix and match elements to come up with a final product that suits their taste and needs. For example, consumers often buy bed frames and beds made by different manufacturers and distributed through different retailers. The parts all fit together because different manufacturers make the goods in standard sizes. These standard dimensions constitute design rules that are binding on manufacturers, wholesalers, retailers, and users. Modularity-in-use thus supports customization of the system to suit the needs and tastes of the end-user. Manufacturers have used modularity-in-production for a century or more. Car makers, for example, routinely arrange to manufacture the components of an automobile at different sites and bring them together for final assembly. They can do so because they have completely and precisely specified how the parts will interact with the vehicle. The engineering specifications of a component (its dimensions, tolerances, functionality, etc.) constitute a set of design rules for the factories that supply the parts. Such process modularity is fundamental to mass production. (Baldwin 2004)

However, the fact that, in a complex system, the elements of use or the tasks of production have been split up and assigned to separate modules does not mean that the design of the system is modular. Indeed systems that are modular-in-use or modular-in-production may rest on designs that are tightly coupled and centrally controlled. For example, a sectional sofa is a suite of furniture that is modular-in-use. Purchasers can combine and recombine the elements of the suite at will. But those elements must be designed as one interdependent whole, or the patterns and shapes will not form a pleasing ensemble. Thus, the sectional sofa suite is modular-in-use, but not modular-in-design. A complex engineering system is modular-in-design if (and only if) the process of designing it can be split up and distributed across separate modules, that are coordinated by design rules, not by ongoing consultations amongst the designers. Of all the "modularity's", modularity-in-design is the least well understood and has the most interesting economic consequences. (Baldwin 2004) This is because new designs are fundamentally options with associated economic option value. Modularity-in-design multiplies the options inherent in a complex system. This in turn both increases the total economic value of the system and changes the ways in which the system can evolve. The rest of this chapter, how to map and measure the option value of modularity-in-design will be mentioned.

2.1.1. Definition of Modularity and Modular Systems

In an article written by Melissa A. Schilling (2000) for the Academy of Management Review, she states that at its most abstract level modularity "refers simply to the degree to which a system's components can be separated and recombined. Systems are said to have a high degree of modularity when their components can be disaggregated and recombined into new configurations – possibly substituting various new components into the configuration – with little loss of functionality."

The term *modularity* in products is used to describe the use of common units to create product variants. It arises from the division of a product (part) into independent components, thus allowing one to standardize components and to create a variety of products. Modularity aims to identify of independent, standardized, or interchangeable units to satisfy a variety of functions. With a wide range of overall functions, the partitioning of a product into *function-oriented* modules is of importance while with a small number of overall function variants, a *production-oriented* solution is the paramount consideration (Paul 1988).

Therefore, a modular design structure has three characteristic parts:

(1) Design rules, which are known and obeyed by teams responsible for individual modules;

(2) So-called hidden modules that "look to" the design rules, but are independent of one another as work is proceeding;

(3) A systems integration and testing module in which the hidden modules are assembled into a system and any remaining, minor problems of incompatibility are resolved.

A complex system design may go from being *interdependent* to being *modular* in the following way. The "designers" of the system must first identify the dependencies between the distinct components and address them via a set of design rules. Second, they must create encapsulated or "hidden" modules corresponding to the components of the system. And third, they must establish separate system integration and testing activity that will assemble the modular components and resolve unforeseen incompatibilities.

2.1.2. Industrial Examples of Modular Designed Products

Product variety refers to the range of product models a company can produce within a particular time period to meet the market demand. Products built around modular product architectures can be varied without significant changes in the manufacturing system. Product variations based on mixing and matching of modular components are now appearing in markets as diverse as aircraft, automobiles, consumer electronics, household appliances, personal computers, software, test instruments, and power tools (Morris 1993).

For example, Swatch produces hundreds of different low cost watch models by assembling the models from different combinations of standard modules (Pine 1992). (see Figure 2.2.)

Figure 2.2. Swatch Watches, Swatch AG 2005.

(Source: http://www.store.swatch.com)

A large number of different hands, faces, and wristbands can be combined with a relatively small selection of movements and cases to create seemingly endless combinations. In the design of the Nippondenso panel meter shown in Figure 2.3., the concept of sectional modularity was applied (Aoki 1980). The old panel meter design was redesigned to establish six standard modules. The combination of the six modules produces 288 different models, of which about 40 are currently being produced.

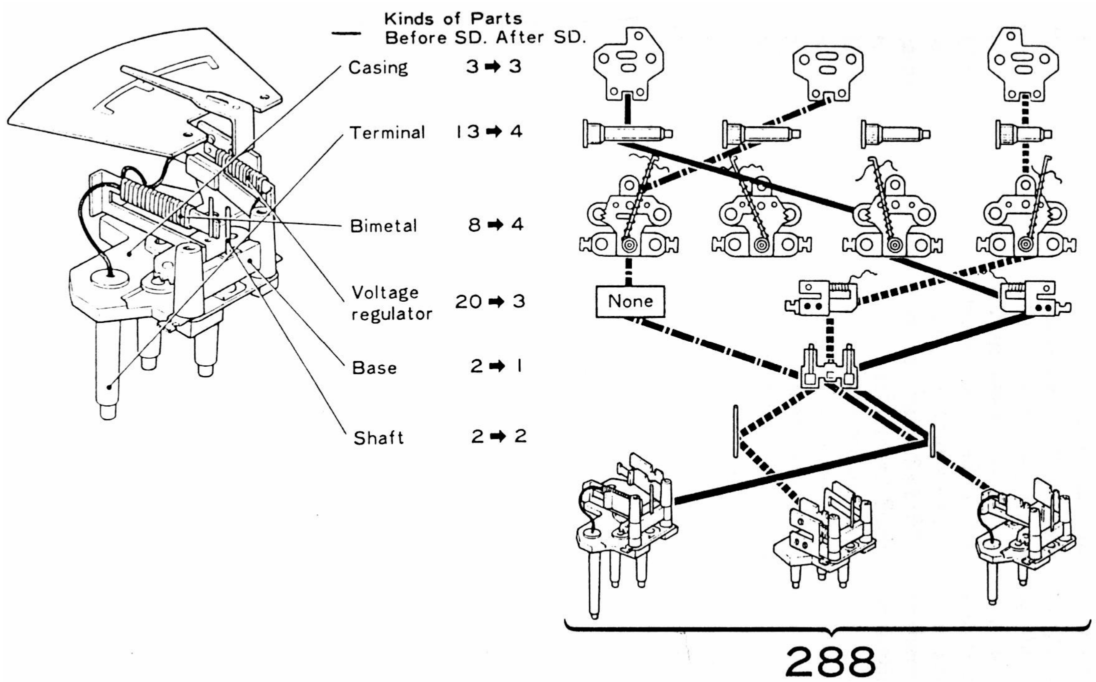

Figure 2.3. Nippondenso panel meter (Aoki 1980)

2.2. Advantages of Modularity at Industrial Design

The advantages of modularity can be defined with six different aspects according to Hu Kexin. They are product development and design, customization, production, quality, purchasing and after-sales. First, in product development and design, modularity can cut the development costs by shortening the development time. As the new products enter into the market earlier than the competitors', the corporation can get much more profit. Second, the worldwide market has entered into a customization explosion time, the quantity and low prices are not the main goals, which the customers pursue any more. Customers need products which can satisfy their own demand. They tend to express that they are different from others by choosing the different commodities. The modularity concept can help the designer develop much more variance within quite a short time. Third, as the number of variants increases, the production section faces a great challenge. To minimize the producing cost, they have to manufacture a much wider range of parts with the same machines as before. In fact modularity is a useful way to create a large number of variants and reduce the number of parts at the same time. Fourth, to survive in the fiercely competitive worldwide market, a high-qualified product at a rather affordable price is a useful weapon for most corporations. Modularity method divides the products into different modules. Before being assembled into an integrated product, modules can get the tested separately. This can cut the cost of reworking and may increase the quality of the product. (Erixon,G.,et al.1994)

Next, on the purchasing side, by defining the modules clearly, the corporations can define their purchase chains clearly. They can then come to a conclusion on what they will buy and what they will make. Finally, after selling the products to the customers, the corporations can benefit the customers again through updating new techniques in the products and providing enough maintenance in time by applying the modularity principals during the product development process.

There are also some disadvantages of modularity. First, modular design can be very complex. The designers have to adjust the parts frequently. Secondly, the designers can easily fall into the “common unit” trap. Thirdly, the variants from the same platform resemble each other and may not be attractive to customers.

Product development and design: Modular design allows for dividing design tasks for parallel development. To accomplish this, the overall design task has to be divided into smaller tasks and the interface between them should be properly defined. (Gershenson 2003) At the same time the development group can also be divided into different subgroups in order to meet different smaller tasks. Compared to the whole group following the serial process, this can save a lot of development time.

Customization: This world has entered into an age of the explosion of variants. When there are not enough goods, people simply want quantity and low prices. Unfortunately each consumer has his or her own favor. Something which may be very common for one consumer may be quite fantastic for another one. Each person has a "currency" of emotion in the brain and that is a rational guiding principle, because each consumer has different experiences and a different culture environment than others. That is why a huge number of variants are needed. Unfortunately increasing the number of product variants will take great design risk. That means the corporation will have to face a huge number of variants to design. Design work could be overwhelming.

Production: In an effort to better respond to the heterogeneous customers' needs, many firms find it appropriate to increase product variety, i.e. the number of different products offered to customers. (Pine II 1993) In fact, as product variety increases, a firm would experience lower performance of its internal operations because of higher direct manufacturing costs (Salvador 2002). More variances mean more different parts to be manufactured. In the manufacturing section it demands more investment on the machines, a bigger area, and more workers.

In the management section firms will have to hire more managers, whose salary is proportionally higher in order to organize the manufacturing, transporting the parts, and delivering the components. Finally, all these costs will raise the products' final price. In fact modularity is a useful method to create a large number of variants and reduce the number of parts at the same time. In the modularity design process, designers first design a limited number of modules. Each module can complete one or more functions separately. Secondly, the designers allocate the interfaces for the modules. Interface is the key which can guarantee that final products composed of different modules will perform correctly. At last as the designers assemble the different modules together, a quite wide range of variants consequently emerge.

Quality: Products' quality is the most important item, which is the customers' basic demand. The recent market has transited from mass production to mass customization. The customers' status in society will continue to rise in the future. About 20 years ago when there were not enough goods, people simply wanted quantity and low prices. Later as the goods' volume increased a lot, consumers did not mind paying extra money for high quality products. Then some companies met serious selling problems because of the poor product quality. Now to protect consumers' benefit, governments and trade organizations have published a lot of strict standards. If a firm's products can not meet the strict standards, they even can not meet the consumers in the market not to mention to able to be sold. Modularity supplies manufacturing a good quality product with variations at an affordable price.

Purchasing: The product now has become quite complex and it is impossible for a company to be expert on manufacturing every component for a product. Purchasing some parts for a whole product can give a corporation a lot benefits such as higher quality, low price and easy to obtain. So a steady supply chain for a corporation has played a more and more important role in their success. Moreover, businesses are increasingly expanding into international markets, which require the ability to manage manufacturing and distribution functions on a global basis. (Krikke 2004)

Figure 2.4. Ikea Customized Modular Table Templates.
(Source: http://www.ikea.com.tr/catalogue06)

A well defined modularized product can enjoy more advantages from purchasing. Ikea, the Swedish furniture maker and retailer, is a very good example. Ikea does not only carefully design and specify the components in its products (such as table tops, table legs and hardware) (see Figure 2.4) but also modularize supply chain. Ikea defines the way that orders will be transmitted to suppliers, the quality standards to which various types of components must be made, the way purchased components must be packed for shipment, the way shipping information must be transmitted by suppliers to Ikea, and so on. Because the suppliers' right and responsibility are defined clearly, Ikea can readily source components from any qualified member of its global network of more than 1800 suppliers. This freedom enables Ikea to configure its supply chain to take maximum advantage of movements in currency exchange rates, fluctuations in shipping rates, suppliers' available production capacities and willingness to offer attractive prices. (Sanchez 2002)

After-sales: As a product has been broke down into different modules in the product design stage, different functions will be up to different modules separately. If some technique gets improvement, the firm can give the consumers the opportunity to enjoy the technical achievement immediately at quite at low price. This can save consumers' cost on the product dramatically. For example to give their consumers the newest and the best goods the firms will not have to redesign the whole product, reorganize the production, and rebuild the selling strategy.

The product's quality has been improved greatly. However, it is still quite hard to guarantee that all the products do not have any defect before the consumers receive them. Even though the products are perfect, they could break down due to unsuitable use. To minimize the negative aspect of the products' failure on consumers' lives, the firms have a responsibility to resolve the problem as soon as they can. In modularized products, different modules fulfill different functions. If modularized products fail it will be much easier to resolve the problem.

Disadvantages: Modular systems are much more difficult to design than comparable interconnected systems. The designers of modular systems must know a great deal about the inner workings of the overall product or process in order to develop the visible design rules necessary to make the modules function as a whole. They have to specify those rules in advance and while designs at the modular level proceed independently, it may seem that all is going well; problems with incomplete or imperfect modularization tend to appear only when the modules come together and work poorly as an integrated whole. (Baldwin 1997)

At the "generate modular concept" stage, designers start to create module fulfilling different kinds of technical solutions for sub-functions which they have obtained from breaking down the products. There is a basic principal in product design and this is that the designer should try their best to reduce the number of the modules. The less modules means less components. It can produce a lot of benefits in a wide range of areas including the manufacturing section, product verification and product assembly. As the designer tries to incorporate as many functions and details as possible in a module, it can be a "common unit" module. That indicates the designers increase the interaction between the components in the module. The components will be designed and produced dependently and because of this the designer loses the main advantage of modularity.

Although by assembling different modules together the designers can get a large number of product variants easily, all the product variants are based on the same set of modules. Most of modular products have their own basic modules which could be shared in all the product variants from the same platform. So sometimes the product variants from the same platform may be a "look a like", and there are not distinct differences between products. This kind of product has not reached the aim of enlarging the product variants, so they can not be attractive to consumers.

It has been clear that modularity can help company perform better on different processes such as product development, manufacturing and product maintenance with less cost. Generally the disadvantages are very important to be careful for the product development group. Group has to refine the modules carefully to make sure that the modules can fulfill different demands in different variants. It is a great challenge of ability. It is quite fair only the well organized high quality industrial designers can develop high quality products.

2.2.1. Benefits and Costs

In the world of industrial design, whenever something is gained through a design decision, something else is given up. In other words, nothing is for free. Whenever a designer makes a decision he or she must carefully weigh the benefits and the costs of that decision. In a sense, design is the art of managing these tradeoffs to obtain the best overall design. The decision to design a modular product is no exception to this rule. While it is true that there is much to be gained from using a modular architecture, there are also some costs involved.

The benefits and costs of product modularity were discussed by Ulrich and Tung (1991). One of the most common motivators for promoting modularity is the need to allow a large variety of products to be constructed from a much smaller set of different modules and components. The result is that any combination of modules and components, as well as the assembly equipment, can be standardized. Potential benefits of modularity include (Nevins and Whitney 1989; Pahl and Beitz 1988; Corbett *et al.* 1991):

(1) Economies of scale. Since each module will usually be produced in relatively large quantities, natural economies of scale arise.

(2) Increased feasibility of product/component change: Since each module interface is strictly specified, changes can be made to a module independently of other modules, provided the interfaces remain within specifications.

(3) Increased product variety: The use of modules means that a great product variety can be achieved using different combinations of modules.

(4) Reduced order lead-time. Since modules are manufactured in relatively large volume, the logistics of production can be organized so as to reduce manufacturing lead time. Hence, the order lead time can be reduced.

(5) Decoupling tasks. Since the interfaces and modules have been standardized, their interfaces enable design tasks and production tasks to be decoupled. This decoupling can result in reduced task complexity and in the ability to complete tasks in parallel.

(6) The ease of product upgrade, maintenance, repair, and disposal. Since a product is decomposed into modules, only certain modules need to be replaced when repair is done. For the same reason, upgrades, maintenance, and disposal are also made simpler.

However, potential costs of modularity include:

(1) Redundant physical architecture (due to decreased function sharing).

(2) Excessive capability due to standardization (designing for the most rigorous application).

(3) The potential for static product architectures and excessive product similarity.

In “Holonic Product Design Workbook” from Loughborough University (Marshall 1997), stated that modular design is for any company that is seeking:

- Flexible or agile manufacturing
- A rationalized introduction of new technology
- An efficient means of deploying customer requirements
- A structured approach for dealing with complexity.

In their book “Design Rules: The Power of Modularity,” Baldwin and Clark (2000) list the following items as benefits of product modularity:

- Modularity increases the range of manageable complexity
- Modularity allows different parts of a large design to be worked on concurrently
- Modularity accommodates uncertainty during design – if knowledge yields a better solution at some point in time into development, the new solution can be incorporated into a module with little or no need for change in the rest of the design.

The benefits of product modularity as outlined by Phal and Beitz (1996) in their book “Engineering Design: A Systematic Approach” are split into two categories. The categories and corresponding benefits are listed below:

Table 2.1. Benefits of Product Modularity. (Phal and Beitz 1996)

Benefits to the manufacturer:	**Benefits to the user:**
Ready documentation is available for project planning and design	Short delivery times
Additional design effort is needed for unforeseeable orders only	
Combinations with non-modules are possible	Better exchange possibilities and easier maintenance
Overall scheduling is simplified and delivery dates may be improved	
Computer-aided execution of orders is greatly facilitated	Better spare parts service
Calculations are simplified	
Modules can be manufactured for stock with consequent savings	Possible changes of functions and extensions of the range
Appropriate subdivision of assemblies ensures favorable assembly conditions	
Modular product technology can be applied at successive stages of product development, for example, in product planning, in the preparation of drawing and parts lists, in the purchase of raw materials and semi-finished materials in the production of parts, in assembly work, and also in marketing.	Almost total elimination of failures thanks to well-developed products

The benefits of modularity outlined by Ulrich and Tung (1991) in "Fundamentals of Product Modularity" are shown Figure 2.2.

Table 2.2. Fundamentals of Product Modularity. (Ulrich and Tung 1991)

Improved component economies of scale	Ease of component verification and testing
Improved product variety	Ease of managing differential consumption
Improved order lead-time	Ease of product change
Improved design and product focus	Facilitates decoupling of tasks
Ease of product diagnosis, maintenance, repair, and disposal	Facilitates production, installation and use

The benefits of modularity are always achieved at some cost. The following is a summary of the costs associated with modularity.

The costs of modularity as outlined by Phal and Beitz (1996) in their book "Engineering Design: A Systematic Approach" are again split into two categories. The categories and corresponding costs are listed bellow:

Table 2.3. The costs of modularity. (Phal and Beitz 1996)

Costs to the manufacturer:	**Costs to the user:**
Adaptations to special customer's wishes are not as easily made as they are with individual designs (loss of flexibility and market orientation)	Special wishes cannot be met easily
The stock of drawings may be inadequate	
Changes can only be considered at long intervals because original development costs are high	Quality might be less satisfactory than they would be with integrated designs
Technical features and overall shape are more strongly influenced by the design of modules than they would be by individual designs	
Production costs are increased, for example because of the need for accurate locating surfaces	Weight and size of product will be larger than a comparable integrated design
Increased assembly effort and care are required	
Rare combinations needed to impellent unusual designs may prove costly	
Since the user's as well as the producer's interests have to be taken into consideration, the determination of an optimal modular system may prove very difficult	

The costs of modularity outlined by Ulrich and Tung (1991) in “Fundamentals of Product Modularity” are:

- Increased likelihood of static product architecture
- Compromised performance optimization
- Ease of reverse engineering for competitors
- Increased unit variable costs
- Excess in product similarity

2.2.2. Challenges

The notion of modular design must be quite a challenge to management. Through modularity you can achieve very high levels of product variety, while at the same time achieving low cost for development as well as cost savings in production. Modularity is pushing out the productivity frontier in product creation and is changing the rules of competition. What some companies today are already doing with modular design is changing a lot of assumptions in management about what is possible. The first company in an industry that understands how modularity lets you approach the market in new ways and implements a modular strategy can rewrite the rules of competition. (Sanchez 2000)

In effect, the advent of modularity allows the locus of product definition to shift from producers to consumers. What producers have had to do for decades was to try to figure out what product variations-what "bundles" of product functions, features, and performance levels-would sell and then offer those bundles to the market, hoping that you have guessed right. What modularity makes possible is strategies in which producers define designers that will accept a range of component variations that provide different functions, features, and performance levels-and then offer a menu of choices to consumers. Modularity is already beginning to happen in a number of industries-and not just with products like PCs. Modularization is the norm, for example, in the global bicycle industry. You can configure your bicycle the way you want with the components from the different suppliers who are all making their components to fit in a standard architecture.

2.2.2.1. Standardization

Modularity is a standardization of some of the items important at the design process. From this point of view; each final product player has its own structure. However, around certain key components there are standardized interfaces, especially around the most cost-intensive components, because there are advantages to using the same component design in many final products so long as the customer does not differentiate the product on the basis of that component. People need to get the reliability and performance of a component up and the cost down is in everybody's best interests. And in that situation, over time, a component producer who has the best component will begin to attract a very large share of the market, creating an interface standard for that kind of component.

In furniture industry; modularity is very important and so comes standardization, which brings many advantages as explained in previous section. Below; first in Figure 2.5, is an example of modular seating furniture system, that the company has gone to a standardization according to consumer needs and in Figure 2.6 is an example from modular furniture industry which shows detailed modules and lets the user to customize his/her own configuration. The example is from Germany’s most important modular furniture company.

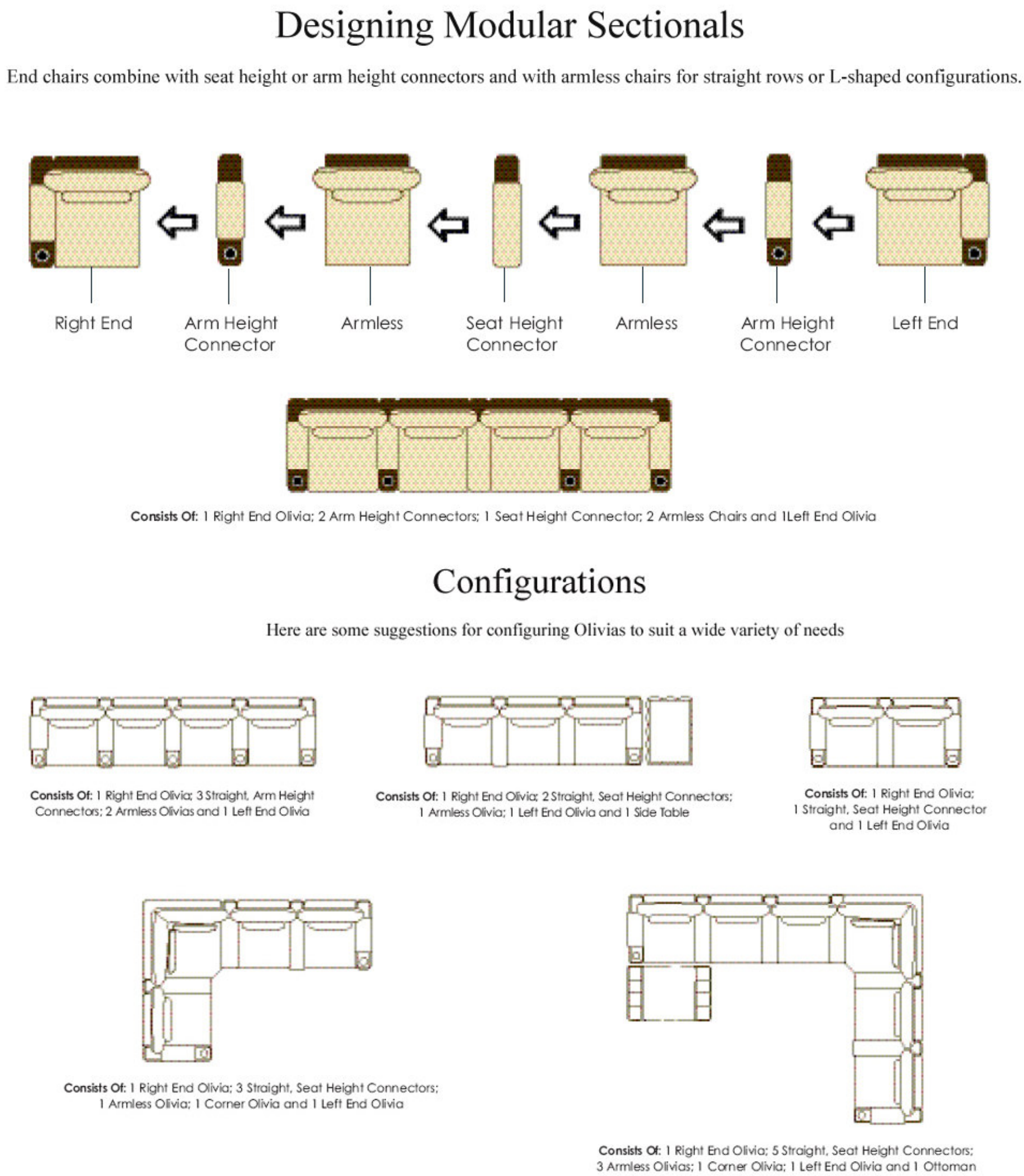

Figure 2.5. An example of Modular Seating Furniture.

(Source: http://www.salamanderdesigns.com)

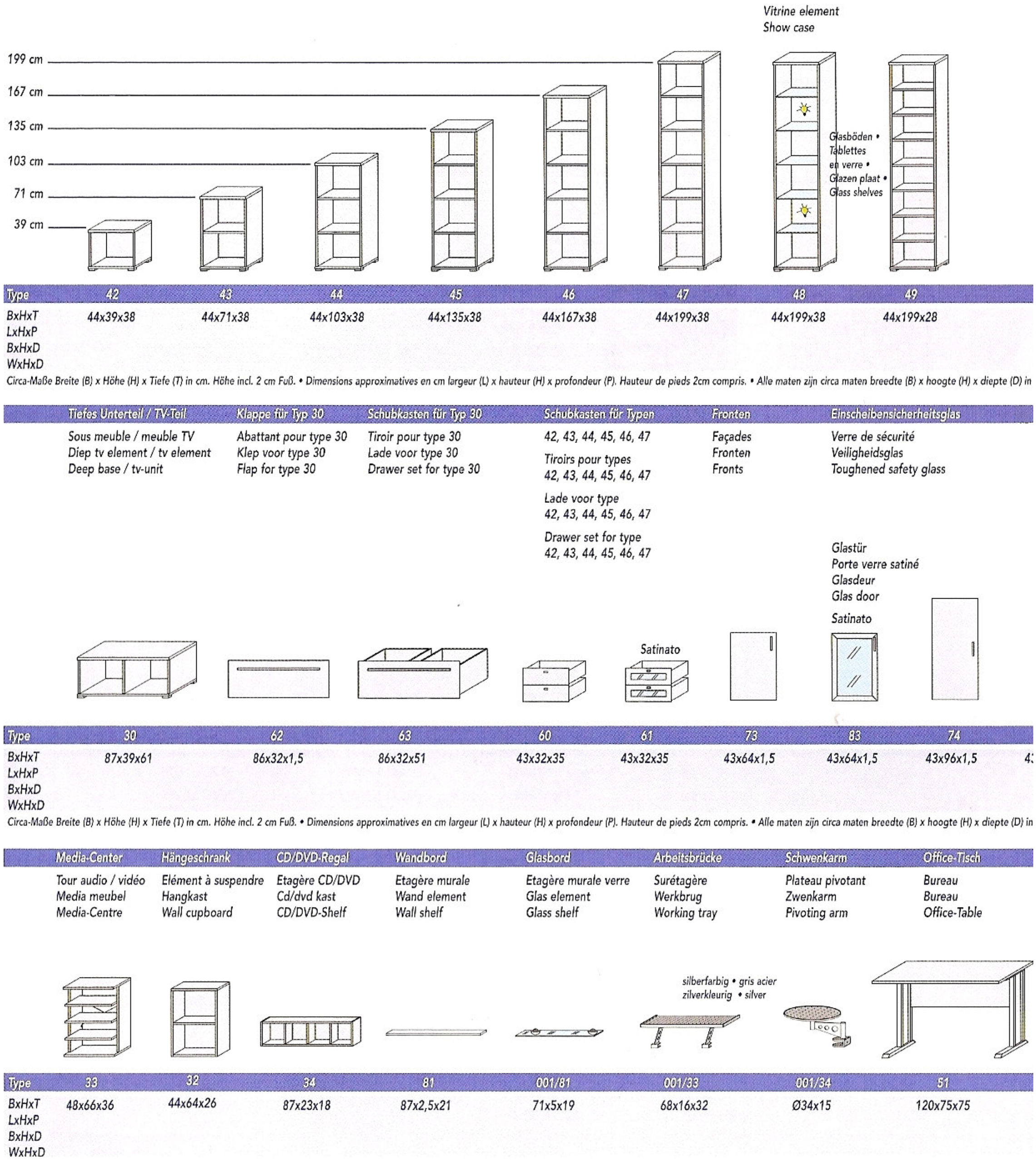

Figure 2.6. An Example of Modular Panel System from Furniture Industry.

(Source: http://www.csschmal.com)

2.2.2.2. Reusability

In the mass production industry, when a break with a former design proves to be the best way forward, backward compatibility proves to be a major problem. Giving backward and forward compatibility to the consumer is a major benefit that a producer can choose to provide through a modular approach. Since a product is decomposed into modules, only certain modules need to be replaced when repair is done. For the same reason, modularity can facilitate upgrades maintenance and disposal simpler and also modularity allows transferring many of the benefits to configure product variations and upgrades to customers. Reusability is a central factor here, especially for the user, who saves money.

Reusability is important both for the user and the producer. Reusability of components and processes has become a central issue for a lot of companies in their design strategies. There are a number of reasons for this. The relative cost of development versus production is shifting more and more to greater investments in development. If you can go through one component design process and create a component design that can be used in a number of product variations or across product generations, or preferably both, you save tremendous amounts of money on development costs. You can also be very fast in bringing improved products based on selectively upgraded components to the market in the future. A second benefit of reusing components is that there are economies of learning and quality improvements at the component level. With time we learn how to make reused components cheaper and better. One of the keys to improving the reliability of products is reuse of components. The more you reuse a component and the more you work at incrementally improving that component and its production process, the more reliable that component becomes. (Sanchez 2000)

2.2.2.3. Life-cycle of Modularity

Life-cycle modularity is a relative property. Products possess a higher or lower degree of modularity. A product with a higher degree of modularity either contains a larger percentage of components or subassemblies that are modular or contains components and subassemblies, which are, on average, more modular. Subassemblies, which are relatively modular in nature, are *modules*. (Gershenson 1999)

Modules contain a high number of components that have minimal dependencies upon and similarities to other components not in the module. These dependencies and similarities include those that arise from the component interactions and those which arise from the various processes the components undergo during their life-cycle. In an ideal module, each component is independent of all components not contained in that module throughout the entire product life-cycle (independence). In addition, each component in the module is processed in the same manner during each life-cycle stage (similarity) (Gershenson and Prasad 1997). This definition expands the form-function relationship to a form-process relationship. Similarity is a new perspective on the separation of form and process. Each part of the form (module) must undergo the same life-cycle processes. Independence and similarity represent a significant increase in the rigor of defining product modules versus past form/function independence. To increase independence and similarity, a product must be designed with the following three facets of modularity:

Attribute Independence: Component attributes have fewer dependencies on attributes of other modules, called external attributes. If there are dependencies, fewer attributes are dependent upon one another and attributes that are related to external attributes are less dependent. *E.g.*, Lego pieces which can be of any color, size, shape, or material as long as they have the correct dot to attach to other pieces and an impression to accept other pieces. Attribute independence allows for the redesign of a module with minimized effects on the rest of the product. Attribute similarity is excluded because having similar but unrelated components is not detrimental as long as attribute independence is maintained.

Process Independence: Each task of each life-cycle process of each component in a module has fewer dependencies on the processes of external components. This requires that the processes a module undergoes during its life-cycle are independent of the processes undergone by external modules. Any dependencies that do exist are minimized in number and criticality. *E.g.*, in separation for recycling, techniques that utilize grinding and separation by material density are dependent upon the disassembly of all components containing materials that are not compatible and are of a similar density. If the disassembly process occurred later in the retirement process, grinding and density separation would not be possible. Process independence allows for the reduced cost in each life-cycle process and the redesign of a module in isolation if processes should change.

Process Similarity: Group components and sub assemblies that undergo the same or compatible lifecycle processes into the same module. *E.g.*, if a product is being recycled through grinding, it would be least expensive if all components undergoing this task were in the same module therefore the entire module could be ground and then no other grinding would be necessary. Process similarity minimizes the number of external components that undergo the same processes, creates a strong differentiation between modules, reduces process repetition, and reduces process costs. Process similarity also conserves redesign effort by insuring that changes to individual life-cycle processes only affect one module of the product.

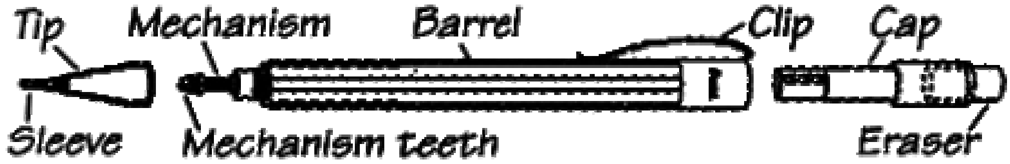

Figure 2.7. Exploded view of the mechanical pencil highlighting the four modules: cone/tip, clutch/teeth, barrel, and eraser.

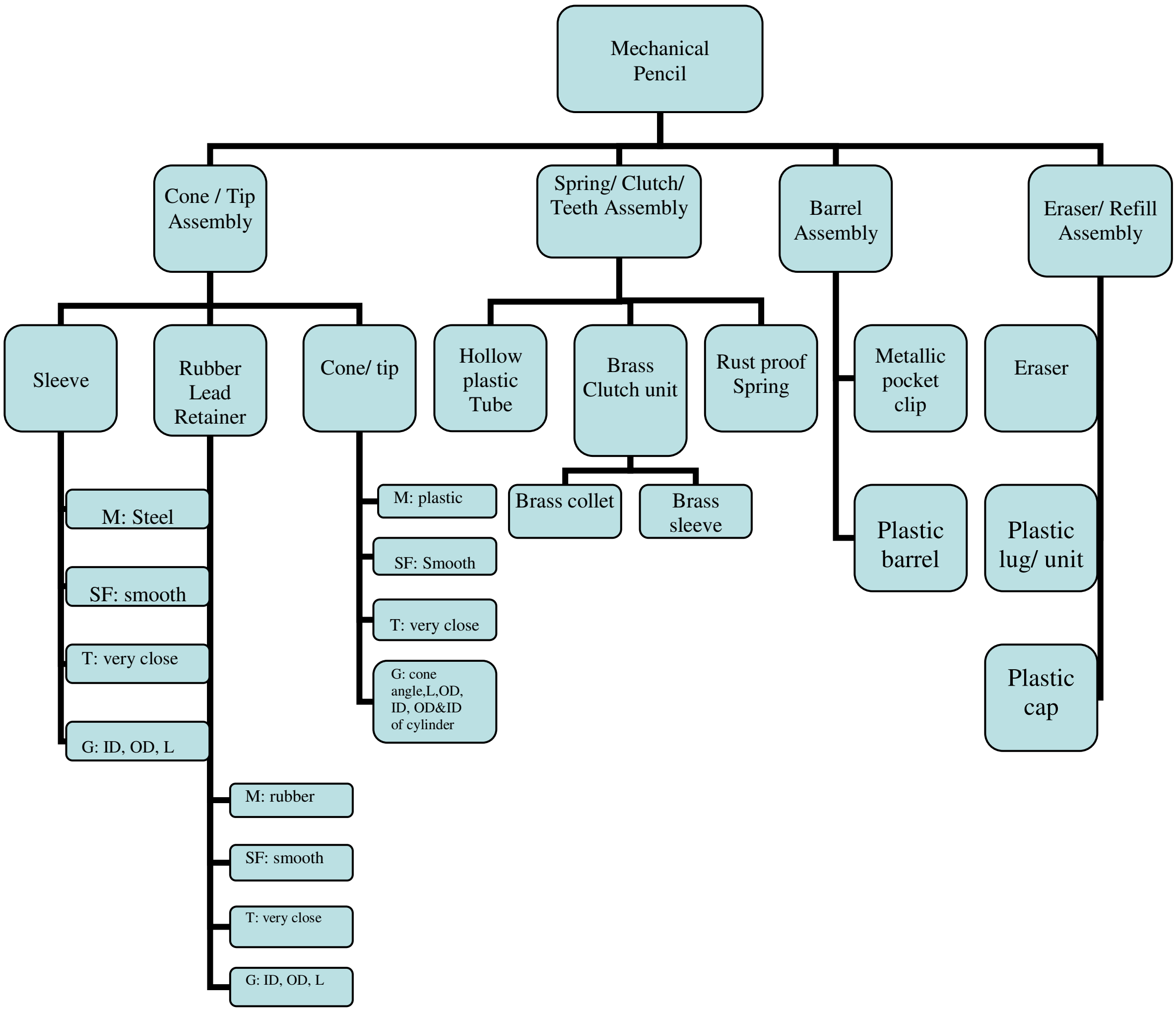

Figure 2.8. A partial component tree of a mechanical pencil cone/tip assembly.

Generating a Component Tree - A component tree details the physical relationships among components at all levels of abstraction. To develop a component tree, the product is divided into its constitutive modules and components. The modules are further classified into subassemblies, then individual components, and lastly product attributes that describe the components. A partial component graph for a mechanical pencil highlighting the attributes of the cone/tip assembly is shown in Figure 2.8. From Figure 2.7 it can be seen that the cone/tip assembly is comprised of components such as sleeve, rubber lead retainer, and cone/tip with similar geometric attributes but very different material attributes (steel, rubber, and plastic).

2.3. Concept of Modularity

As a concept of modularity, modular design is a special form of product design, aims to identify components with a high degree of interaction (Sanchez 1993). Design is often defined as the creation of a synthesized solution in the from of products, processes or systems that satisfy perceived needs through mapping between functional requirements (*FR*s) in the functional domain and the design parameters (*DP*s) of the physical domain through the proper selection of *DP*s that satisfy *FR*s (Suh 1990), i.e., $[FR] = [A]\bullet[DP]$, where $[A]$ is the design matrix. A functional element corresponds to a subsystem (mechanism), and interconnections correspond to function flows in function-oriented modularity. Based on these functions, six types of functional similarity are considered in the identification of modular components: geometric, temporal, force, electrical, thermal, and photometric. The design of modular products at the conceptual level involves determining a design matrix $[A]$ such that the functional requirement space is mapped into the modular functional space. Then, the modular functional space is mapped into the module space based on consideration of module performance, e.g., size, speed, and weight. The mapping among these three different spaces is illustrated in Figure 2.9. The elements of modular functional space are classified as follows (based on Pahl 1988):

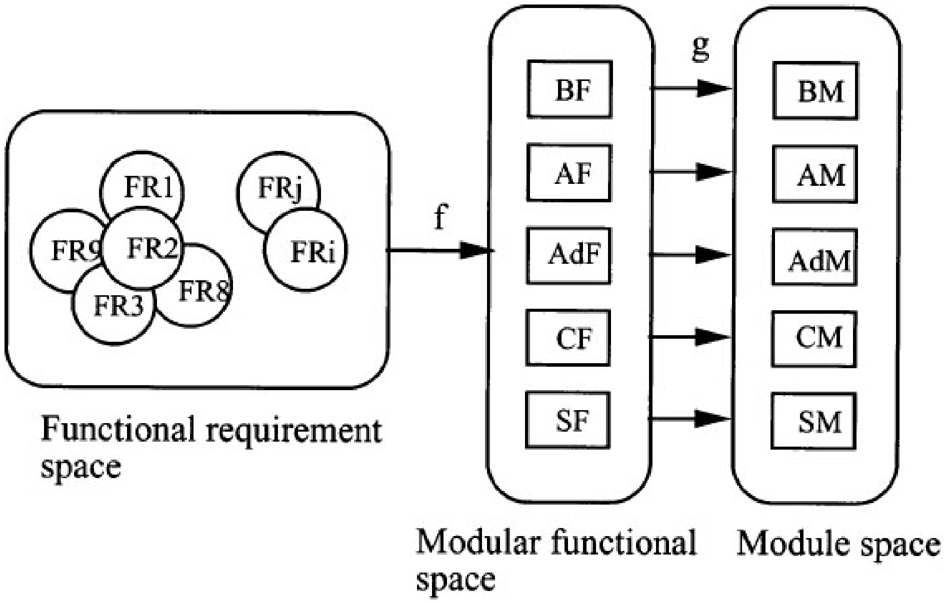

Figure 2.9. Mapping in three design spaces. (Pahl 1988)

BF: basic functions existent in most products, e.g., the power supply in a computer;

AF: auxiliary functions characteristic of variant products resulting from the various types of modularity, e.g., the protection/esthetic function of a lamp cover;

AdF: adaptive functions which are adaptive to different modules/basic components, e.g., the converting function of a computer inference card that standardizes I/O signals;

SF: special functions that may or may not exist, e.g., the eye protection function in a computer product;

CF: customer-specified functions, e.g., the feedback function of vision detection of a missile as specified by the Department of Defense.

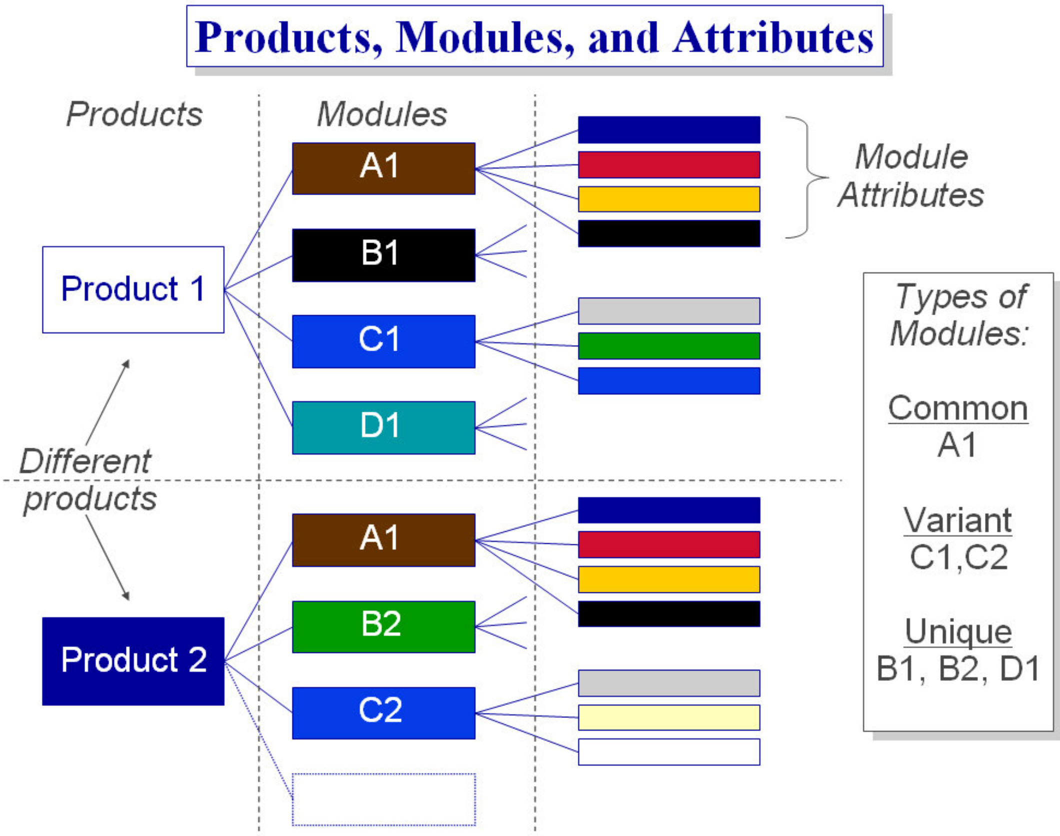

Figure 2.10. Products, Modules, and Attributes

(Source: http://www.mne.psu.edu/simpson/courses/me579)

The elements of module component space are classified as basic modules, auxiliary modules, adaptive modules, special module, and custom-specified (non-module) elements as presented in Section II. Pahl and Beitz (1988) summarized the development of modular products as follows:

Step 1. Clarify the task: Generate specifications. A module normally fulfills several main functions.

Step 2. Establish a functional structure: Subdivide the main functions into a minimum number of similar and recurring sub functions (BF, AF, AdF, SF, and CF) based on two constraints:

(i) The functional structures of the product variants considered for modularity must be logically and physically compatible.

(ii) The sub functions determined must be interchangeable.

Step 3. Determine the methodology to be used to implement the sub functions. Determine solution principles for implementation of the variant sub functions.

Precondition: Look for principles that provide variants without changing working principles and the basic design.

Step 4. Explore the feasibility between interfaces of modules and basic components (geometric, kinematics, and non-motion machine primitives).

Step 5. Review the constraints. A concept similar to modular design is the "core product" concept. (Shirley 1990) examined the problem of redesigning a large product set so as to improve product performance and reduce manufacturing costs. The design features of this "core" product (a prototype) are used to redesign the remaining members of the family. In this way, the design time is reduced. Closely related to the core product concept is the idea of the modular design process. Process modularity makes it possible to handle some aspects of a design independently of other activities. The use of the core product concept and modular design process allows companies to quickly adapt to changes in product and process technologies, and the consumer needs change. By reducing the time and the amount of resources consumed in responding to these changes, system flexibility is enhanced. Moreover, changes can be implemented in a systematic and incremental manner.

2.3.1. Types of Modularity

Modules are main parts of mass production. They can be used in various types and places in production. Basically, there are two different types of modules. First one is function modules. Function modules help to implement technical functions independently or in combination with other functions. And the other one is production modules. Production modules are designed independently of their functions and are based on production considerations alone. Function modules are classified as *basic*, *auxiliary*, *adaptive*, and *non-modules* (Pahl and Beitz 1988)

(1) A *basic module* is a module implementing *basic functions*. The basic functions are not variable in principle and are fundamental to a product or system.

(2) An *auxiliary module* corresponds to auxiliary functions that are used in conjunction with the basic modules to create various products.

(3) An *adaptive module* is a module in which adaptive functions are implemented. Adaptive functions adapt a part or a system to other products or systems. Adaptive modules handle unpredictable constraints.

(4) A non-module implements customer-specific functions that do occur even in the most careful design development. Non-modules have to be designed individually for specific tasks to satisfy the customer needs.

Modularity is viewed by Ulrich and Tung (1991) as depending on two characteristics of a design:

(1) Similarity between the physical and functional architecture of the design,

(2) Minimization of incidental interactions between physical components. Based on the interactions within a product, six categories of modularity have been defined (Pine 1993): (See Figure 2.10.)

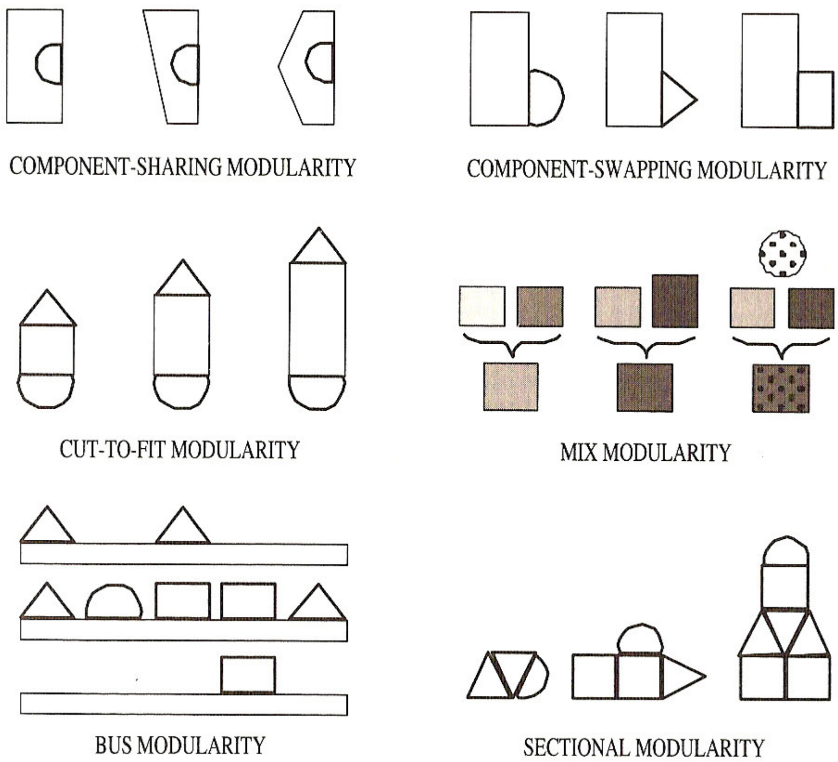

Figure 2.11: Six Types of Modularity for the Mass Customization of Products and Services (Pine 1993)

2.3.1.1. Component Sharing Modularity

In component-sharing modularity, the same component is used across multiple products to provide economies of scope. This form of modularity is the most important in putting the "mass" back into a proliferating product line whose costs are rising as fast as, if not faster than, the number of products. If company completely redesigned its power tool product lines-twice-to take advantage of component-sharing modularity, it can have greatly reduced costs while providing more variety and speedier product development.

This kind of modularity never results in true individual customization (except in combination with other types), but allows the low cost production of a great variety of products and services. Component-sharing modularity is best used to reduce the number of parts and thereby the costs of an existing product line that already has high variety.

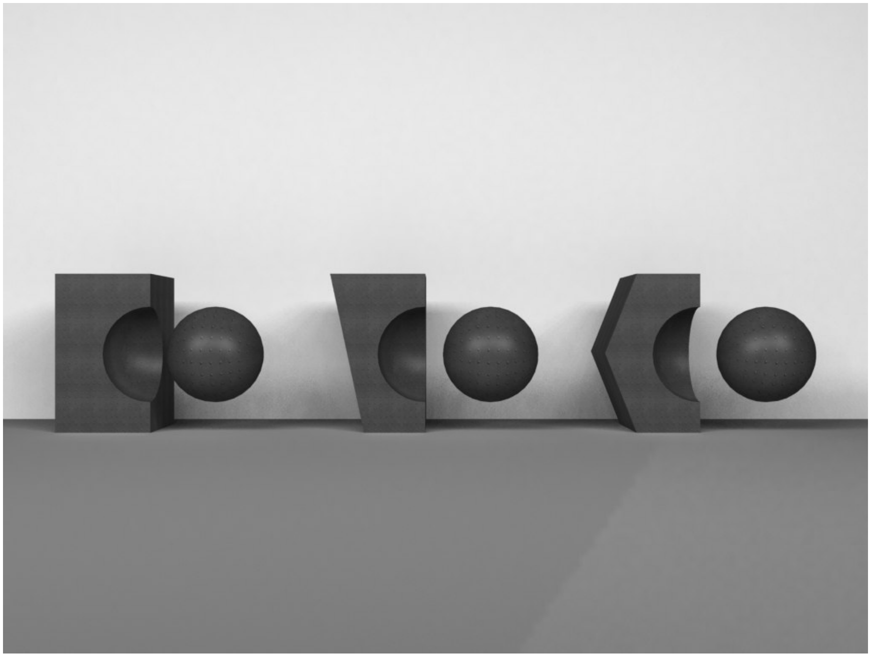

Figure 2.12. An illustration of Component Sharing Modularity (Pine 1993)

Once a product line has been redesigned, even greater variety can be created without any corresponding increase in costs. Heavy equipment maker Komatsu found its costs increasing with its product variety throughout the 1970s as it began exporting to different markets around the world. To lower its costs while remaining responsive to the varied wants and needs of local markets, Komatsu standardized a core module that could be shared across all of its major products and created a number of components that could be shared across the different product models created for different local markets. This then allowed the company to move easily into new markets and provide further local customization. (Davis and Davidson 1991)

2.3.1.2. Component-Swapping Modularity

This method is the complement of component-sharing modularity. Here, different components are paired with the same basic product, creating as many products as there are components to swap. In many cases, the distinction between component sharing and component swapping is a matter of degree. Consider Swatch watches: The basic watch elements a component shared across all the fashion products (component sharing) and the watch parts the basic product and the incredible variety of face styles the components (component swapping).

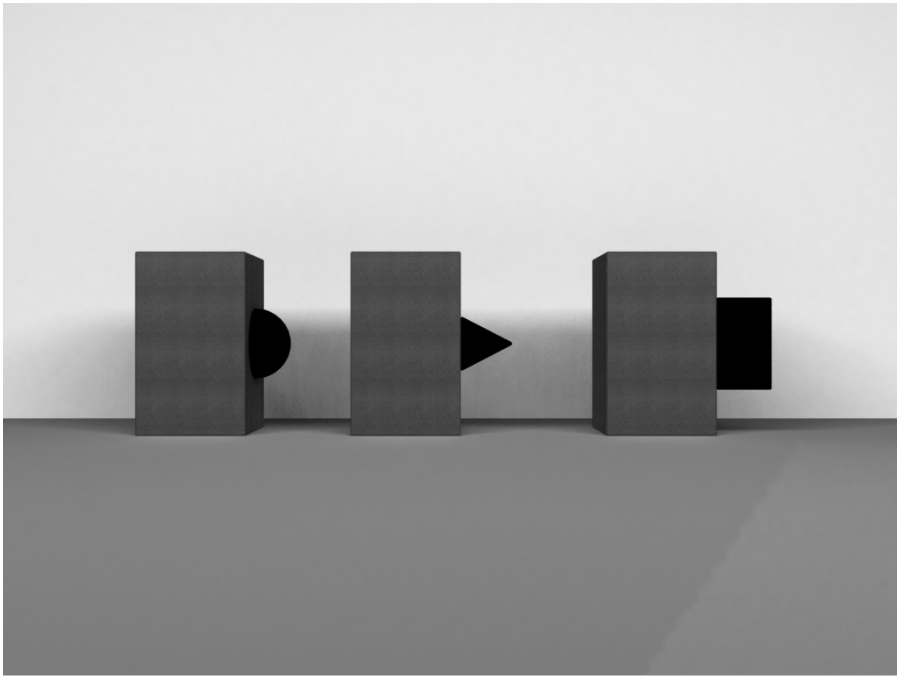

Figure 2.13. An illustration of Component-Swapping Modularity (Pine 1993)

A trivial case of component swapping is the form letter. Hyatt Legal Services performs sophisticated component swapping with standardized legal documents as the basic product and customizing services as the components. Create-A-Book, a line of children's books personalized to individual boys and girls, provides another, not dissimilar example. Over a dozen professionally written and illustrated generic titles provide the basic products for this company. The buyer of a particular book, usually a relative, is asked personal questions about the recipient (such as name, mother's name, place of birth, and so on), which provide the components to swap into the basic product.

A personal computer sprinkles the information appropriately throughout the text, and within fifteen minutes the pages of the book are printed on a laser printer and bound into a normal book cover. For a good price similar to that for quality titles available in retail stores, children receive their own customized book.

Customizing services around standardized products (or services), visited earlier, can also be thought of as component-swapping modularity. The standard set provides the basic product, and the customizing services are the components swapped in and attached to it. Most point-of-delivery customization is also component swapping. The basic product-for example, bowling ball, T-shirt, eyeglass frame-is produced centrally, while the customizing component-drilled holes, heat-applied transfer, lenses-is added locally. With photograph developing, shoe repair, dry cleaning, and other point -of-sale service examples, the standard service itself is the basic product, and customers supply their own components to be placed into that service.

For a company providing a standardized product or service today, the key to taking advantage of component-swapping modularity is to find the most customizable part of the product or service and separate it into a component that can easily be reintegrated. For greatest effectiveness, the separated component should have three characteristics:

(1) It should provide high value to the user;

(2) Once separated, it should be easily and seamlessly reintegrated; and

(3) It should have great variety to meet differing customer needs and wants. True individual customization comes when there are an infinite number of components to be swapped. Variety that customers are unlikely to run across anyone else with exactly the same product, like Swatch watches.

2.3.1.3. Cut to Fit Modularity

This technique is similar to the previous two types, except that in cut-to-fit modularity one or more of the components is continually variable within preset or practical limits. Custom Cut Technologies' process for mass-customizing suits clearly cuts to fit each of its components (jacket body, sleeves and so forth). Englert's gutter and metal-roofing machines cut the raw materials to the precise measure of a house. At self-service salad bars, consumers can choose the portion desired of each ingredient.

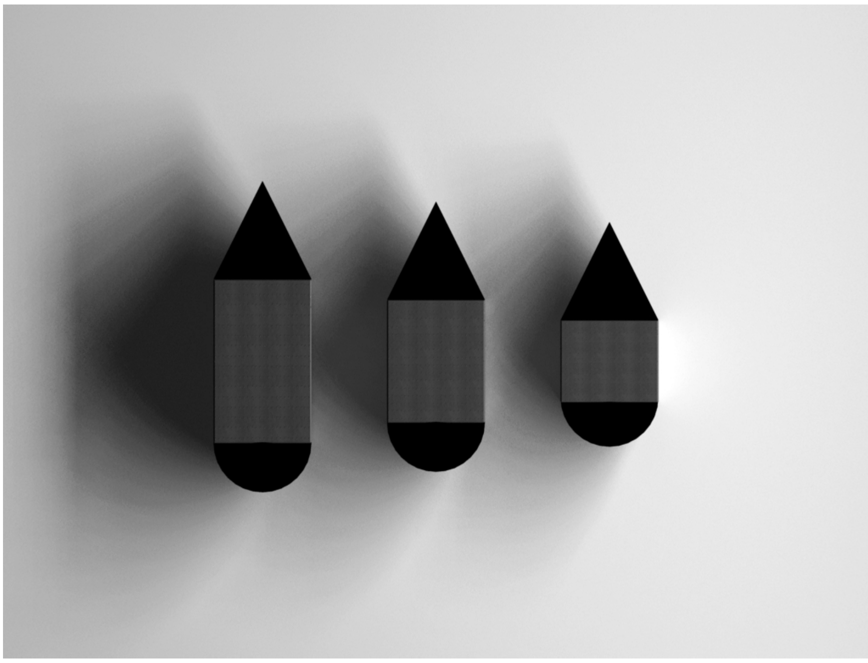

Figure 2.14. An illustration of Cut to Fit Modularity (Pine 1993)

The National Bicycle Industrial Co., a subsidiary of Matsushita in Japan, provides individually customized bicycles through cut-to-fit and component-sharing modularity combined. Its factory, as *Fortune relates*, "is ready to produce any of 11,231,862 variations on 18 models of racing, road, and mountain bikes in 199 color patterns and about as many sizes as there are people. (Daviss 1991) The process starts with shopkeeper who determines a customer's model, color, and design preferences, which define the sharable components to use, then precisely measures him or her on a special frame for the cut-to-fit components. All the specifications are faxed to the factory, where a computer creates custom blueprints for both craftsmen and robots. The latter measure and cut each piece of the frame to fit the individual's measurements, weld the pieces together, and apply the base coat of paint. The skilled workers perform most of the assembly work and all of the final touches, including silk-screening the customer's name on the frame.

Cut-to-fit modularity is most useful for products whose custom value rests greatly on a component that can be continually varied to match individual wants and needs. If the current product line has components that step up discontinuously in size-such as off-the-rack suits and standard bicycles in two of the examples above-then competitive advantage can be gained by mass customizing the products to fit individuals, eliminating the compromises customers must otherwise make. This is the case with a large number of products, including beds, office chairs, and automobile seats, in which particular advantage can be gained by an organization's ability to cater economically to hard-to-fit individuals at the extremes who generally must not only compromise but sacrifice comfort and/or style to accept standard sizes.

All clothing meets the above description; cut-to-fit modularity should be the next big program in the apparel industry once Quick Response is firmly rooted. Companies like Custom Cut Technologies that are already practicing it should gain a distinct competitive advantage if they execute it well.

2.3.1.4. Mix Modularity

This type of modularity can use any of the above types, with the clear distinction that the components are so mixed together that they themselves become something different. When particular color paint is mixed together, for example, those components are no longer visible in the end product. Fertilizer is another commodity mat has moved to mass customization. Today, fertilizer can be custom-blended for each hectare of a farm according to the type of soil, slope, amount of sun, and so forth. At least one manager in the business believes that companies will someday "customize the blend 'or each square meter, right as it is mixed into the earth." (Daviss 1991)

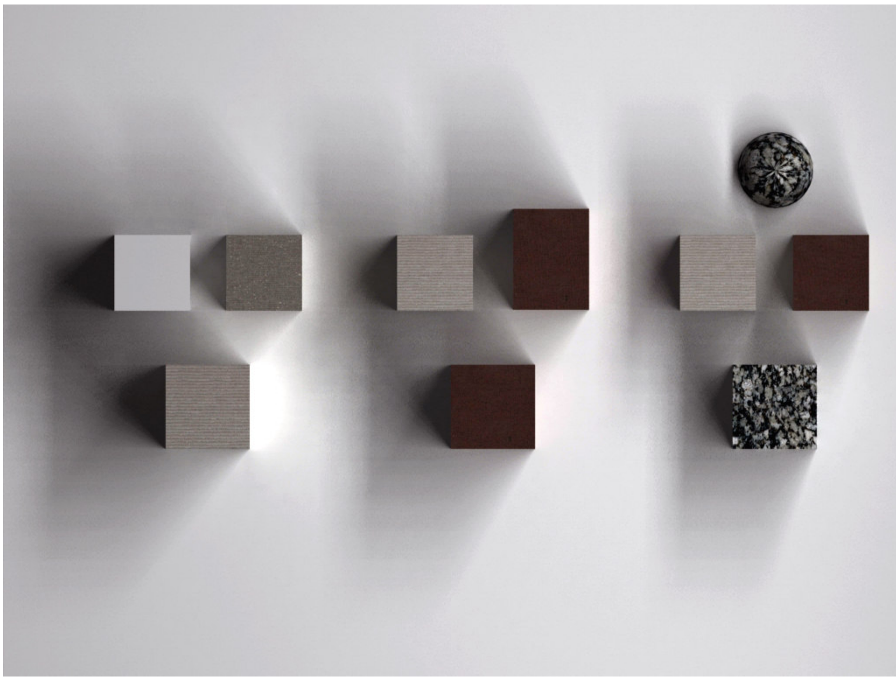

Figure 2.15: An illustration of Mix Modularity (Pine 1993)

Mexican restaurants create an incredible variety of meals by mixing relatively few components: tortillas, beans, various meats, and various sauces. Cereal companies are mixing the same basic components to proliferate the number of breakfast cereals. Campbell's Soup varies the recipes of their soups by region of the country to cater to local tastes.

In fact, the key factor in determining if you can take advantage of mix modularity is *recipe.* Anything with a recipe can be varied for different markets, different locales, and indeed for different individuals. To reach perfect customization requires that you move from processing your recipe according to a predetermined plan to a process-to order operation, and then economically reduce the batch size to one.

Actually, that last step has already been substantially invented for many consumer products: it's called the vending machine. People can already choose various options for a cup of coffee, which the vending machine mixes. Why can't customers choose how spicy they want their instant soup, how much cinnamon to put in their cereal, how much syrup they want in their Pepsi? If Pepsi were to create a vending machine that allowed customers to vary the amount of syrup, additional flavorings (e.g., cherry, lemon, chocolate), sweetener, and caffeine according to their individual tastes, likes, and dislikes-and then charge according to the amounts of each-it not only would achieve full mass customization but would probably have a big winner on its hands. It might even be possible to add bottling capability along with personal laser-printed labels in about the same space as all of Pepsi's varieties take up in a supermarket.

2.3.1.5. Bus Modularity

This type of modularity uses a standard structure that can attach a number of different kinds of components. The term comes from computers and other electronic equipment that use a bus, or backplane, that forms the primary pathway of information transfer between processing units, memory, disk drives, and other components that can plug into the bus. Track lighting, with different kinds of lights inserted anywhere in a track and automatically connected to an electrical circuit, is another common example.

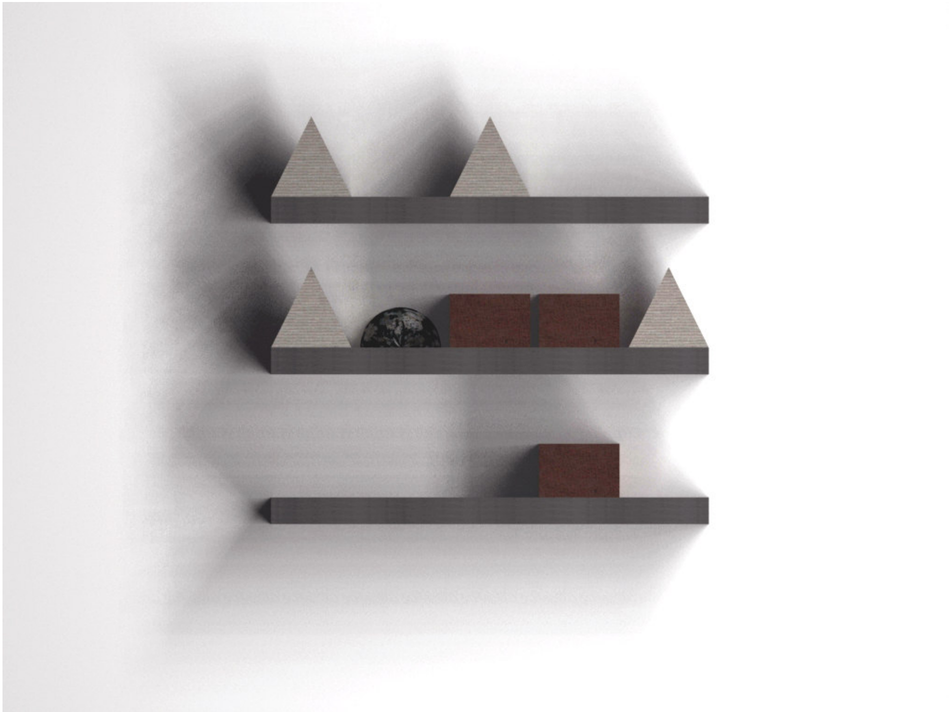

Figure 2.16. An illustration of Bus Modularity (Pine 1993)

According to me, once getting much beyond these obvious examples, bus modularity is the most difficult type to comprehend because the bus is usually hidden and often somewhat abstract. Personics uses bus modularity: the standardized length of tape is the bus, onto which are placed any number of different kinds of songs. In services, A Tp.L. Minitel, TWA Getaway Vacations, and CNN all use this type of modularity: the infrastructure of each service is the bus, defining what services can and cannot plug into each one, but allowing a broad number of individually customized transactions (at least potential. in the case of CNN). The key distinction of bus modularity is that a standardized structure allows variation in the type, number, and location of modules that can plug into it. (Pine 1993)

An example of bus modularity Pine gives in his book; the magazine *Farm Journal,* founded in 1877 to service farmers. In the Philadelphia area, provides an interesting illustration. It went national in the early 1900s, but farming became more specialized over the years, and the magazine began producing regional versions in 1952. Beginning around 1980, it went further by customizing its fourteen issues a year. Each subscriber is asked to fill out a questionnaire about his or her particular farm (including questions about the crops or livestock raised, number of acres devoted to each crop and size of herd, and so forth), which is entered into an on-line database. Each subscriber then receives an editorial core of about fifty pages along with individualized articles-and advertising-based on the information in the database. Each month hundreds of different *Farm Journals* are sent to 800,000 subscribers, and sometimes the number of customized versions runs well into the thousands. (Pine 1993; Hiromoto 1988)

The structure of the magazine and the process by which it is created provides the bus to which differing numbers of editorial pages, advertisements, and articles are attached for individual subscribers. The technology behind this capability is Selectronic Binding, a process developed by R. R. Donnelley & Sons of Chicago. Donnelley works with other magazines and catalogue makers, and has created similar technology for books, called Books on Demand McGraw-Hill uses this technology-along with software jointly written with Eastman Kodak Co. that uses bus modularity in electronically building and sequencing books chapter by chapter-to mass-customize textbooks for individual college classes. (Pine 1993; Worthy 1991)

The key to using bus modularity is of course the existence of a bus. If your product or service has a definite standard but changeable structure, think about breaking it up by, first, defining the product architecture or service infrastructure that is *really* required for each customer, and second, modularizing everything else into the components that can be plugged into that standard structure.

The automobile could take advantage of bus modularity. The basic platform chassis and wiring harness that connects all of the electronics can provide the bus structure; *everything else* can plug into it. GM's Pontiac Fiero, with a modularized body and other components, has come closest to this concept in actual production, and Chrysler has proposed a production concept consisting of twenty-eight modules. Ford has also done work in this area. Nissan, however, appears to be the company that wants to first mass-customize individual automobiles. Its vision for car manufacture is "the five A's"-Any volume, anytime, anybody, anywhere, and anything. Nissan is working toward this vision through a joint university industry research program in Japan known as Manufacturing twenty first Participants in this program foresee full mass customization of automobiles in the first year of the twenty-first century utilizing not only all the different types of modularity discussed so far (bus, Cut-to-fit, component-swapping, and component-sharing), but also time compression, point-of-sale manufacturing, customizability, and every other technique discussed. An extended quote from a translation of the research report illuminates the breadth of Nissan's vision:

The most important objective is to create a system to produce low-volume, special-niche vehicles at reasonable cost. The great numbers of such models make it obvious that very fast, inexpensive new model development is necessary. Reducing the time and cost of new model development and start-up is the number one priority of the Japanese auto industry heading into the 1990s.

Many assembly ideas have been considered. All of the most promising ones assume final assembly of cars from large modules with each module being sub assembled on a short line.

Cars would have to be designed with structural modules that can be sub assembled in different locations, then brought together for final assembly of the structure, followed by attachment of the body panels. The external shape of the completed body is thereby partly independent of the form of the structural framework. If the design could ingeniously allow for dimensional variations, final assembly might even be done at the dealership.

Many features of the car can be custom-designed, depending on how much the customer wants to pay, of course. The seat contour can be fitted to the customer, the car's lighting system designed as the customer likes, the instrument panel layout modified to suit personal preferences-again with safety checks. Within limits, prosumers can create the shape of body panels, design their own trim, and "imaginer" sound systems to their own tastes. The electronic possibilities may be particularly bountiful. (Pine 1993)

In ten years, some of the features may be commonly modified on the run. For example, the stiffness of suspension can be adjusted while the car is in operation. To producers, the car company will sell the service of creating and maintaining modular-structure cars.

There are few products more complex than automobiles, and few processes more complex than automobile manufacture. If automobiles can be mass-customized using bus modularity and all the other techniques-and there is little doubt they will be-most any product or service can also be mass-customized.

2.3.1.6. Sectional Modularity

The final type of modularity provides the greatest degree of variety and customization. Sectional modularity allows the configuration of any number of different types of components in arbitrary ways-as long as each component is connected to another at standard interfaces. The classic example is Lego building blocks with their locking cylinder interfaces. The number of objects that can be built with Lego's is limited only by the imagination. (See Figure 2.17.)

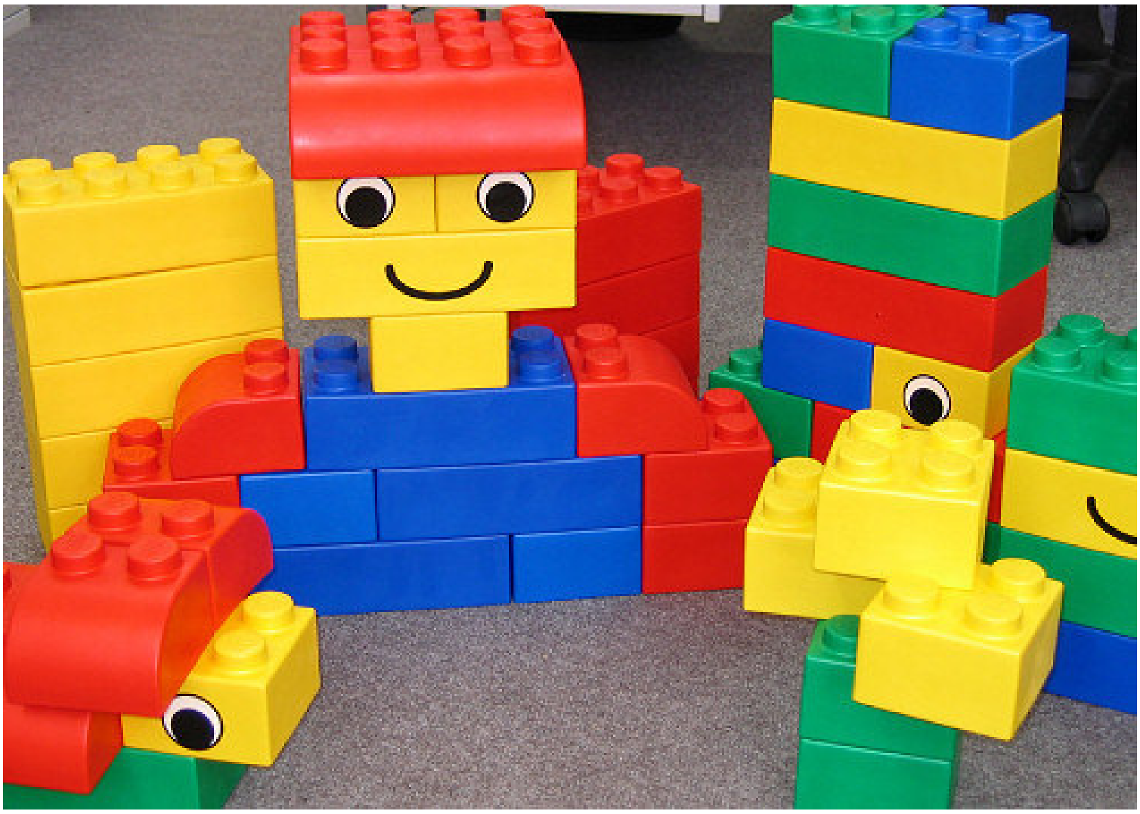

Figure 2.17. An example of Sectional Modularity, Lego (http://www.carmarthenshirechildrenspartnership.org.uk)

With sectional modularity, the structure or architecture of the product itself can change, providing tremendous possibilities for variety and customization. Bally Engineered Structures once again provides a robust example; its modular panels are essentially highly sophisticated Lego blocks that can be interlocked to produce anything from a flower cooler to an eight-story refrigerated warehouse. Dow Jones News/Retrieval and most of the other customized information providers use sectional modularity. The individual information elements are components that can be organized in any order to create mass-customized newspapers, research reports, and so on.

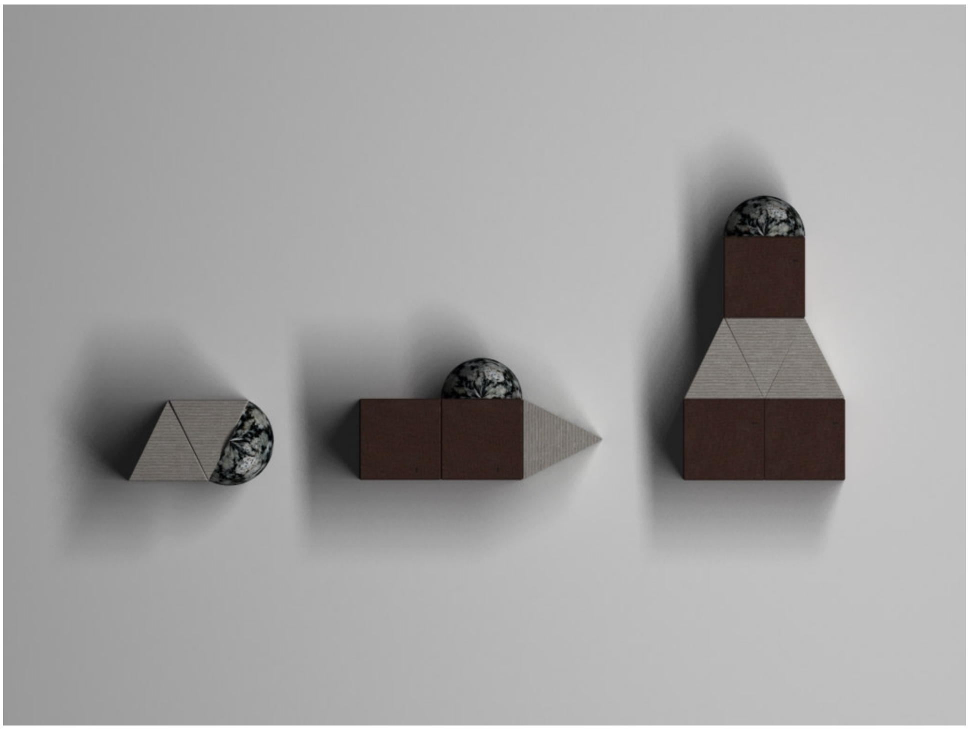

Figure 2.18. An illustration of Sectional Modularity. (Pine 1993)

Agfa Corporation of Wilmington, Massachusetts, has taken the mass customization of books, magazines, and other documents a step further with its Shared Document Management System (SDMS). This product goes far beyond the ability to select and organize articles or chapters into predefined formats. With SDMS, "document objects" can be any size and any type of information (text, tables, formulas, graphics, images, and eventually multimedia audio and video) that can be put together in any way desired by the user.

Agfa uses a relatively new technology in the computer industry known as object-oriented architecture. This technology has the potential for revolutionizing software development-moving it from its traditional Craft Production orientation directly into the new frontier of Mass Customization-through the concept of reuse. In object oriented systems, a piece of program code is a highly modular object, with the interfaces between modules simply and completely defined by the object type. Objects can be reused any number of times in any number of different programs, creating sectional modularity that allows the quick development of radically different applications. In practice, object-oriented technology has not progressed to the point where full applications can be developed completely from modules without creating any new code from scratch.

Many Japanese software organizations have taken a different route, following the trail of Japanese automakers by moving from Craft to Mass Production in the 1970s and 1980s and more recently to Mass Customization. Hitachi, Toshiba, NEC, Fujitsu, and other Japanese companies have created flexible production systems, known as software factories, where programmers focus on a particular kind of product and are provided with a strong tool structure to, among other things, reuse significant portions of program code through sectional modularity. According to Michael Cusumano of MIT, the Japanese are at the stage in software where they were in automobiles in the 1960s: their quality and productivity are much higher than that of the United States, their basic flexible production system is in place, but they have yet to generate the level of innovation and creativity to compete effectively with American companies.

Sectional modularity is the most robust of the six types, but it is also the most difficult to achieve. The key is to develop an interface that allows sections or objects of different types to interlock. Few products can have mechanisms as simple as Lego's, but the interfaces can be developed over time, usually by building upon those defined for component sharing and component swapping while modularizing more function into smaller components.

It may be much easier to provide sectional modularity in services. James Brian Quinn and Penny Paquette of Dartmouth, who have studied the use of technology in service industries extensively, have come to the following conclusion:

Contrary to much popular dogma, well-managed service technologies can simultaneously deliver both *lowest cost outputs* and *maximum personalization and customization* for customers. In accomplishing this, enterprises generally obtain strategic advantage not through traditional economies of scale, but through *focusing on the smallest activity or cost units* that can be efficiently measured and replicated-and then *cloning and mixing these units* across as wide a geographical and applications range as possible.

In other words, many service companies achieve mass customization through the creation of low-level sectional modules-the authors call these components micro-units-that can be mixed "in a variety of combinations to match localized or individual customer needs." For example, American Express captures as micro-units each and every transaction-whether retail, lodging, entertainment, transportation, and so on-that its customers make with both its credit card and travel agency businesses, and then mixes and matches the customer patterns and company capabilities to add value for them. According to Quinn and Paquette: (American Express] can identify lifestyle changes (like marriage or moving) or match forthcoming travel plans with its customers' specific buying habits to notify them of special promotions, product offerings, or services AmEx's retailers may be presenting in their local or planned travel areas. From its larger information base AmEx can also provide more detailed information services to its two million retailers customers-like demographic and comparative analyses of their customer bases or individual customers' needs for wheelchair, pickup, or other convenience services. These can provide unique value for both consumer and retailer customers.

The key to micro-management is breaking down both operations and markets into such detail that-by properly cross-matrixing the data-one can discern how a very slight change in one arena may affect some aspect at the other. The ability to micro-manage, target, and customize operations in this fashion, because of the knowledge base that size permits, is becoming one of the most important uses of scale in services.

One of the interesting but little-used facets of sectional and, to a lesser extent, bus modularity is that products can become reconfigurable. Lego's, of course, can be rapidly reconfigured into something completely different. Agfa's Shared Document Management System allows any document to be reconfigured by "sliding" in and out different modules; from whole chapters to sentence fragments (although at least an entire page would have to be reproduced). Upgradeability and reconfigurability have long been provided by mainframe and minicomputer providers through bus modularity; it is now becoming important to personal computer owners and in 1991, manufacturers began responding with bus modularity that makes it unnecessary for owners to throw away a model to gain significant enhancements and Nissan has explored the concept of "the evolving car" that owners could bring in for the latest innovations or styling every few years.

In both products and services, the ability to mass-customize through sectional modularity provides the most robust capabilities for mass customization.

CHAPTER 3

CUSTOMIZATION AT MODULAR SYSTEMS

3.1. Definition of Customization

It is obvious that people are different and everyone has different characteristics, so that they have choices differing from each other. Different preferences need different products. No one would like to decide what to buy under the control of someone. In poor times we did not have a choice, but in a wealthy economy like in these days the customer is the one with power. The customer guides the designers and the companies about the products to be produced.

Mass Customization has arisen and it is also called 'The New Frontier in Business Competition', because this was the new way to produce: In the new frontier, a wealth of variety and customization is available to consumers and businesses through the flexibility and responsiveness of companies practicing this new system of management. (Pine 1993)

Simply stated, mass customization is about choice. It is about giving customers a unique end product when, where and how they want it. Mass customization enables manufacturers to customize products quickly at a cost, efficiency and speed close to those of mass production. The core of mass customization is the ability to increase product variety and customization without corresponding increases in costs. This increase in product variety and customization is made possible through flexibility and quick responsiveness. However, there is another important thing that designers and companies have to give importance: Mass Customization should be affordable. Mass Customization is not only meant for the rich, it is meant for a great public that has a growing desire for product personalization.

A delivery process through which mass-market goods and services are individualized to satisfy a very specific customer needs at an affordable price. Mass Customization has arisen from two directions:

1. The demand for customization in the market. Customers want choices and are not content with mass products any more.

2. New insights and concepts in production and logistics, which make wider product differentiation possible, without extra costs, and in many cases even cheaper.

Mass customization makes it possible to manufacture products as per customer's desire or specifications, as opposed to producing a generic product to be placed in an inventory in hopes that some customer will later purchase it. The mass production cost curve and the mass customized production cost curve is in Figure 3.1. It is observed that the difference of these curves from the curve that depicts the price that customers are willing to pay is significant. Mass production has an economic advantage over high volume production rather than in low volume production.

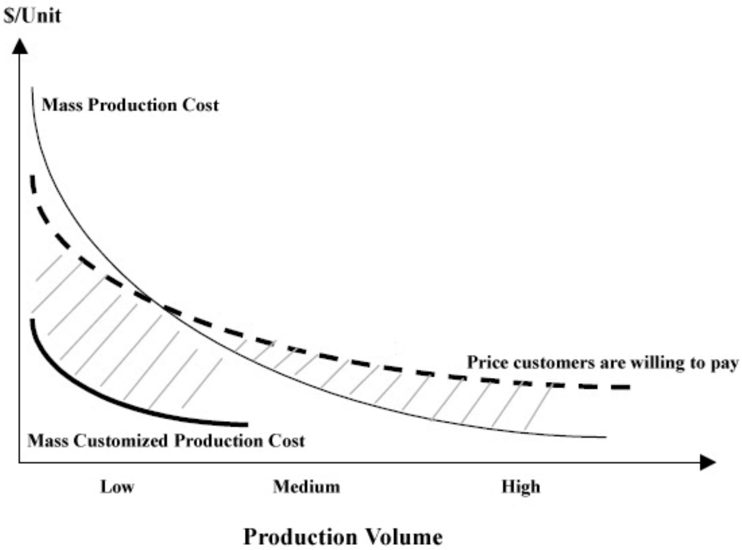

Figure 3.1. The Economic Implications of Mass Customization (Tseng et al., 1998).

However, the profits obtained by these products are relatively less than the profits obtained by using mass customized production. Thus, the capability to satisfy individual customer needs can translate into higher profit margins. This is the key advantage of pursuing mass customization, which enables manufacturing enterprises to satisfy their customers' demand for variety and at the same time minimize costs.

Mass customization was born by the *convergence of need and capability*. Markets are becoming highly volatile because of changing customer needs, technological advances, and diminishing product life cycles.

Today, most companies are looking for different business strategies to redefine themselves in this changing environment. In order to have a competitive edge and survive in a global economy where customer diversity is extreme, companies have to provide “personalized” products for individual customers. Successful enterprises are those who can use these new capabilities to satisfy these new needs. All these factors are expected to be even more influential in the future.

Tomorrow, enterprises in all branches of industry would be forced to react to the growing individualization of demand, yet, at the same time, increasing competitive pressure would dictate that costs must also continue to decrease. These reasons have made it more necessary for companies to embrace mass customization. It makes it possible to customize products quickly for individual customers or for niche markets at better than mass production efficiency and speed.

Due to better practices being used for mass customization, it has indirectly helped to reduce the cost of inventory, obsolescence, discounting, distribution, setup, equipment utilization, floor space, and material overhead, and information systems. At the same time, the ability to give the customers what they want, when they want it enables the manufacturer to charge premium prices and thus earn more profits.

3.1.1. Evolution of Mass Customization

“Mass Customization” was anticipated in 1970 by Alvin Toffler in “Future Shock” and delineated (as well as named) in 1987 by Stan Davis in “Future Perfect”. “Mass Customization” is a new way of viewing business competition, one that makes the identification and the fulfillment of the wants and needs of individual customers paramount without sacrificing efficiency, effectiveness and low costs. (Pine 1993)

The “American System” of mass production that superseded the craft mentality of European production was successful because of the innovative management ideas that were applied to producing standard products with a high degree of conformance to specifications.

Rather than emphasizing the technical achievements that where necessary to make mass production a reality, Pine argues that the conceptual foundations of the system of mass production, conceived by Henry Ford and his contemporaries and continually improved in the years that followed by managers and workers alike, formed the basis for the economic success of America. The markets that supported this model of production were large and homogeneous; they demanded standard products that could be delivered at low cost. That the Ford Model “T” (see Figure 3.2) was always black was less important to buyers than the success with which mass production techniques systematically reduced the unit price of these automobiles during a time when the relative wealth of individuals was rising.

Figure 3.2. Ford T.
(Source: http://www.ford.com)

Many of the ideas that form the basis of manufacturing strategy in America developed within the context of this industrial renaissance. Abernathy and Utterback (1978) outlined a model of innovation in products and processes. Their model predicted a high degree of product design innovation in the earliest stages of new product introduction. It was during this period that the firm tweaked the features of the product to meet the preferences of a test market.

Manufacturing used general purpose equipment, at a relatively high cost per unit, to produce the small volumes required during this introduction phase. As the life cycle of the product advanced, product innovation declined dramatically, and the focus of innovation was in the production process that was now engineered with special purpose machines and methods to produce countless identical units at a very low unit cost. After the process stabilized, innovation in product and process was predicted to be very low, with improved efficiency and resulting lower unit cost the sole incentive for innovation. Successful and profitable products had long life cycles that justified the development of machine tools and mechanized facilities dedicated to producing them.

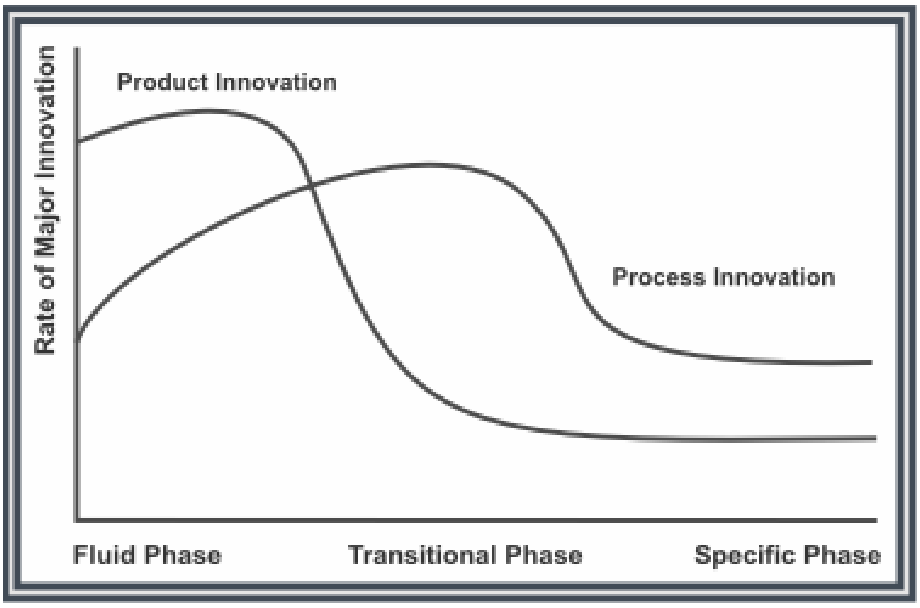

Figure 3.3. Abernathy and Utterback Product Model, 1978.

In a review of Joseph Pine's article by David P. Christy, it was assumed that the way to win orders in the marketplace was to produce products at low cost—products that met the requirements of large markets and that could be mass-produced by lean and efficient production technologies. According to him, the consequences of the mass-production approach are now legendary. To continue to succeed employing this strategy, lower and lower costs must be pursued constantly and the life cycle of products must be extended. This logic leads to a penchant for efficiency in domestic manufacturing plants and a push toward producing offshore in low wage locations. Rather than constantly refining the product to the changing tastes of market niches, mass-production prescribes the reduction of variety and resists customization.

As a result, the evolution of mass customization under the construction of mass production can be focused with the terms beneath:

- Middle Ages – Craft Production
- Master Craftsmen and Apprentices
- One off products, high labor content, expensive
- 18th Century – Industrial Revolution

- Movement of people off land to towns and cities
- Sub-division of work ➔ loss of traditional skills
- United States – Industrial Development started later, from mid-19th Century
- Industrial workers had greater skills
- More use of these skills in U.S. factories
- Greater innovation – Colt weapons company developed standardized parts to assist battlefield repairs
- Development of mass production in early 20th Century ➔ U.S. becomes global power

Mass Production to Mass Customization

- 1970's – Slowing Economy – Rising Oil Prices
- Need for alternative approach
- 1970's-1980's – Increasing competition within U.S. market from outside countries, esp. Japan
- Late 80's-early 90's: Literature proposing MC
- Development of internet (esp. product configuration systems) in mid-1990's opens door to widespread use of Mass Customization

Significant Literature

- 1970 – Alvin Toffler: 'Future Shock'
- "Consumers and producers working together" = "Prosumers"
- 1987 – Stan Davis: 'Future Perfect'
- First use of the term 'Mass Customization'
- 1991 – B. Joseph Pine: Mass Customization – The New Frontier in Business Competition
- First detailed description of mass customization concept – replace economies of scale with 'Economies of Scope'.

3.2. Types of Mass Customization

The definition of mass customization implies that the goal is to detect customers' needs first and then to fulfill these needs with efficiency that almost equals that of mass production. Often the definition is supplemented by the requirement that the individualized goods do not carry the price premiums connected traditionally with (craft) customization. However, mass customization practice shows that consumers are frequently willing to pay a price premium for customization to reflect the added value of customer satisfaction due to individualized solutions, i.e. the increment of utility customers gain from a product that better fits to their needs than the best standard product attainable. We consider the value of a solution for the individual customer as the defining element of mass customization. A customer centric enterprise recognizes that customers have alternatives of choice which are reflected through their purchase decisions: Customers can either choose mass customized goods which provide better fit, compromise and buy a standard product of lesser fit (and price), or purchase a truly customized product with excess features but also at a higher price. Thus, value reflects the price customers are willing to pay for the increase in satisfaction resulting from the better fit of a (customized) solution for their requirements. Mass customization is only applicable to those products for which the value of customization, to the extent that customers are willing to pay for it, exceeds the cost of customizing.

The competitive advantage of mass customization is based on combining the efficiency of mass production with the differentiation possibilities of customization. Mass customization is performed on four levels. While the *differentiation level* of mass customization is based on the additional utility customers gain from a product or service that corresponds better to their needs, the *cost level* demands that this can be done at total costs that will not lead to such a price increase that the customization process implies a switch of market segments. The information collected in the course of individualization serves to build up a lasting individual relationship with each customer and, thus, to increase customer loyalty (*relationship level*). While the first three levels have a customer centric perspective, a fourth level takes an internal view and relates to the fulfillment system of a mass customizing company: Mass customization operations are performed in a fixed *solution space* that represents. Correspondingly, a successful mass customization system is characterized by *stable* but still flexible and responsive processes that provide a dynamic flow of products. While a traditional (craft) customizer re-invents not only its products but also its processes for each individual customer, a mass customizer uses stable processes to deliver high variety goods. A main enabler of *stable processes* is to modularize goods and services. This provides the capability to efficiently deliver individual modules of customer value within the structure of the modular architecture. Setting the solution space becomes one of the foremost competitive challenges of a mass customization company, as this space determines what universe of benefits an offer is intended to provide to customers, and then within that universe what specific permutations of functionality can be provided.(See Figure 3.4.)

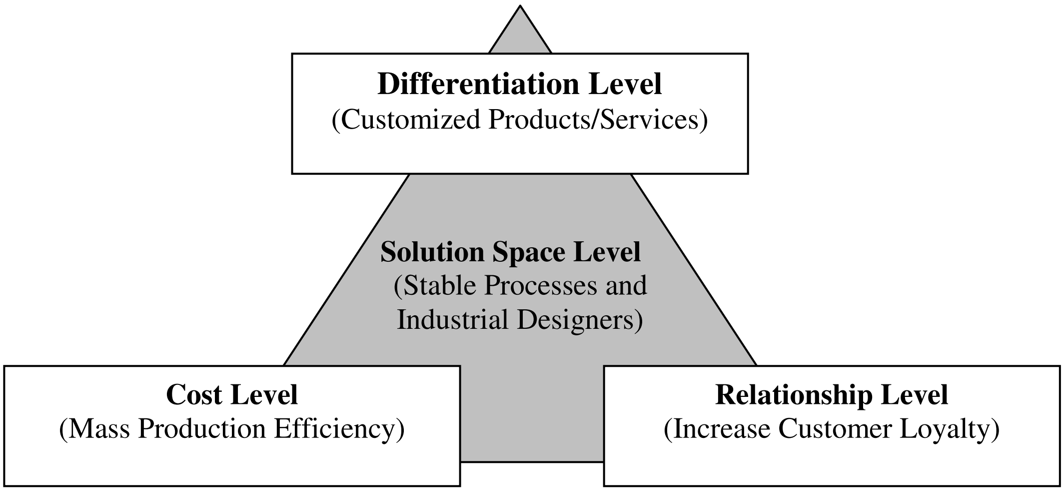

Figure 3.4. The Four Levels of Mass Customization.
(Source: http://www.madeforone.com)

Besides the levels of customization, Design techniques and mass production also bring to customers four different types of customization. First collaborative customization is when the business and customer have joint control over the design tool. It's generally better than cosmetic collaboration. Then there's transparent customization, where the service provider customizes the product for you but doesn't tell you what it's doing. It observes your behavior and then gives you what you want, as in a top hotel. Finally, there's adaptive customization, in which the customer controls the design tool or the tool is imbedded into the product itself.

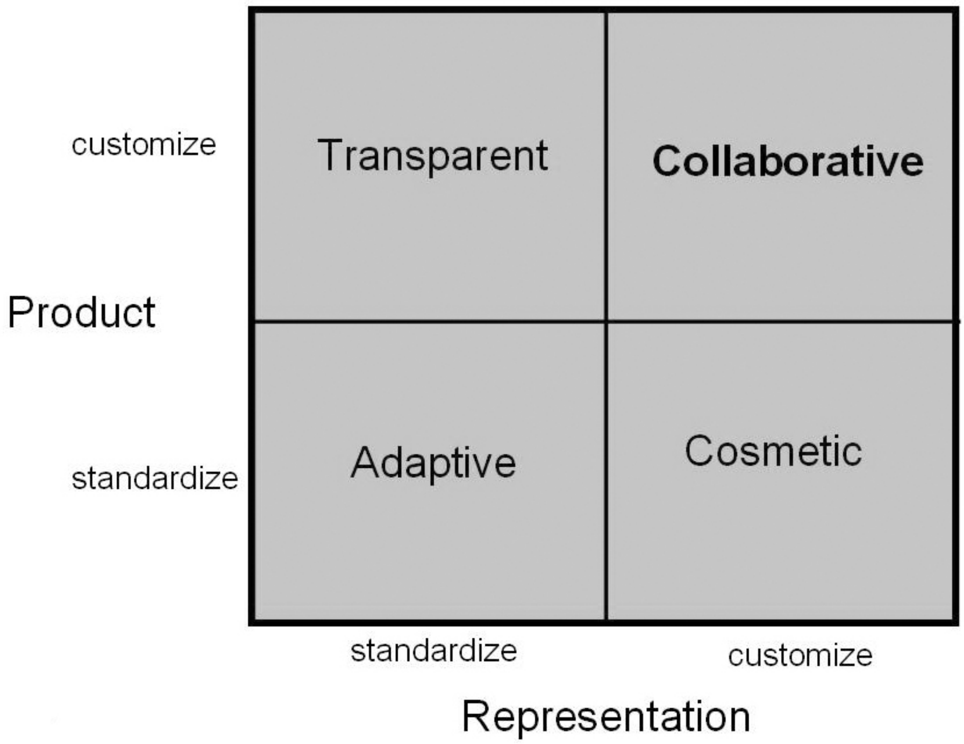

Figure 3.5. Types of Mass Customization (Pine 1993).

3.2.1. Collaborative Customization

A collaborative approach is most often associated with mass customization. This approach is an interaction with individual customers to help them articulate their needs. This direct communication with the customers allows companies to identify the exact offering that satisfies those needs and to make a customized product for them. The most significant catalyst for this approach is the customer's inability to make decisions on multidimensional trade-offs that exist when purchasing a mass-produced product. Business conditions, where this problem is present, are eyeglasses, shoes and clothing apparel industries. Collaborative customization allows the customer to exchange ideas with a company representative as early as the design stage and alternate the numerous possibilities available to them until a choice can be made. The benefit to the company in business conditions such as these allows them to minimize cost by having tight controls on inventory while providing super customer service.

Most challenging, difficult and also expensive way to mass customize is based on using customer interaction in specifying product or service features. This cooperative model is needed when it is difficult for customer to express product preferences or when product is attached with complicated specifications, which in whole forms the end product. In this case even the seller can't know what customer eventually wants.

The most important feature of collaborative customization is consumer and producers engage in a dialogue to determine customer requirements. Computer industries, clothing and footwear, furniture and some services can be good examples of collaborative customization. (See Figure 3.6)

Figure 3.6: An example of Collaborative Customization.
(Source: http://www.asymptote.net/downloads/fullscreen_images/a3.pdf)

Collaborative customization crates some disadvantages to the companies. As an effect of customer orientation is, that head buying customer can demand information about, for example, products assembly order from production line whenever he wants. This affects to loads and production programs.

Product articles are quite unique. There are problems in product coding, because code can change if color changes. In a big company coding is in key position. That can be cause more expenses to the companies.

Focus of the knowledge in this kind of mass customization is in issues concerning products and their components, different materials, and also abilities to flexible, dynamic, and "nimble" reflections according to the new kind of needs of the customer.

Particularly in this type of mass customization two separate customer classes must be differentiated: final end-customers and the head buying company as a customer within the supply chain.

Within the supply chain the transparency through the whole chain must be emphasized, and issues like open and standard interfaces between the partners' systems become extremely important. In developed and deep partnership also the customer is one essential partner of the supply chain. However, there are many obstacles for integration. Firstly, there are different kinds of information systems in different parts of supply chain. They can differ from each other both by type and lifetime. Secondly, longest supply chains can range from small machine shops to a global machinery manufacturer, which increases the inner variety of the supply chain. Thirdly, at the end of the chain there is not always a small company. Even the procurement of critical components can in a small company be done from a major company with international operations. Inside of this kind of a chain – or more correctly a supply chain network – should be very clear description of product data, which is adopted and used in all parts of supply chain. Also a description of division of work inside value chain processes is needed.

Today, supply chains are based on very broad forecasting abilities while changes in order and delivery volumes cause additional expenses. By using modern planning systems it is possible to create true-like virtual items, which are not possible to produce in real world for example due to the properties of the materials. For example, head buying customer's planners hadn't noticed anything strange in their manufacturing plans, because only the subcontractors has that kind of knowledge on materials, and only their skilled workers having long experience on materials were able to notice the plans to be useless.

3.2.2. Cosmetic Customization

Cosmetic customization is exactly as it sounds. This approach is proposed for companies that already have products that are well liked by almost all customers and only the product's form or appearance needs must be customized. It is intended for companies to do the little extra to instill value in the way a product or service is presented to the customer. Gilmore and Pine give the example of Hertz Corporation #1 Gold Program. This program allows customers to by pass lines, be taken directly to their car, which is under an identified canopy with their name above it. (Pine, 1993) When this type of customization is performed well, it replaces the inefficient responses to customers' requests with a cost-effective capability to offer every customer the exact form of the standard product he or she wants.

It can be described as the presentation of a standardized product differently to different consumers. The usage of the products is similar; the only aspect that differs is how the product is presented to them. Here the focus is at the end or near the end of the value chain.

Cosmetic mass customized product is unique in appearance only, the way its use is all the same. Some examples of cosmetic customization are like; customer's chosen text or image on T-shirts, mouse mats, baseball caps, mugs etc. (See Figure 3.7 and 3.8)

Figure 3.7: Customer's Chosen cap and sweatshirt.

(Source: http://www.customink.com)

Figure 3.8: Customer's own signature is used as an image on the mug.

(Source: http://www.customink.com.)

Cosmetic mass customization can be defined genuinely imposing way to tailor the same base product or service for different customer groups, despite the name. In the end of the production process the color, accessories, and other customer's personality or product's intended use related improvements can be taken into notice. This way of customization can be successfully put into practice in such businesses, where customer is satisfied to customization of final stage of core process and it is not needed to intervene to actual core solutions.

Companies manufacturing appliances, machinery or other goods meant for long-term use had many ideas about intelligence of appliances. In these product areas ability to record usage information, make fault-analysis and control over quantity and quality of production can be significant competitive advantage for manufacturing industries in the future.

However, in some interviews very ambitious projects were discussed. Projects where traditionally manufactured product had a computer installed inside with capabilities to store, process and communicate data and information. This way information technology opens new doors for not only to make product's utilization possibilities more diversified, but also to manage customer relations and control the supply chain.

3.2.3. Transparent Customization

In manufacturing the development has lead to a position where importance of services as a part of business grows. Product and production oriented companies have to acquire knowledge of services production or at least search for partners who has service competencies in their industry. Hence, e-Business provides one way to offer some opportunities in traditional after-sales functions. E-Business is not just one technical loop of order-delivery-invoice –chain, but also a new form of producing services.

Third way to put mass customization in practice is based on idea that customers are not bothered with feature definitions and different inquiries. The idea of customization is based on collecting and analyzing customer knowledge through enterprise resource planning systems and from different service channels. Collecting and storing customer preferences extensively can yield growth of expertise on customer needs which can be realized in next customer service situations.

When using transparent customization, producer provides customized product without consumer being necessarily being aware that it has been customized can be used when consumer’s needs are predictable or can be easily deduced, and when customers do not want their requirements repeated. For example, repeat orders for customized clothing, e-commerce like amazon.com chemicals etc.(see Figure 3.)

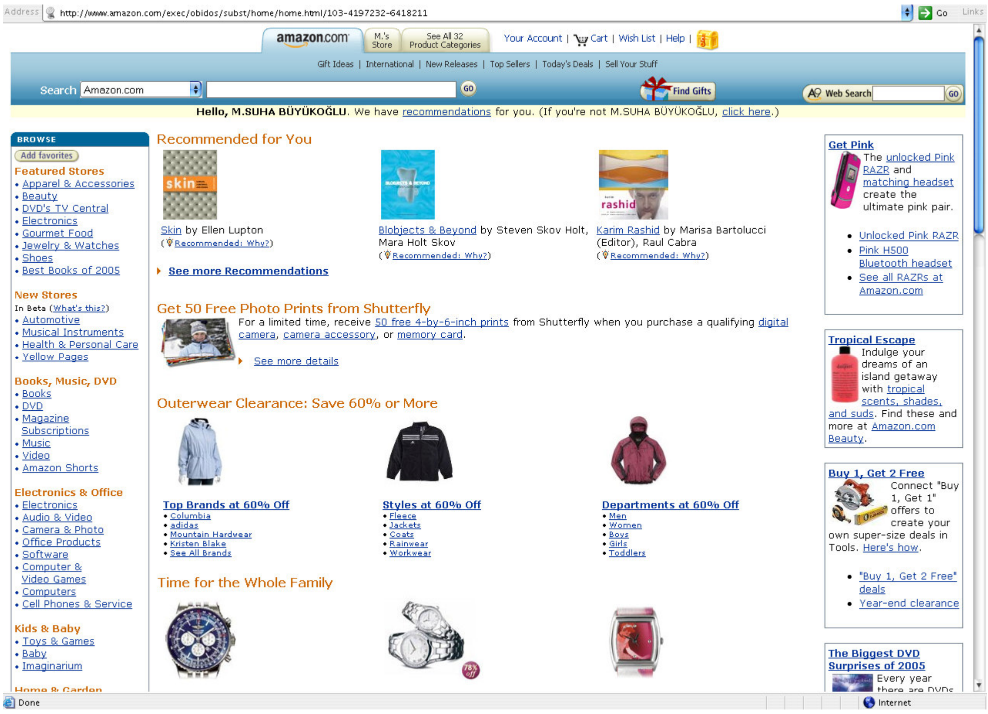

Figure 3. 9. E-commerce site recommends different products to customer.

(Source: http//:www.amazon.com)

Many of the companies were in the situation where company had many long lasting, successful customer relations. Capital goods these customers had acquired formed a kind of bridgehead for company. As the customer relations evolve, customers need to be taken into account better. For example, in manufacturing business it means MRO services (spare part, maintenance and usability) and auxiliary activities related to monitoring and extending product lifecycles. Many companies have prepared to build service and maintenance connections to machines and systems, which they already have delivered to all over the world, for example by using mobile communication technology.

In this type of mass customization is knowledge on customers, after-sale processes, abilities to monitor systems or products already delivered, and other that kind of activities enabling to extend the lifecycle of the product. In this analysis it is possible to use relational or object-based databases or newer data warehouse systems, data mining and creation techniques, which are able to identify previously undetected customer behavior models.

3.2.4. Adaptive Customization

Offering a standard product which customers can alter themselves in order to customize the product to their needs.

In adaptive customization, the company gives the customer a standard offering with many options. e.g. Pizzas, Vending Machines. Product is designed so that users can alter it themselves to fit unique requirements on different occasions For example, customers customize their Web access according to their individual needs. High-end office chairs, and certain electronic devices. A familiar example is a car, in which the seat, steering wheel, mirrors are adjustable and in some cases today, programmable.

Figure 3.10. Coffee Vending Machine

(Source: http://www.e-vending.com/coffee_ vending_machines.htm.)

Adaptive mass customization is based on forward planning and representations of almost all possible combinations of product modules. For example a designing system can be offered to help designing in cooperation with customer features of a machine or for example constructing different lighting alternatives (product configuration tools). Product or service itself or its representation doesn't change that much because inside the product families different alternatives can be varied.

Currently, most of the mass customization in the footwear industry is in the aesthetic domain, and shoe sizing based on only foot length and width are used. This method may require several fitting trials before the preferred fit for foot and shoe can be achieved. For groups that are unable to give their subjective opinions (for example, subjects who have no sensation in their feet and children who cannot express the degree of fit), a fitting trial is somewhat meaningless. With the proliferation of e-commerce, footwear purchase through internet can be greatly enhanced if a fit metric is present. Thus it is vital that the proper "clearance" between the foot and shoe be present for the foot to function as needed. An example of a customized e-commerce is below. (See Figure 3.11)

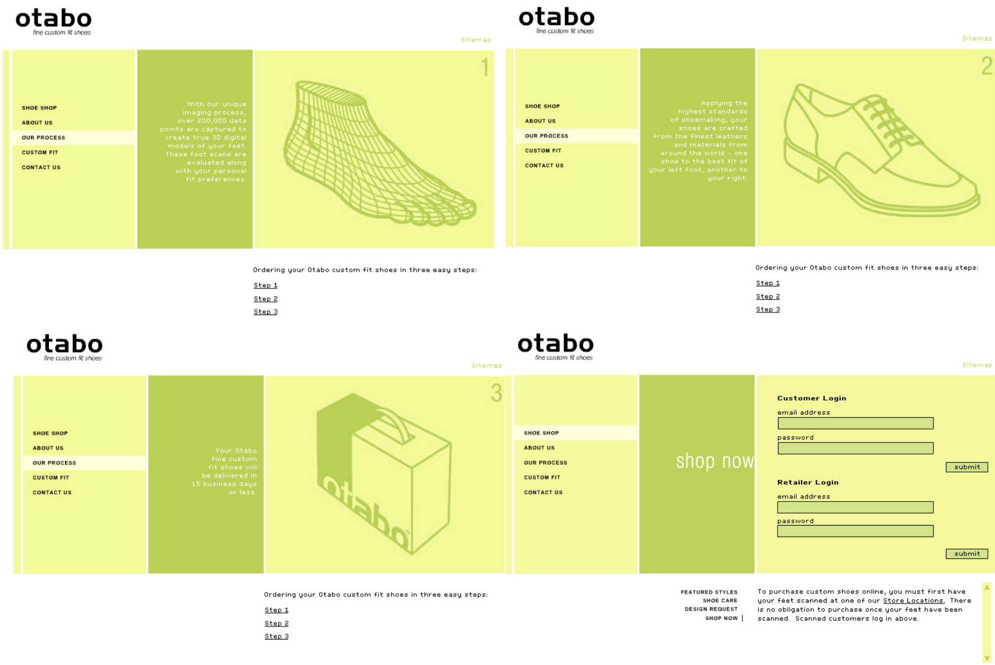

Figure 3.11. Customized e-commerce example of a shoe company.

(Source: http://www.otabo.com)

3.3. Advances of Mass Customization

The challenges involved with designing a product and its manufacturing process for customization are inherent in the differences between mass production and mass customization. These differences are detailed in Table 3.1.

Table 3.1. The Differences between Mass Production and Mass Customization (Pine 1993).

	MASS PRODUCTION	MASS CUSTOMIZATION
FOCUS	Efficiency through stability and control	Variety and customization through flexibility and quick responsiveness
GOAL	Developing, producing, marketing, and delivering goods and services at prices low enough that nearly everyone can afford them	Developing, producing, marketing, and delivering affordable goods and services with enough variety and customization that nearly everyone finds exactly what they want
KEY FEATURES	Stable demand	Fragmented demand
	Large, homogeneous markets	Heterogeneous niches
	Low-cost, consistent quality, standardized goods and services	Low-cost, high-quality, customized goods and services
	Long product development cycles	Short product development cycles
	Long product life cycles	Short product life cycles

The key differences outlined in Table 3.1. – mass customizations uncertain demand, heterogeneous niches, and short product life cycles – are some of the key challenges in the design of a customized part.

Firstly, uncertain demand poses a serious problem for design of products for customization. It is difficult to provide variety while being unsure of the demand of the large variety of products to be manufactured. Today enterprises need a production system that can adapt quickly to changing market conditions, provide the lowest costs, and give customers what they want and when they want it. The challenge for customization is to have techniques that are unaffected to varying demand of the products.

Secondly, one needs to interact with customers and understand what they want. This interaction not only helps in providing products that will satisfy the customers but also getting to know the trends of customers. The challenge is to provide products that satisfy the changing requirements of the customers. The change in the customer requirements may be in terms of change in the required design parameters. During the life cycle of a product line, there are many times when the design parameters need to be changed to suit the customer requirements. It is not possible to have a product line that would be perfectly satisfying all the customer requirements during the entire life cycle of the product family. In such cases, it is always beneficial to have some of the design parameters of the product family that can be tweaked to satisfy the customer needs. One of the main objectives of being able to change design parameters is to increase the demand in the existing products by customizing the product according to exact customer specifications. Moreover, new markets can also be explored by such variations.

Thirdly, since product life cycles are shortening, it is important to have the transition of old products into new products easily. Moreover, capturing of new markets to satisfy the needs of the customer must be possible. In this thesis, marketplace is the space in which the manufacturer has demand for his products and wishes to sell his products in this space. This is the space in which the manufacturer designs his product family.

This need is better understood by analyzing the Figure 3.12. The figure helps to show the life cycle of a product family by plotting the market capture of variants of a product family over time.

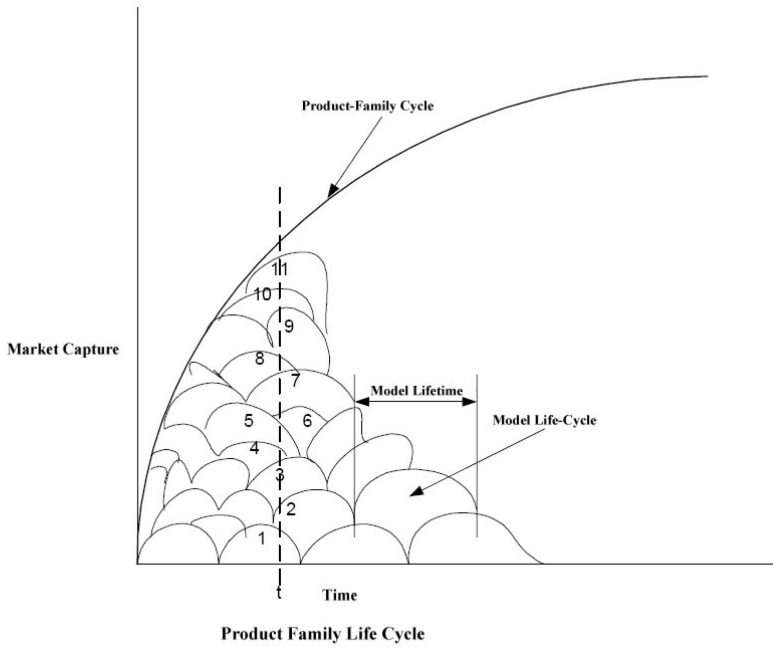

Figure 3.12. Product Family Life Cycle (Uzumeri 1997)

One must first clearly distinguish between the terms of model and family. Uzumeri and Susan define a model to be a product design that differs sufficiently from other designs that the manufacturer assigns it a distinctive commercial designation, and a product family to be a set of models that a given manufacturer makes and considers to be related (Uzumeri 1997). Simpson defines product family as a group of products which share common form features and function(s), targeting one or multiple market niches (Simpson 1998). Here, form features refer generally to the shape and characterizing features of a product; function refers generally to the utilization intent of a product. A derivative or product variant or model is a specific instantiation of a product platform within a product family which possesses unique form features and function(s) from other members in the product family. In Figure 3.12, it is seen that every model or product variant has its own lifetime. This is the time that the model remains in the market. After its lifetime, that model is retired and a new variant is brought into the market. The model life cycle represents the rise and fall of market capture of the model. It is seen that model 5 had a large market capture before half its lifetime. At its conception and end, its market share is very less.

In the early stages of the product family, less variety is provided, i.e., less models are present. As time passes, the variety increases to capture greater market share. After longer periods (not shown in figure), the market share of the products reduces. As more models that are targeted to distinct customer needs are developed, the market share of individual models tends to become smaller. So, it is not necessary that more variety will lead to larger market capture. However, the advantage is that increase of variety of the models leads to greater satisfaction of customers and hence major changes are not required in the models in the immediate future (Uzumeri and Susan 1997). To have this design longevity, the already existing variety must preferably evolve to satisfy future needs of individual customers. Accordingly, the major challenges for mass customization are to provide such variety that can evolve as time passes. Competition and other factors make it absolutely necessary to extend the marketplace and capture other adjacent market spaces.

The concept of Mass Customization could become one of the most important principles guiding businesses in 21st Century. Mass Customization is beneficial because it offers flexibility, lowers inventory cost and enables niche marketing to a market of one. Customized production transforms raw materials into individually differentiated products, giving consumers a wide variety of product choices. Mass Customization involves the production and delivery of high quality custom made products to the masses at low prices similar to those expected from mass production. (Cox & Alm 1991).

As a conclusion, advantages of customization can be summarized in the following:

- Customer has control over product
- Does not have to pay for features he/she does not want
- ‘Not in your size’ or ‘Not as you wish’ becomes a thing of the past
- Company does not have finished product inventory ➔ better use of working capital
- Easier for company to differentiate product
- Levels out economic fluctuations
- When slowdown occurs, less backlog of inventory
- Prices do not have to be cut as much
- Therefore, less likelihood of recession

3.4. Modularity to Mass Customization

When the idea of mass production was introduced in the late nineteenth century, most of the enterprises were small, family -owned firms based on craft production. At the time machinery was coming largely to factories, not to replace the workers, but to help them in their work, which created the technological ground for mass production. Management paradigm and technological development together with a great success story, spread out by Henry Ford’s production engineers, made the break through of mass production. After the World War II mass production became the dominant manufacturing paradigm of the world’s industrial production.

Idea of mass production is ‘*the shared goal of developing, producing, marketing, and delivering goods and services at prices low enough that nearly everyone can afford them’* (Pine 1993). Mass production was heavily dependent on specialized machines and men to achieve smooth flow of production and low costs that resulted in low prices. Companies grew bigger, because achieving the ‘economies of scale’ guaranteed even lower prices, and thus, better position in the markets.

Mass production is an ideal way to produce goods for homogenous markets. However, in the end of twentieth century situation started to change significantly as the market became more fragmented. This situation has led to breakdown of mass production paradigm and introduction of new one, mass customization. Mass customization, as an organizational strategy, is arising in direct response to the turbulence that has splintered the mass market (Hart 1995).

The shift to mass customization is happening mainly because of three major drivers:

1. Free and dynamic global markets: As the world's markets are opening, the competition is tightening respectively. Information technology has made it possible to manage globally distributed companies efficiently, bringing global companies with their 'economy of scale' to compete with local competitors. Unable to compete with price, local companies have to differentiate themselves to certain market segment and/or achieve customers satisfaction with better quality or outstanding services. This has lead to variety of offerings and paying more attention to customers' preferences.

2. Market fragmentation: As the supply is increasing because of the competition, customers can be more selective when purchasing goods. This leads to market fragmentation. Here, a company that better satisfies its customers' individual wants and needs will have greater sales (Pine 1993). With the flexible manufacturing systems and computer-integrated manufacturing techniques that have made it more economical to produce a greater variety of products, companies are able to provide products to ever smaller customer groups, which further accelerate fragmentation.

3. Shorter product life cycles: Mass-market breakdown has been further abetted by technology (Hart 1995). Stable demand is affected by technological shocks: new methods of manufacturing that prove more successful at achieving production goals (Pine 1993) or improves existing and introduces new features that make the products more compelling. As with mass production, the shift to mass customization is able to happen because there are three required factors.

1) Mass customization as a manufacturing paradigm has existed a while already. It was already anticipated in 1970 by Alvin Toffler in Future Shock and delineated (as well as named) in 1987 by Stan Davis in Future Perfect (Pine 1993).

2) Manufacturing technology has developed and made it possible to produce smaller series economically with flexible manufacturing systems. Also the emergence of Internet has made it fast and easy to gather information about customer preferences.

3) The success stories like Dell's have brought the idea to public debate. Even though there are many drivers and success stories already, we don't believe that mass customization is going to achieve such popularity, that mass production achieved at the time. Mass customization might become the leading production paradigm, but it won't dominate the markets like the mass production dominated before. This is because of the one market segment (and a pretty big one) that looks only for cheapest price. This development trend can be noticed currently in Finnish grocery stores. As the foreign grocery chains are penetrating the markets with 'hard-discount' stores, all the main Finnish based grocery store chains are also introducing their own hard discount brands, which are acquired in alliance with different European procurement organizations.

There is a large demand for customized goods anyhow. And as more and more companies are pursuing the mass customization paradigm starting to offer more variety and customization, market segments are narrowing down to smaller and smaller segments and eventually there is left *markets of one* individual customer. While development toward mass customization is still under way, Pine and Gilmore (1999) have already envisioned the future challenges after the mass customization roadmap has been walked trough. They think that the next management challenge is development toward *'Experience Economy'*. This can be justified, because if customizing a good automatically turned it into a service, customizing a service automatically turned it into an experience. If that were true, they realized, experiences would have to be a distinct economic offering, as distinct from services as services were from goods. Pine and Gilmore continue addressing also the next relevant question: but what happens when you customize experiences? You can turn them into what is often called *life-transforming experiences*, and thus was discovered the fifth and final economic offering in the Progression of Economic Value: transformations (Pine 2003).

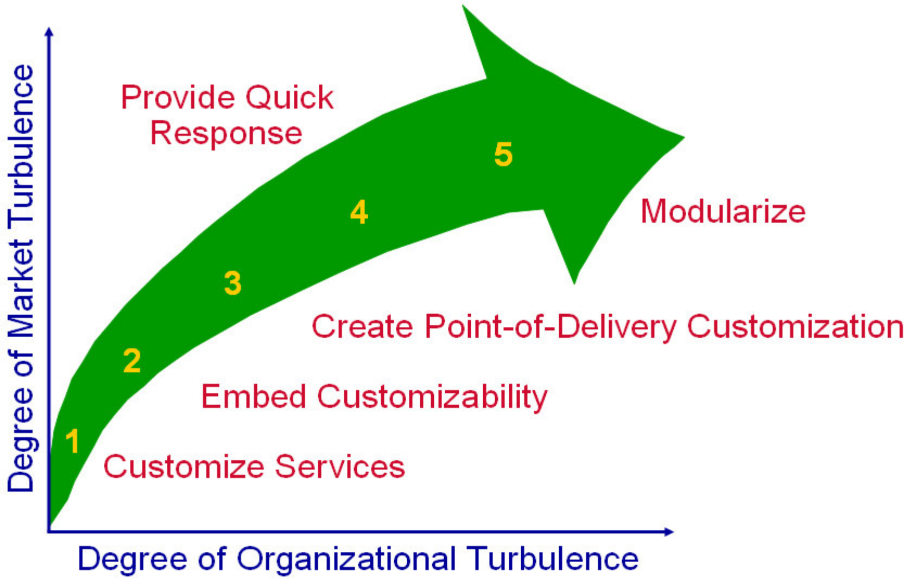

Figure 3.13. Pine’s Five Steps to Mass Customization

(Sources: Pine II 1993)

Modularity means mass customization: Often, modularity is seen as the key for mass customization. It is true that modular product and service architectures often guarantee mass customization. Complexity related costs and economies of scale and learning result from a strong modular system. But often, many design possibilities and degrees of freedom translate into one term from the perspective of an inexperienced customer: complexity and “mass confusion”.

Mass Customization is not like “Lego”. The toy maker faces today the strong challenge that it’s modular system is too complex for most of today’s kids. Lego and many mass customization systems lack a good design tool in order to translate the product modularity into needs and wishes of the customer. True, modularity is an important prerequisite for mass customization. But without a strong configuration system that is based not on product architectures but on the customer’s needs modularity is useless.

Customization According to Consumer: Consumers want choice. Consumers want individuality. Consumers want customization. Many companies follow these believe. But this is only one part of the truth. Customers are not buying individuality; they are purchasing a product or service that fits exactly their needs and desires. Only few customers honor long configuration processes. Most users want to find their fitting solution as smooth and simple as possible. Mass Customization concepts based primary on the promise of customization will fail.

Mass Customization and Personalization: Being customer centric includes a wide range of strategies, approaches and ideas. Agile manufacturing, focused factories, flexible specialization, lean manufacturing, customer relationship management, and mass customization are strategies that emerged from the literature in the last decades. Despite different backgrounds and focus, the major objective of these new concepts is to improve the ability of enterprises to react faster to changing customers' needs and to address the heterogeneity of demand more efficiently.

Author of the book "Emotional Design", Donald A. Norman, asking the how mass-produced objects can have personal meaning. Many companies provide customization services or allow special orders and specifications and many pro-vide a flexible product that, once it has been purchased, can be tunedand tailored by the people who use it and so that many companies have tried to overcome the sameness oftheir product offerings by allowing customers to "customize" them. This usually means is that the purchaser can choose the color orselect from a list of accessories and extra-cost features. Cell phones can be equipped with different faceplates, so user can get one in differ-ent colors or designs or paint it ownself. Some web sites advertisethat user can design his own shoes, although, in fact, the only realalternatives user has are some choices among a fixed number of sizes, styles, colors, and materials (e.g., leather or cloth).

According to Donald A. Norman, that manufacturing to order—mass customization—will extend to everything: clothes, computers, automobiles, furniture. All products would be manufactured specifically to specification: specify the configuration, wait a few days, and there itis. Some computer manufacturers already work this way, assembling products only after they have been ordered, allowing the customer to configure the product according to their desires. This has a benefit to the manufacturer as well: items are only manufac-tured after they have been purchased, which means that no stockpileof finished products is required, dramatically reducing the cost ofinventory. When manufacturing processes are designed for mass customization, individual orders can be made in hours or days. The form of customization is limited. User can not design a radically new form of furniture, automobile, or computer this way. All user can do is to select from a fixed set of options. Things do notbecome personal because we have selected some alternatives from acatalog of choices. To make something personal means expressingsome sense of ownership, of pride. It means to have some individualistic touch. This is a far cry from the mass customization that allows aconsumer to choose one of a fixed set of alternatives, but has little orno real personal relevance, little or no emotional value. Emotionalvalue now that is a worthy goal of design.

The authors discuss whether the additional costs and hurdles of mass customization in mini-plants could be counterbalanced by the advantages of such a decentralized setting (compared to both mass production and centralized mass customization). Advantages could arise from new cost saving potentials and a higher consumers' willingness to pay for a customized solution. However, at the bottom line there is no generic rule as to when mass customization does pay. Only by evaluating the influencing factors of a particular situation can an answer be provided. Especially in Europe there is a long tradition of designing and manufacturing customer specific products such as machinery, ships and cars. The author evaluates synergies, similarities as well as limitations and potentials of both mass customization and (traditional) customer driven manufacturing. While the theoretical foundations of user modeling and personalization techniques have been discussed in literature for several years, their practical implementation has been neglected for a long time. Personalization technologies to individualize the dialogue between man and machine pragmatically by user modeling based on content based filtering as well as social filtering. Gros sharpens view of being customer centric by approaching customization as art. Applied art was once an important field of industry. However, as a result of industrialization and mass production, the link between art and consumer goods has been broken for almost a century. Now it could be assumed that new mass customization technologies may favor a rebirth of the association between art and consumer goods, a relationship coined 'art customization' by the author.

Mass customization strategies: An explicit mass customization strategy is unique to the company developing and implementing it (Hart 1995). As with any new innovation, essential is not the innovation itself but how it's being implemented and practiced in every day life. Any universal directions can't be given, how companies should pursue mass customization strategy, but some outlines can be drawn.

Mass customization has been defined in many ways depending on definer's point-of view. Hart (1995) for example defines the mass customization concept by using two distinct definitions: (1) ability to provide your customers with anything they want profitably, any time they want, anywhere they want, any way they want it, and (2) the use of flexible processes and organizational structures to produce varied and often individually customized products and services at the low cost of a standardized, mass production system. Later on, Hart (1996) tones his definition promising '*anything at anytime*' to '*… produce varied and often individually customized products and services at the price of standardized, mass-produced alternatives*'.

Several authors propose a continuous framework upon which MC may be developed; namely, MC can occur at various points along the value chain, ranging from simple "adaptation" of delivered products by customers themselves, up to the total customization of product sale, design, fabrication, assembly, and delivery (Da Silveira et al. 2001). Browne et al. (1996) present a framework of decoupling points in different levels of mass customization. Four different designs are represented by varying the position of the decoupling point (Alfnes 2000). These designs range from providing unique products (Engineer to order) via two customization levels (Make to order and Assemble to order) to providing standard products from a final stock (Make to stock).

Lampel and Mintzberg (1996) define a continuum of five MC strategies involving different configurations of process, product and customer transaction. Gilmore and Pine (1997) identify four customization alternatives corresponding to change/no change in product and presentation.

From these frameworks four dimensions of mass customization can be identified: process, product, service and representation. However, these four dimensions are not independent, but rather interlaced. It is clear, that production design largely defines the extent of product's customization alternatives, and vice versa. Also the representation of product is interlaced with service dimension. For example Gilmore and Pine (1997) gives an example how product's representation can change when offering individual or customized service, as in the case of Hertz.

In conclusion, there are only two interdependent dimensions of mass customization. From this point of view, we decided to adapt Gilmore and Pine's (1997) classification of mass customization, as it has captured the most fundamental dimensions of mass customization: product and representation. Furthermore, it was evaluated to be useful framework for qualitative, empirical research by the research team.

Gilmore and Pine (1997) identify four customization strategies: collaborative (designers' dialogue with customers to identify their precise needs), adaptive (standard but customizable products can be altered by customers themselves), cosmetic (standard products are packaged specially for each customer), and transparent (goods and services are customized for each customer by observing their behavior).

Figure 3.14. describes the framework used in an empirical research. The original framework is modified changing both product and representation categories to dimensions. It is seen that in empirical settings the scales should rather be flexible sliding from one extreme to other than just offering two options: change or no change.

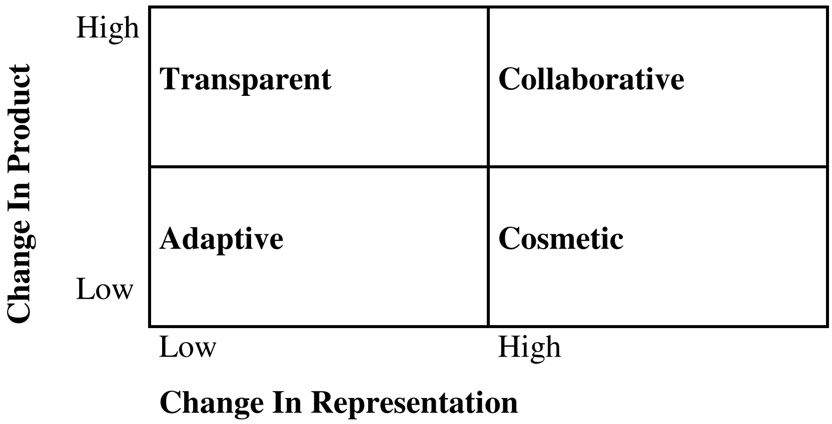

Figure 3.14. Mass customization alternatives (modified from Gilmore and Pine 1997).

Management of different stages of mass-customization is a clear challenge for companies (Pine 1997). In many companies operations have started from very user-oriented perspective, producing customers defined products, leaving production series short. This kind of customization is usually a joint problem solving with the user, e.g. cooperative customization.

Cooperative customization cannot be carried on forever, at least not for the same consumers. This is because almost in all industries production occurs. This means that originally customized products can turn to be more standard and be bought as a mass product with a lower cost. Standard products can replace previously customized product. This is common for example in software industry. Yet, there are always companies who have superior and unique knowledge not easily imitated, such as different kinds of protected innovations (Barney 1991, Hargadon & Sutton 1997). These companies can prize their products and services with proper margins.

Mass-customization with customer can also be done either in a transparent or adaptive way. In both cases customer doesn't necessarily recognize how his/her needs are tailored into the product or service. Transparent customization requires the use of a large and diversified data warehouse, which contains detailed knowledge about customer and customer's product and service needs. In adaptive customization you do not always know what customer wants, but by increasing the modularity of products or services customization level increases.

Products can also be customized in a cosmetic way. Then customer-defined product changes are usually done in the end of the manufacturing process. These can be done for example in the assembly line, of which the car industry is an excellent example. This kind of model for operations demands flexible manufacturing and adequate volume to be meaningful.

America's history of innovative manufacturing practices reaches back to the mid-1800s, when forward-thinking industrial pioneers opened new business frontiers with The American System of Manufactures, a production concept that focused on the use of interchangeable parts. On its heels, the 20th century ushered in the age of mass production and the assembly line.

Today we have mass customization, a concept that aims to blend the efficiencies of volume production with modular-type components that are specified by customers to varying degrees. It's a trend that has been driven by nimble companies such as Dell Computer, which raised the bar on customer service by introducing custom-configured desktops in the 1980s. Amid this era characterized by complex assembly processes and a made-to-order mentality, many in construction supply are looking to establish or expand flexible manufacturing capabilities. And they are not alone. These days many examples of customization can be found.

Overall, there are many variations on the theme and many potential benefits, such as optimized inventory and improved market responsiveness. At an even higher level, customization can facilitate the ability to create an "experience" for customers' perceived value and margin, according to mass customization gurus James Gilmore and Joseph Pine. The challenge for companies looking to capitalize on any type of customer specification-driven process is to engineer profitable manufacturing systems that can produce small-batch or single-unit orders according to demand, rather than pumping out predetermined stock levels. The key here is learning to balance the cost and level of customization with profit margins and productivity. Of course this is not easy, but it can be accomplished in construction supply with a dedicated focus on modularization; flow configurations and information technology to support flexible manufacturing environments.

CHAPTER 4

CASE STUDY

In this chapter, it is aimed to combine a synthesis by considering the analysis in previous chapters, which are on customization at modular system designs. As a case study, I studied the "Resolve Office System" designed by Ayşe Birsel for Herman Miller on the basis of my industrial design background and the studies I have conducted hereabout.

> When the first panel-based furniture, the Action Office system, was introduced three decades ago, there were no computers in the office; there were no cables to manage. There was no internet, no groupware, no e-commerce and no e-mail. There were 10 million fewer office workers, 6 billion fewer square feet of office space, and an information technology industry 1000 times smaller than it is today. An overbearing hierarchy dominated office culture. Most companies thought locally, not globally. There were no telemarketers, knowledge workers, call centers, telecommuters, or IT people. (Birsel 1999)

Three decades later, enormous changes signal a grand opportunity to revisit, reexamine, and react to the issues in the work environment-to resolve the problem of designing a new system of furniture. The office environment, however, is beset with several contradictory forces, or dichotomies, that challenge any quest for simple solutions. There are conflicting interests between individuals, who have unique personalities, and corporations, which want to present a united, collective identity; between individuals who desire domain and organizations that push for optimum density; between people who crave humane environments and technologies that force compromises in lighting, air circulation, and acoustics; between the imperative to upgrade high-performance computer tools and software and the need to upgrade furniture and infrastructure.

According to me, Ayşe Birsel's design Resolve Office concept takes the solution from a different view morely coming from principles of the nature itself. Its smart structure is based on 120-degree angles that create open, inviting, space-efficient workstations where people feel comfortable and connected. Resolve gives people the tools to be productive, and lets an organization use its resources effectively.

Figure 4.1. Resolve Office System designed by Ayşe Birsel for Herman Miller.
(Source: www.hermanmiller.com)

Results of Research before the Design

- The average churn rate for all industries grew 14 percent over the last decade of the 20th century to reach an average annual churn rate of 44 percent. Increasing churn requires frequently disconnecting and reconnecting networked technology and appliances. Architecture, interior spaces, and even corporate cultures are taking on a higher level of openness and transparency.
- Emphasis is shifting to the efficient and appropriate use of materials in design and open, light architecture. Rising real estate costs demand efficient use of space, while performance needs require that smaller workspaces safely and comfortably support workers.
- Paper is now primarily a display medium; to serve its function, paper must be kept on display—visible and accessible, out in the open. Many companies are moving filing out of workstations and into archival off-site storage facilities or shared on-site storage areas.

Work space and environment: The people who work in these organizations spend a lot of their time gazing into a computer monitor and have become accustomed to nearly instantaneous information retrieval. Away from their screens, they become impatient with walls and file drawers that conceal coworkers and reference documents. They want to be able to see at a glance whether a colleague is in her office or otherwise occupied. They want their work surface to organize documents for visual access the way their computer desktop does.

Office work and the environments that support it are also undergoing a dematerialization of sorts. Information processing and communication are increasingly accomplished in the virtual reality of cyberspace. Work involves the use of fewer physical artifacts as people create, store, and manipulate files, documents, and images in a two-dimensional, digital world. Even workstation personalization is moving on-screen as people customize their computer desktops with “wallpaper,” screen savers, family photos. (See Figure 4.2)

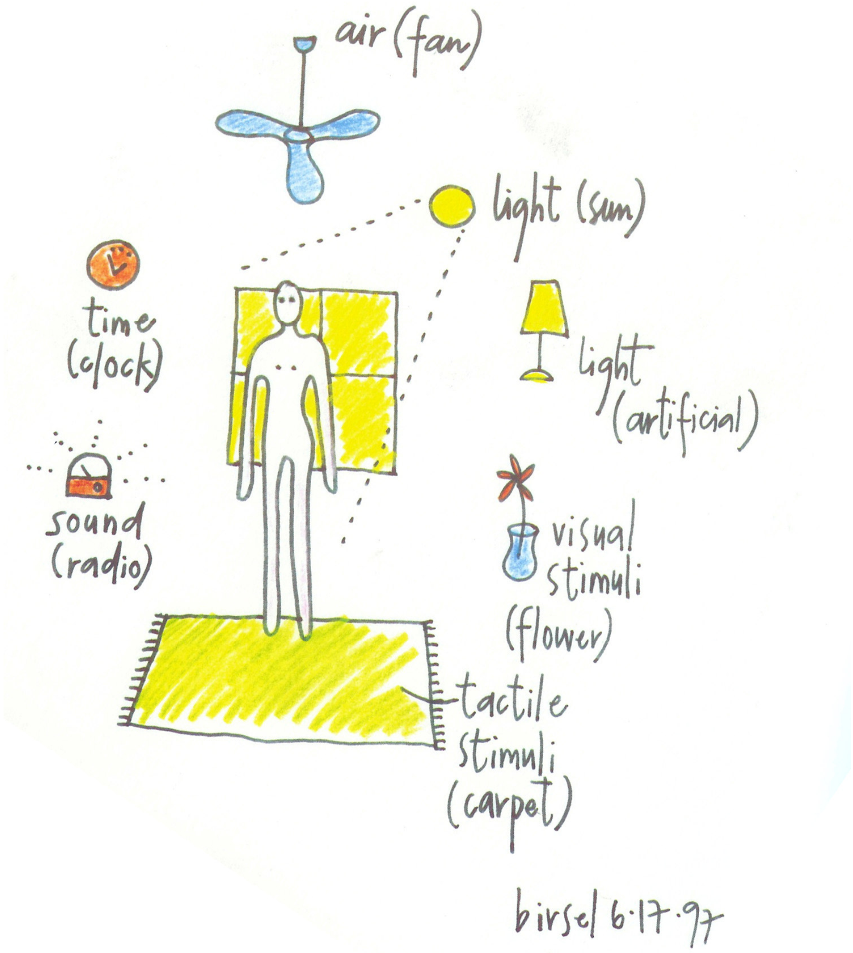

Figure 4.2. A Sketch Drawn by Ayşe Birsel, designer of Resolve (Birsel 1999)

Besides, people are willing to change their work environments up to their needs and also characters. This system is a good example of collaborative customization.

> Information technology has served to concentrate personal work space into a much smaller area than formerly. With the mobility that portable technology affords, many people complete a significant amount of their work outside the corporate workplace—in their homes or on the road. The work they do on-site is more likely to be collaborative and to take place in shared spaces like conference and project rooms. People working alone in their offices are usually focused on the corner of their workstation where their computer is located. Personalization seems centered around the monitor, which people frequently adorn with toys, figurines, photos.(Miller 2000)

Design Elements Of The System:

There are six elements taken as a case in this system which lets the user to understand Resolve as a system with the help of a very simple logic: through a natural geometrical progression: from point to line to plane to volume. By joining two points together and creating a line; connecting four lines and making a plane; causing the plane to take height and depth and volume is created the evolution of Resolve System. Point, line, plane, and volume sum up the spatial thinking behind Resolve.

In the book written by Christopher Klein, it is stated as: "The simplest way to develop this awareness and control is to isolate some basic elements of design and try to understand them one at a time." (Klein 1996)

People typically respond to things as wholes, assigning them overall labels- road, girl, house, tree, sea- but it is possible to separate these images into the parts we are seeing. That is we can pick out the lines, colors, textures, values and shapes. So a modular system design should respond to the whole.

1. Person: Two more dimensions complete the story of office environments people and time. People come first; Resolve is built for people. Time, a fundamental component in the function of any built environment and a dimension central to all work.

Resolve doesn't start with a place (floor plan) or a thing (computer). It starts with a person. Starting by considering the needs and desires of a human engaged at work is the most important item of today.

> The habits, rhythms, and dreams of the person reverberate through the design of Resolve, and the system must in turn feed back tools and capabilities to enrich people at work. A truly new work environment must make individual workers more comfortable, more included, more connected, more effective. Only then can it proceed to account for all the other factors that make offices such complex places: technology, teams, facility management, architecture, real estate. (Birsel 1999)

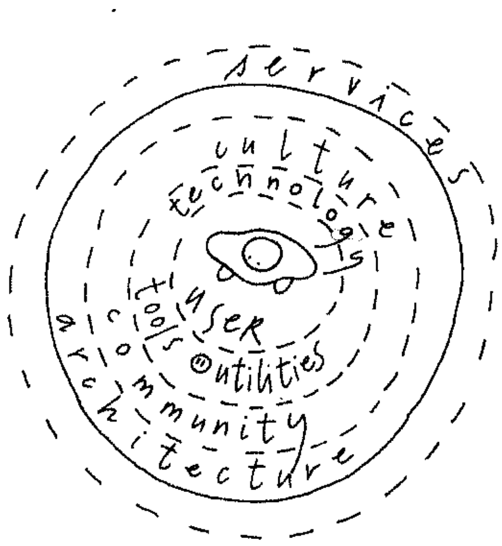

Figure 4.3. A Sketch Of Ayşe Birsel For Person Based Design.(Birsel 1999)

2. Point: The point is the most basic element of geometry, the starting point. What is the minimum required to create an office? You'd need a person, technology, and a connection for that technology. If the *point* is the connection: the town well, the source, heart, and hub. “In Resolve, the point is pulled up into the air to become a pole.”(Birsel 1999)

By putting power and data into that pole, bring in a person with a laptop, and you have the beginning of an office. And this is the beginning of Resolve: a point-based office system)

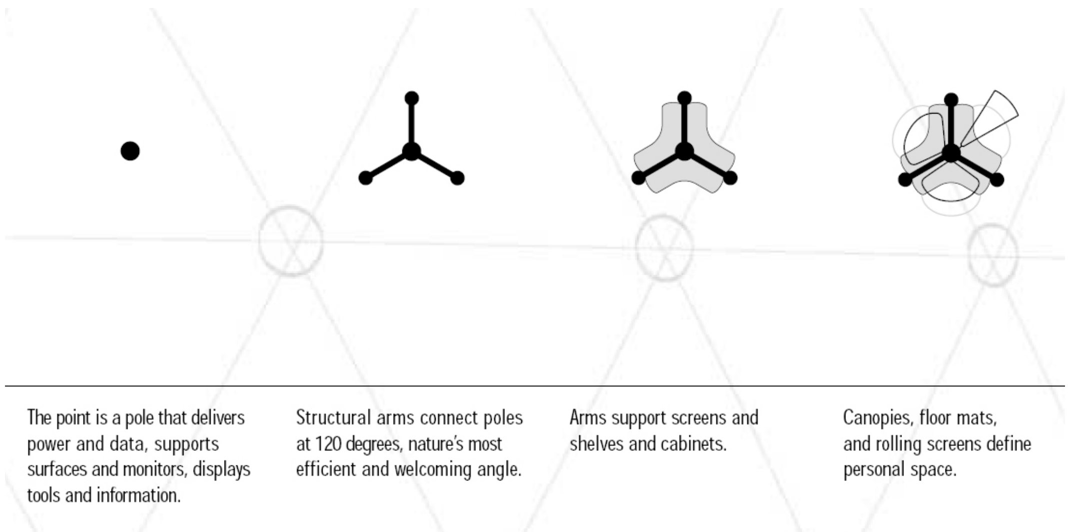

Figure 4.4. From Point to Shape.

(Source: www.hermanmiller.com)

3. Line: There are two reasons to expand from a point to a line: for structure and connection. In Resolve, poles support arms that branch out at 120 degrees-the most economical way to create a stable structure, and nature's favorite angle for building complex, connected structures. It is the way branches grow, bubbles form, and honeycombs are made. It's all about optimizing and using materials efficiently and perhaps the most persuasive and endearing reason for the 120-degree angle: It is the angle while intuitively makes the person when opening arms to welcome someone. This is why Resolve feels so welcoming. (Miller 2000)

The second reason to join points is for connection. The points, or poles, in Resolve are connected to each other at the top by an overhead delivery system of troughs and trusses. Today, delivery is like the circulatory system of the office. It supplies energy, information, power, life. In Resolve, delivery is separated from the workstation by putting it overhead. Resolve frees up the workstation from the requirements of cable management to become lighter, more open, and more flexible. The overhead elements become a lay-in, dedicated path for cables. By putting outlets on the poles, connecting to power and data becomes intuitive, easy to locate, and easy to reach.

From points and lines to constellations: "With poles, arms, and the overhead trusses, we have created the wire frame or scaffold of Resolve. It is called as infrastructure." (Miller 2000)

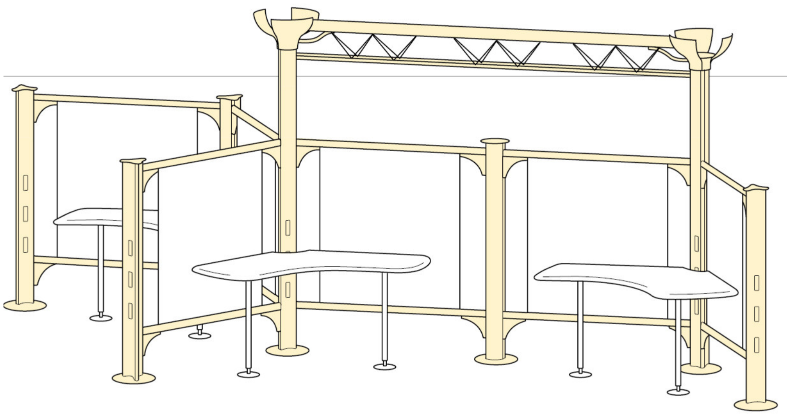

Figure 4.5. Infrastructure of Resolve System

(Source: www.hermanmiller.com)

The next step in creating environments with Resolve is to organize the infrastructure into patterns that you can plan with, repeat, and recognize. Taking inspiration from the skies, these patterns have been grouped into constellations that have been named according to their shapes.

One Resolve constellation is the Delta, made up of a pole with three outstretched arms-each at 120 degrees-creating three separate work spaces, each a two-sided envelope.

Another two-sided constellation is the Zigzag, and it looks just like that-alternating poles, arms, and trusses combining to create adjacent work spaces on either side of a zigzag spine.

A third constellation is the Shell'", a three-sided pocket, increasing enclosure and footprint.

The four-sided Half Honey is ideal for accommodating more storage and work surfaces, and the five-sided Honey'" (like the cell of a honeycomb) provides maximum enclosure.

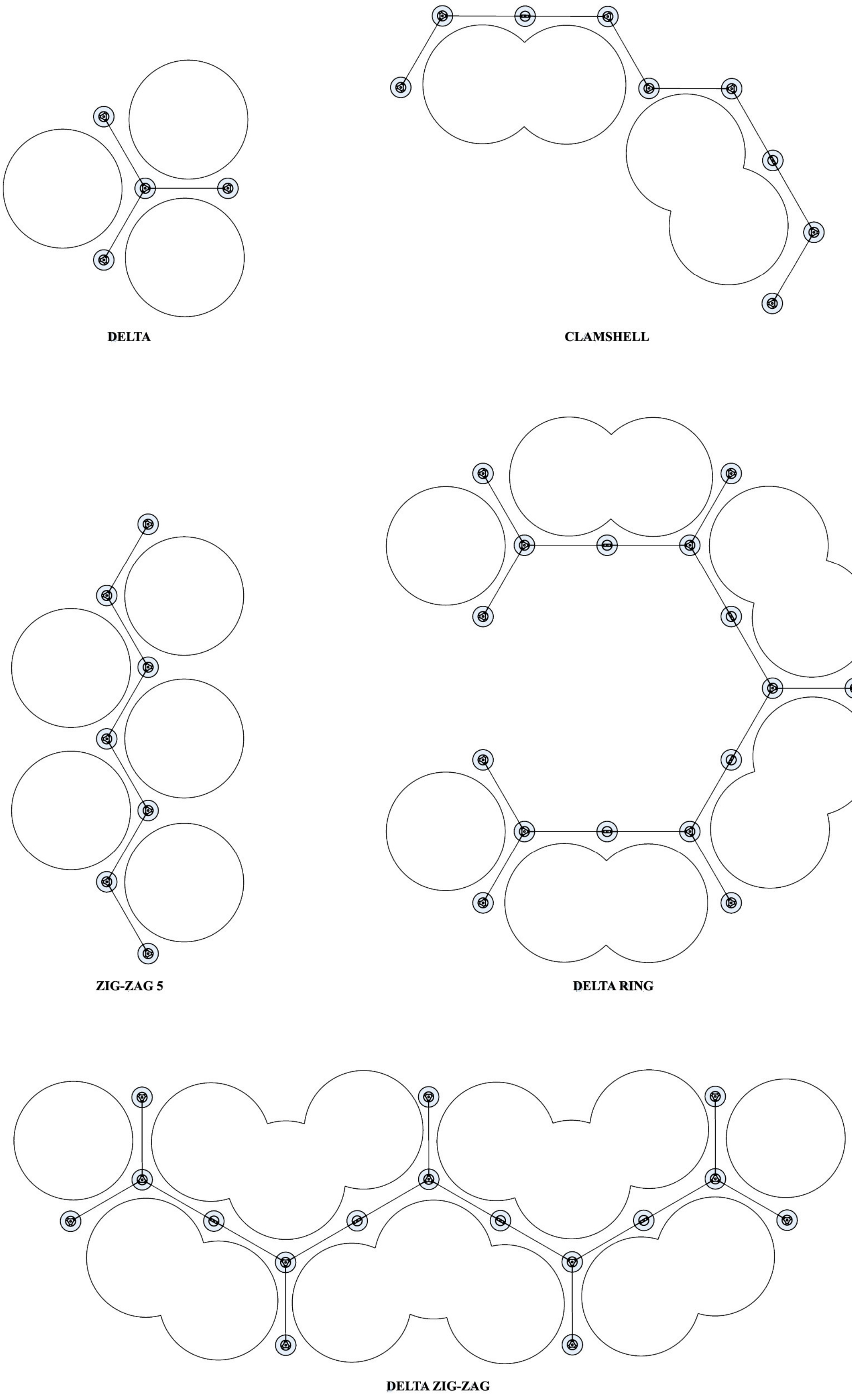

Figure 4.6. Templates of the System

(Source: www.hermanmiller.com)

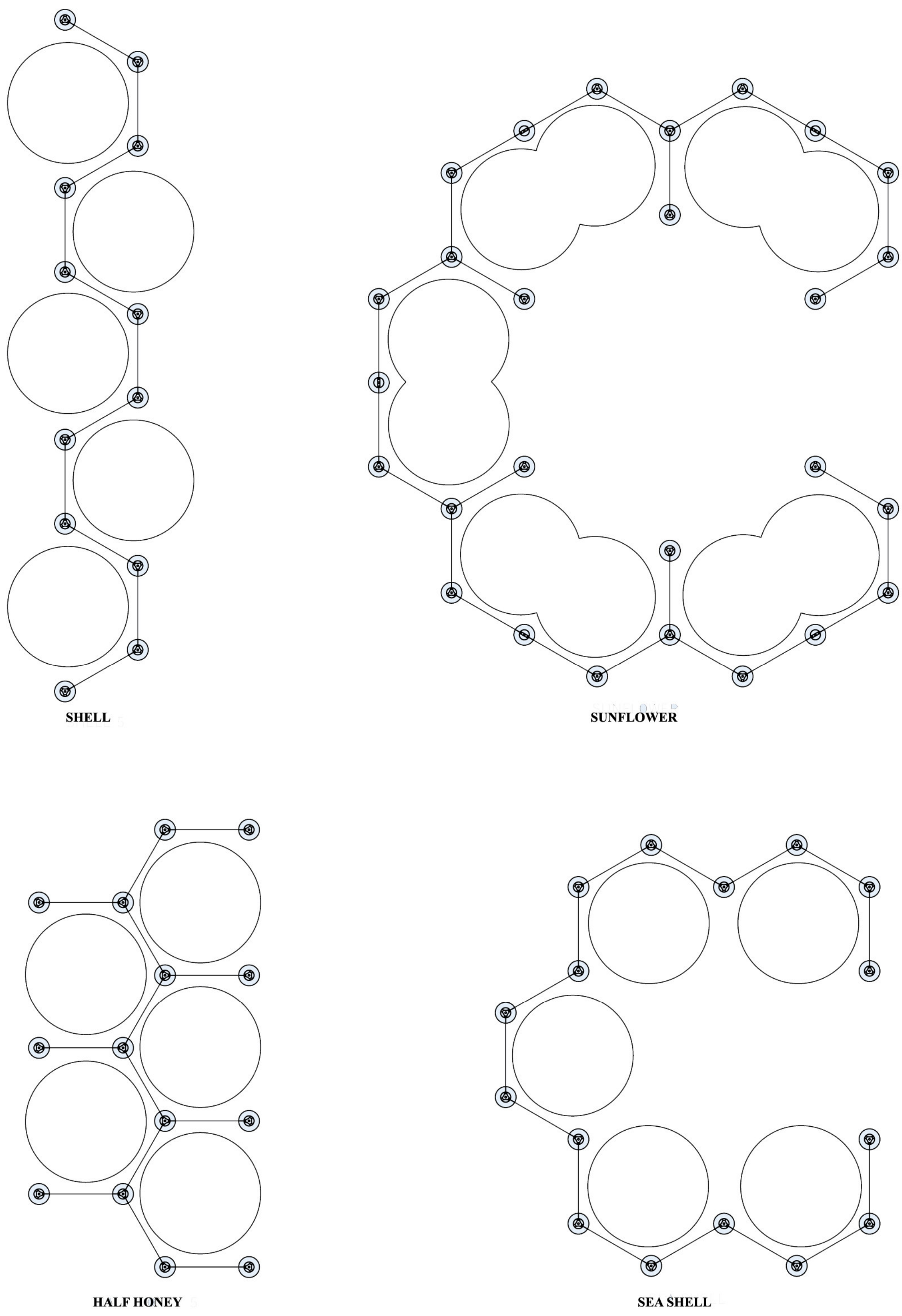

Figure 4.7. Templates of the System
(Source: www.hermanmiller.com)

Clustering these basic five constellations into more complex and efficient patterns results in myriad new constellations. Without the constraint of 90-degree angles, Resolve can grow in many dimensions, where the patterns of work and people and organizations need growth.

4. Plane: Leveraging the vertical, several kinds of planes function in different ways in the Resolve system.

The vertical planes: the display screen, boundary screen, and the computer screen, more and more, visual communication can be seen as the *vertical* display of information. Television screens, billboards, LED stock quote zippers, bus shelter and phone booth advertisements, street-side signage, newspapers.

> Work itself has become more and more about the vertical display of information, since most of work focuses people on the computer monitor. Monitors create an expansive and seamless easel for the display of paper, printed materials, photographs, notes, lists, invitations, and other visual references. They enable people to display the visual cues of work, helping to reinforce memory of what needs to get done. Since the translucent display screens mimic the luminosity of the computer monitor, they mediate the often abrupt change we force our eyes to make when we shift from looking toward light (the computer screen) and opaque panels and back again. In Resolve, display is the voice of delivery. (Birsel 1999)

Boundary screens-vertical planes can be digitally printed to display identity (brand, team, or personal), cultural iconography, signage, way-finding, advertising, and other graphic treatments. There are no limits to what can be put on a boundary screen. By building in deliberate breaks between screens and poles, user is able to provide a visual caesura, or pause, in the composition of a Resolve work space. These openings serve to modulate the cocooning effect, reduce isolation, and encourage connection. (Miller 2000) They help to expand your view beyond the computer, while the display screen mirror doubles as a rearview window to the space behind you.

> These visual devices provide an ergonomic benefit, inviting you to take breaks from the computer monitor and exercise your eyes. They also help you feel more connected to your surroundings and coworkers, enhancing your sense of belonging, and encouraging you to see the whole office environment as your own. Resolve doesn't box you in; it lets light and air through. Resolve System doesn't block windows; it allows for the perception of time of day, seasons, and things that happen outside the building. (Miller 2000)

Horizontal planes: Extending an arm out in front and sweep it from side to side is just a description of the shape and size of the desk, the work surface. (See Figure 4.8.)

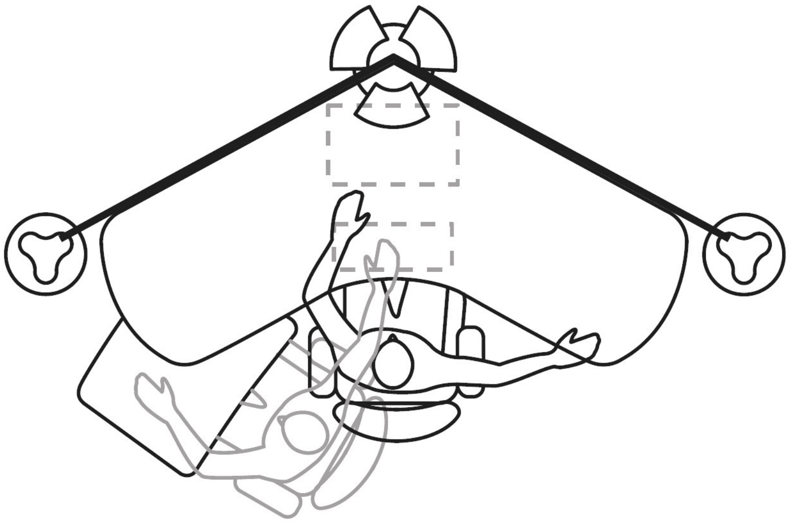

Figure 4.8. Illustration of a Person’s Optimum Angle at Work Space.
(Source: www.hermanmiller.com)

Horizontal planes in Resolve: bookshelves, pole shelves, monitor pods, and input tables. Together, they create a landscape for paper, tools, keyboards, mice, laptops, books, binders, and other items people like to have near them. Horizontal surfaces are used differently than vertical ones, for writing, collecting, looking things up, and resting mugs on. Usually, the items on horizontal surfaces vary wildly in terms of how long they stick around. A pile of documents may sit on a desk for a month before being archived. Clipped articles, rebate cards, and assorted ephemera occupy horizontal surfaces in a more active kind of way. These kinds of items pass over and across our desks like cars through an intersection, sometimes stopping, sometimes slowing barely at all. Resolve's varied horizontal surfaces help in prioritizing tools and make sense of work. (Miller 2000)

The input table truly breaks ground in its simplicity and power. A mobile surface for keyboarding, writing, reading, and meeting-way beyond an adjustable keyboard tray-the input table allows for infinite freedom of movement in relation to the monitor or work surface. Orienting input table together with the other mobile elements enables to customize relationship to nearby work spaces, determining boundary, privacy, and domain. For convene an impromptu meeting with a coworker, two people can easily group around an input table for document support, or you can wheel two or more input tables together to increase your meeting area. When you're done, slip them back to your work space and continue with your day.

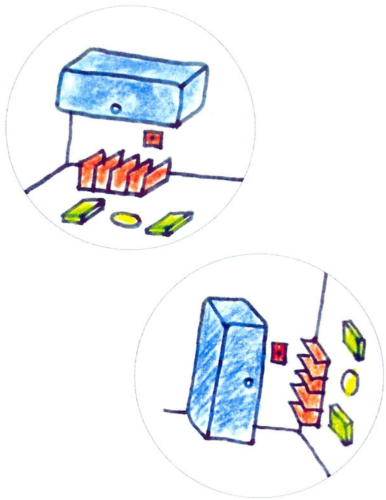

Figure 4.9. A sketch drawn by Ayşe Birsel. (Birsel 1999)

5. Volume through plane: The Resolve canopy provides a fixed, umbrella like shelter, helping to scale the workstation 10 personal proportions. By delineating the space above the person, the canopy increases perception of the depth and size of space. In a vast, open office area, canopies give a visual reference to personal domain and help feeling sheltered and secure.

The rolling screen is a moveable privacy element that creates a tent-like shelter, as well as providing glare control; it can be rotated with the sun. It acts simultaneously as a door and a window, defining the open and closed areas of the work space and providing a desirable, versatile back to the workstation. Flormats in Resolve define the work space footprint in the absence of hard boundaries. They enable the measurement and provision of correct distances from walls, columns, and other Resolve constellations, for passage ways, and for personal space. They differentiate public space from individual space.

When these all elements come together, volume is created. Ingredients work together to evoke the feeling of space that transcends the actual physical dimensions. Like the combined effect of blanket, umbrella, and novel at the beach, the components of Resolve work together to articulate a sense of place in ways we recognize to be familiar, satisfying, and magical. (Birsel 1999)

Main Technical Points of the System:

- System is scaffolding made up of vertical poles and horizontal arms which is organized in 120-degree angles for maximum efficiency as a framework for offices.
- Technically movable cable management exists to overhead through to make the workstations lighter and easier to change.
- Lightweight and light-transmitting screens hang to enclose without secluding.
- The work surfaces and storage connect to the arms to minimize structure and maximize stability.
- Whole architectural environment from floor to ceiling without infringing on windows and walls can be used with the help of growing 120-degree patterns.
- Lightweight components which lets the system flexible.
- System consists of limited and controlled number of modules brings many facilities as it is explained in previous chapters.
- Easy to assemble and disassemble, easy to remember and order also. Lightweight and 95% recyclable components.
- Concept of the system and components can be customized according to user.

Modularity: The organizations of the new economy are not interested in the architectural monuments that characterized corporate building in the industrial age. The new "dot-coms" tend to inhabit less imposing, more fluid structures that can be changed or left behind at little cost. Many start out in converted warehouse or retail space that is not well suited to interior division by traditional panel systems, which block the large windows, architectural details, and open access that attract these dynamic young enterprises. Lightweight, reduced-mass components make handling easy, even for one person. Below there is a table showing the components of the system. Considering many combinations, many solutions to different problems can be resolved.

Figure 4.10. Connection details of poles

(Source: www.hermanmiller.com)

Figure 4.11. Connection poles of infrastructure

(Source: www.hermanmiller.com)

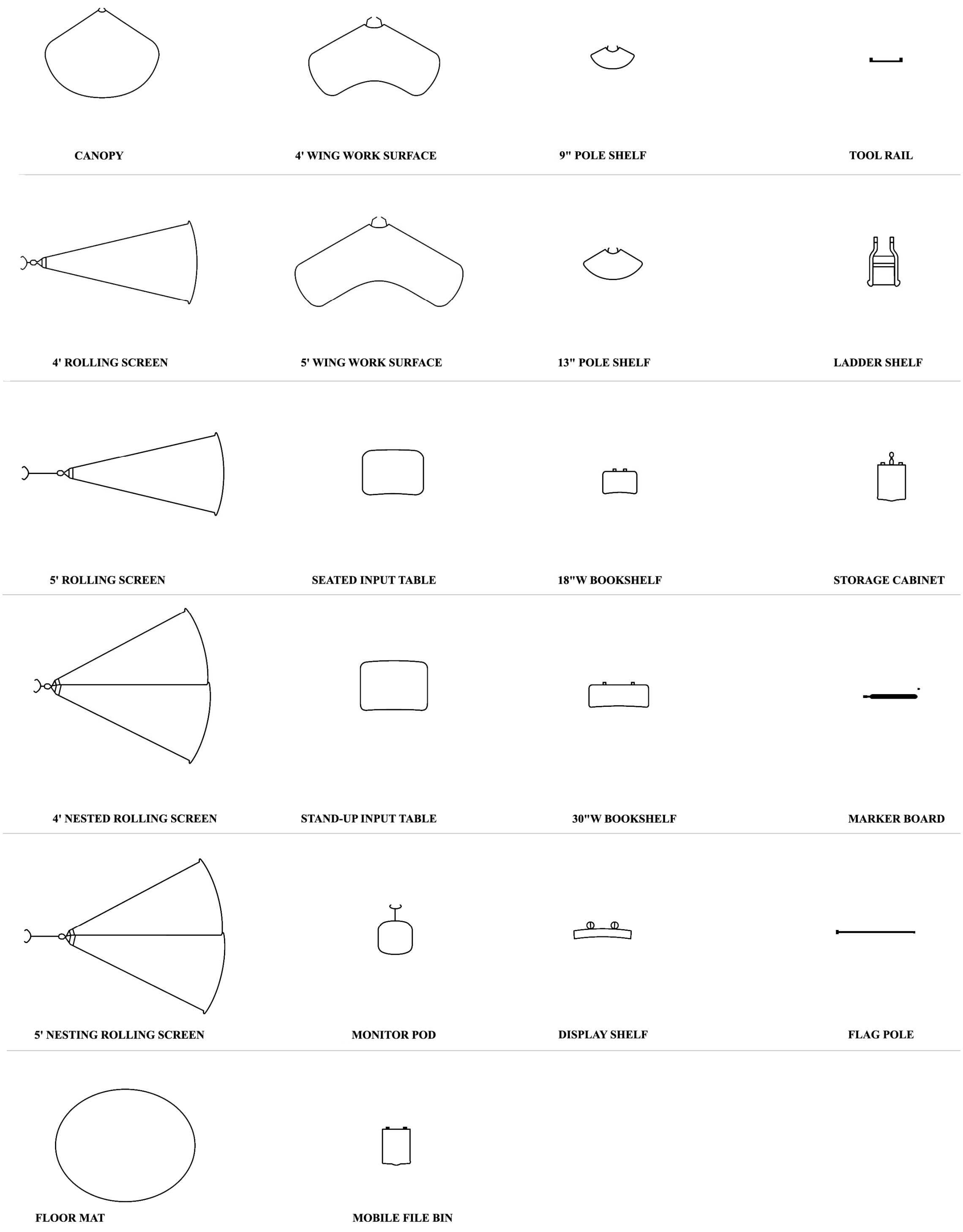

Figure 4.12. Modules of the system

(Source: www.hermanmiller.com)

"Move-Furniture-Not-People" Strategy: According to a study by the Facility Performance Group of the company, "As much as 50 percent of churn due to ongoing co-locations and teaming activities occurs because current furnishings do not adapt in place easily enough." was a result. To reduce the costs of reconfiguring, many companies have adopted a "universal planning" model with standardized workstations. When proximity needs change, they move people around rather than reconfiguring the layout. Considering these results Resolve has been produced.

As decentralized information management systems fill individual work spaces with networked personal computers and printers, and growing numbers of discrete gadgets enter the office, increasing churn requires disconnecting and reconnecting networked technology and a greater numbers of appliances more frequently. Access to cables strung though ceilings, floors, and panels is a growing issue for IT managers charged with ensuring reliable delivery of data and applications to the workstation. This system has given a good design solution with its modularity. So this shows that modularity is a good design method for many problems.

Material: Technological developments in construction materials have enabled and inspired a lighter architecture that does more with fewer materials to further reduce the use of natural resources. Improvements in the tensile strength of materials like Teflon coated fiber glass allow membrane structures to replace heavy steel beam edifices. New, flexible, and self-adjusting "smart" materials create organic structural systems that respond to different conditions as necessary.

Natural light: Growing awareness of circadian rhythms and other physical and psychological effects of daylight have increased interest in using architectural design to provide and augment natural light in interior spaces. In the new "architecture of lightness," the widespread use of glass and other translucent materials allows a high degree of light penetration to the interior. Membrane structures of Teflon-coated fiber glass transmit the full spectrum of visible light, resulting in interior spaces that have the feeling of the outdoors.

Acoustics: Our researchers offer a number of possible reasons for this initially surprising finding. First, observation and experience suggest that greater visual access actually gives people greater control over speech privacy. In wall- or panel-enclosed offices, people are less aware of who might overhear them or whom they might disturb by carrying on a hallway conversation. When people have a clear view of the surrounding environment and the other people in it, they modify their behavior accordingly.

In addition, field and laboratory research have documented findings indicating that noise is a relative phenomenon. It is a person's perception of sound, rather than a decibel level or any other measurable quality that determines its distracting effect. For example, studies show that people are more tolerant of noise if they are generating it themselves or if they associate it with activities they approve of or with people they like.

Practical Matters For Using The Components And Constellation Templates To Sketch Resolve Plans:

- **The 2 + 3 + 4 rule.** A stable Resolve constellation needs at least 2 120-degree angles, 3 arm pairs, and 4 poles. Each in-line pole must be between 2 120-degree angles.
- **Cabinets are not freestanding.** They must attach to support arms or poles.
- **It's only a connector.** Using the in-line pole as a 180-degree connector, extending two sets of arms in a straight line. In-line poles cannot support trusses, lamps, or power and telecommunications delivery.
- **Waste not, want not strategy:** Tall poles to carry power and data overhead, support overhead trusses, or hang 69-inch screens. In all other applications, short poles are used.
- **Uncluttered.** Resolve storage elements are designed for active storage. Locate shared, intermediate, and archival storage outside of the workstation.

Helpful Hints:

- **Second thoughts.** Sides can be easily added to base constellations to accommodate more storage or display or to provide more enclosure.
- **Personal space.** Floor mats define and ensure sufficient personal space for the occupant.
- **Space savings.** Two-sided stations like the Delta and Zigzag work well when space is tight.
- **Time savings.** Simplify planning and inventory management by standardizing on like-size components.
- **Making room.** A 4' work surface on a 5' arm leaves room for attaching storage on either side of the surface: a ladder shelf or cabinet on one side, a tool rail or monitor pod on the other.
- **Making more room.** Work surfaces oriented in an "outbound" position create a peninsula off the pole, making the work space feel larger and freeing up

infrastructure to support additional storage elements.

Customization: The Design on Textile (DOT) program turns Resolve fabric surfaces into canvasses up to imagination. The DOT Collection is composed of 10 series of compelling original images that can be digitally printed on Resolve boundary screens, rolling screens, flags, and canopies. The images are commissioned from several highly respected artists/designers who all used digital tools to create a diverse gallery of styles, colors, and patterns. User can select images from one series or combine images from different series to express the unique character and culture of a workplace and its people. User can intertwine art, color, lighting, and other visual content with a furniture product, user has such freedom in workplace design, and user has the tools to spark such stimulating visual experiences.

The fabric, inks, and hardware that make up DOT products are 100 percent recyclable and environmentally safe. (Miller 2000)

The Designer Series is a sampler of images from several designers, offering options from nature photos to people to abstract graphics. The spectrum of styles and techniques demonstrates some of what can be achieved with digital imaging.(see Figure 4.13)

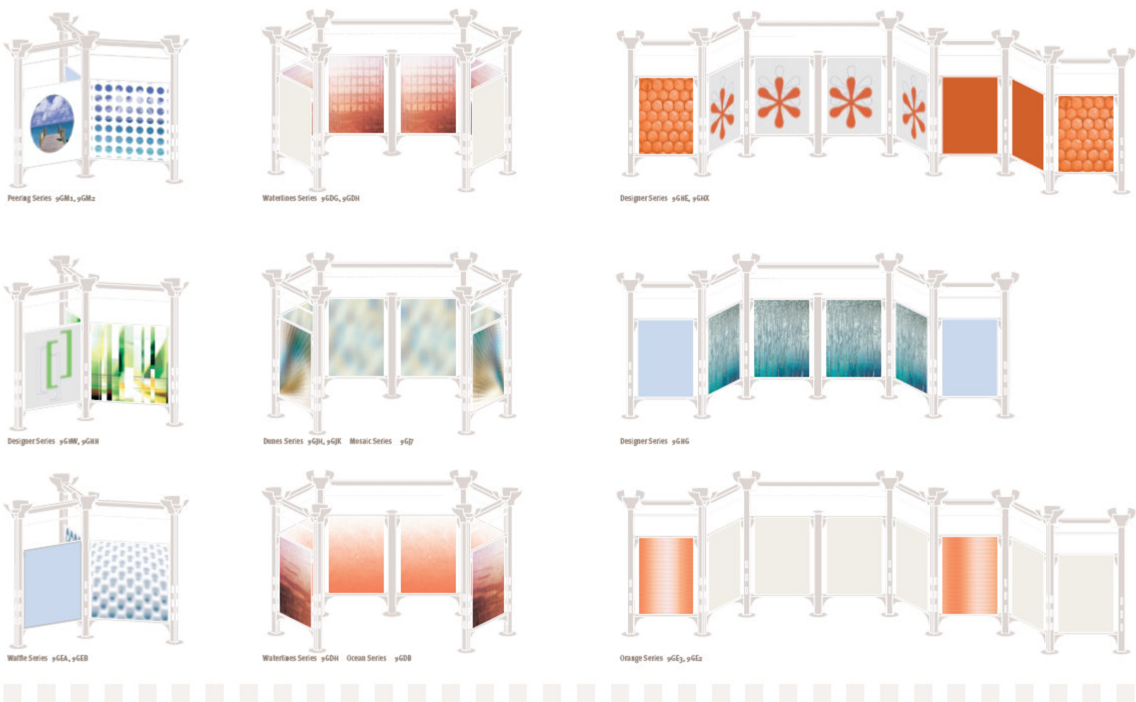

Figure 4.13. Fabrics of Resolve System

(Source: www.hermanmiller.com)

Table 4.1. Features of Overview

<table>
<tr><th colspan="5">FEATURES OF OVERVIEW</th></tr>
<tr><th></th><th colspan="2">MODULARITY</th><th colspan="2">CUSTOMIZATION</th></tr>
<tr><td>DEFINITIONS</td><td colspan="2">Modularity; refers simply to the degree to which a system’s components can be separated and recombined.</td><td colspan="2">Mass customization is a business strategy that aims at fulfilling
individual customer needs with near mass production efficiency (Pine 1993)</td></tr>
<tr><td rowspan="4">TYPES AND EXAMPLES</td><td>COMPONENT SHARING:
- Komatsu
- Swatch</td><td>COMPONENT SWAPPING
- Bowling ball, T-shirt, eyeglass frame,
- Swatch</td><td rowspan="2">COLLABORATIVE:
- Computers, clothing ,footwear, furniture, some services

- Eye Tailor
- Digitoe</td><td rowspan="2">TRANSPARENT :
- Smart ads – use observable behavior to show different ads
- Smart offers – one-to-one marketing
Example- repeat orders for customized clothing, chemicals...</td></tr>
<tr><td rowspan="2">CUT TO FIT MODULARITY:
- The National Bicycle Industrial Co.
- Custom Cut Technologies' jacket body, sleeves, lapels etc.</td><td rowspan="2">MIX MODULARITY:
- Campbell's Soup
- Vending Machines</td></tr>
<tr><td rowspan="2">ADAPTIVE:
- Eye System
- High-end office chairs, R7 golf club, certain electronic devices</td><td rowspan="2">COSMETIC:
- Customer’s chosen text or image on T-shirts, mouse mats, baseball caps, mugs etc.
- Planters Peanuts</td></tr>
<tr><td>BUS MODULARITY:
Personics, Tp.L. Minitel, TWA Getaway Vacations, and CNN</td><td>SECTIONAL MODULARITY:
-Lego, Agfa, Hitachi, Toshiba, NEC, Fujitsu</td></tr>
<tr><td rowspan="9">BENEFITS AND COSTS</td><td>Improved component economies of scale</td><td>Redundant physical architecture</td><td colspan="2">Increased customer satisfaction</td></tr>
<tr><td>Improved product variety</td><td>Excessive capability due to standardization</td><td colspan="2">Continual improvements, eventual technological superiority</td></tr>
<tr><td>Improved order lead-time</td><td>The potential for static product architectures and excessive product similarity</td><td colspan="2">Integration of innovation and production</td></tr>
<tr><td>Improved design and product focus</td><td>Increased likelihood of static product architecture</td><td colspan="2">Low costs and short cycle times</td></tr>
<tr><td>Ease of product diagnosis, maintenance, repair, and disposal</td><td>Compromised performance optimization</td><td colspan="2">Better fulfillment of customer wants and needs</td></tr>
<tr><td>Ease of component verification and testing</td><td>Ease of reverse engineering for competitors</td><td colspan="2">Frequent process innovations</td></tr>
<tr><td>Ease of managing differential consumption</td><td>Increased unit variable costs</td><td colspan="2" rowspan="3">Mutually beneficial relationships with other firms</td></tr>
<tr><td>Ease of product change</td><td rowspan="2">Excess in product similarity</td></tr>
<tr><td>Facilitates decoupling of tasks</td></tr>
</table>

FEATURES OF OVERVIEW		
	MODULARITY	**CUSTOMIZATION**
CHALLENGES	STANDARDIZATION	FLEXIBILITY
	REUSABILITY	MODULARITY
	LIFE-CYCLE	REUSABILITY
ADVANTAGES	**PRODUCT DEVELOPMENT AND DESIGN:** Modularity can cut the development costs by shortening the development time	Customer has control over product
	CUSTOMIZATION: The modularity concept can help the designer develop much more variance within quite a short time.	Does not have to pay for features he/she does not want
	PRODUCTION: Modularity is a useful way to create a large number of variants and reduce the number of parts at the same time.	'Not in your size' or 'Not as you wish' becomes a thing of the past
	QUALITY: Modules can get the tested separately; this can cut the cost of reworking and may increase the quality of the product.	Company does not have finished product inventory è better use of working capital
	PURCHASING: By defining the modules clearly, the corporations can define their purchase chains clearly	Easier for company to differentiate product
	AFTER - SALES: The corporations can benefit the customers again through updating new techniques in the products and providing enough maintenance in time by applying the modularity principals during the product development process	Levels out economic fluctuations When slowdown occurs, less backlog of inventory Prices do not have to be cut as much Therefore, less likelihood of recession
DISADVANTAGES	Modular design can be very complex	Increase in throughput time
	The designers can easily fall into the "common unit" trap	Extra inspections needed
	The variants from the same platform resemble each other and may not be attractive to customers	Tied up resources

RESOLVE SYSTEM		
	MODULARITY FEATURES	**CUSTOMIZATION FEATURES**
TYPES	Component sharing and component-swapping are the complements of each other as the distinction between both is a matter of degree. Because both of them provides high value to the user; once separated, modules should be easily and seamlessly reintegrated; and system should have great variety to meet differing customer needs and wants; which Resolve is facing all	Collaborative customization is used generally at furniture industry. At Resolve System all features of collaborative customization can be seen. Because user specifications are determined with a professional research and by the way user has control over the design tool.
	Mix modularity can use any of the other types, with the clear distinction that the components are so mixed together that they themselves become something different, so at Resolve system this type of modularity allows customizing the units according to user.	Adaptive customization, in which the customer controls the design tool or the tool is imbedded into the product itself and Resolve system can be the example because inside the product families different alternatives can be varied.
	Cut-to fit modularity is also used throughout the system because at storage systems and table tops and office chairs, components are discontinuous in size for fitting the user needs.	Transparent customization, where the service provider customizes the product for user but doesn't tell what it's doing. It observes your behavior and then gives user what he wants. So not very related with the system. Transparent and also cosmetic customization is explained at previous pages.
	Bus modularity is also used as the slot as the panels which also lets customization of the accents of Resolve system.	
FEATURES	At Resolve system, modularity is used throughout all the system infrastructure as it is scaffolding made up of vertical poles and horizontal arms organized in 120 degree angles.	Concept of the system and components can be customized according to user. User needs are considered and determined throughout a professional research.
	Easy to assemble and disassemble, easy to remember and order.	95% recyclable materials and environmentally modules are used.
	System consists of limited and controlled number of modules brings many facilities.	Resolve fabric surfaces into canvasses up to imagination.

CONCLUSION

In my opinion, at the end of this paper some weakness will be selected to interpret modularity's limitations. Firstly modular systems are much more difficult to design than comparable interconnected systems. Secondly the designers tend to produce a "common unit" rather than a modular system. Thirdly the variants from the same platform sometimes look alike. Thus, Resolve System is a very good example for carrying out the main points of thesis.

The research presented in this document focuses on developing design tools, based on past and present academic research, for use in industrial settings where the design of a customizable modular system is the goal.

CHAPTER 5

CONCLUSION

In this study it has been attempted to emphasize that customization at modular system design concepts and aspects are a part of industrial design processes and has a very important role.

Furthermore analyzes the aspect of what is commonly understood as "modularity" and “modular systems” in the industrial design literature.

Concept of modularity is analyzed and types of modularity are explained including good and bad applications of modularity in the second chapter.

As can be understood the intension of the thesis is to analyze the role of customization at modular system design and to emphasize the aspects of modularity and customization both at different industries.

Besides customization brings modularity which has meaning as; every customized product is produced as modular. So that, these phrases have meanings very interdependent. Modularity can exist without customization however it is not enough for today. People’s needs change towards upon recycle, reusable, qualified and customized products. Thus as a result of user needs modularity is interdependent to customization and while customization is a method of considering user needs has to be formed using modular product design.

In the third chapter, customization analyzed through modularity. Types of customization and examples from different industries are chosen to support the thesis. The effects of mass customization can be seen anywhere growing. However there are some points to be careful like; the choices should not have a chaos effect as it is a subject of fractal structures. Chaos, effects user and so design becomes unsuccessful.

According to me, mass customization is possible because of the newest techniques and the changes in business processes. But the most important reason for a success in mass customization lies in human’s actions. There are many techniques and methods available, but it still has to be realized by people themselves. In implementing mass customization in a company it is very important that user is defined and well known. Knowing the principles of economic value creation and mass customization are also good bases that will lead to a successful ending.

Another important fact is not to copy other competitors. Changing business processes can be done in various ways, but every company is different and thus has to deal with things differently. A company should try to be focused on its own area and try to follow the steps in a way that fits.

At the end of the thesis, there is a good example which meets at every point to what has been analyzed through the thesis. A modular system furniture design is taken, as an example. In this system, design elements are stated as:

1. Person,
2. Point,
3. Line,
4. Plane,
5. Volume.

Besides, these elements are taken considering modularity principles. As a result of researches, made by the professional design group, user needs are determined and according to user needs, design concept is stated. Customization is a main part of design concept because person is the starting point of the system.

As a result, my study became a useful application guide for modular system designers.

REFERENCES

Aarts, E.,Marzano,S.,(2003), "*The New Everyday*" (010 Publishers, Rotterdam, The Netherlands)

Abernathy, W. J. and J. M. Utterback, 1978, "Pattern of industrial innovation", (*Technology Review*, 80, 7, June-July).

Alexander, C., "Perception and Modular Co-ordination", *Journal of the Royal Institute of British Architects,* Vol. 66 (1959), pp. 425-429.

Alexander, C., Anninou, A., Black, G. and Rheinfrank, J., "Towards a Personal Workplace", *Architectural Record Interiors,* Vol. Mid-September (1987), pp. 131-141.

Baldwin, Carliss Y. and Kim B. Clark (1992) "Modularity and Real Options: An Exploratory Analysis" (Harvard Business School Working Paper, October).

Baldwin, Carliss Y. ; Clark, Kim B. (1997) "Managing in an Age of Modularity" (Harvard Business Review year: vol: 75 issue: 5 pages: 81-94 publisher: Harvard Business School Publication Corp. provider: Ebsco doc type: Journal paper).

Baldwin, Carliss Y. and Kim B. Clark (2000). "*Design Rules, Volume 1, The Power of Modularity"*, (MIT Press, Cambridge MA).

Baldwin, Carliss Y. and Kim B. Clark (2002) "Where Do Transactions Come From? A Perspective from Engineering Design," (Harvard Business School Working Paper pp. 03-031, Boston, MA).

Birsel, Ayşe, (1999) "Herman Miller, Inc.", (Zeeland, Michigan Printed in U.S.A).

Chun-Che Huang (2000) **"**Overview of Modular Product Development" (*Laboratory of Intelligent Systems and Information Management Department of Information Management National Chi-Nan University R.O.C. Proc. Natl. Sci. Counc. ROC(A)* Vol. 24, No. 3, 2000. pp. 149-165. *Puli, Taiwan).*

Erixon,G.,et al.(1994) "Modularise the product", (Industrilitteratur, Stockholm).

Gershenson J. K., G. J. Prasad , S. Allamneni, (1999): "Modular Product Design: A Life-Cycle View", (*Journal of Integrated Design and Process Science,*Vol. 3, No. 4, 14)

Gershenson, J.K. ; Prasad, G.J. ; Zhang, Y. (2003) “Product modularity: definitions and benefits”, (Journal of Engineering Design year, vol:14, pp. 295-314, Carfax Publishing Company, Ebsco).

Hart, Christopher W. (1996) “Made to Order” (Marketing Management summer 1996, Vol. 5, No. 2, pp. 10-23).

Krikke, Harold ; le Blanc, Ieke ; van de Velde, Steef (2004) “Product Modularity and the Design of Closed-Loop Supply Chains” (California Management Review year, vol, 46 issue, pp. 23-40, California Management, Ebsco).

Kusiak, Andrew (2002) “Integrated product and process design: a modularity perspective” (Journal of Engineering Design year, vol: 13, issue: 3, pp. 223-232, Carfax Publishing Company, Ebsco).

Nevins, J. L. and D. E. Whitney (1989) “Concurrent Design of Products and Processes: a Strategy for the Next Generation in Manufacturing”. (McGraw-Hill, New York, NY, U.S.A.)

Norman, Donald A. (2004) “Emotional Design: Why We Love *(or Hate)* Everyday Things” (Basic Books, Newyork)

Pahl, G. and W. Beitz (1988) “Engineering Design”. (The Design Council, U.K).

Pine II, B.J., (1993). “Mass Customization: The New Frontier in Business Competition”. (Harvard Business School Press, Cambridge, MA).

Pine, B. J., II, (1993), "Mass Customizing Products and Services," (Planning Review, Vol. 22, No. 4, pp. 6).

Pine II, B.J. / Victor, B. / Boynton, A.C. (1993) “Making mass customization work”, (Harvard Business Review, 7(5) 1993, pp.108-121)

Pine II, B.J. / Gilmore J.B. (1999) “The Experience Economy: Work is Theatre & Every Business a Stage”, (Harvard Business School Press, Boston, Massachusetts 1999).

Pine II, B.J. / Gilmore J.B. (2003) “The Pıne and Gılmore Body Of Knowledge, www.customization.com, cited 28 July 2003.

Salvador, F. ; Forza, C. ; Rungtusanatham, M. (2002) “Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions.” (Journal of Operations Management year, vol: 20 issue: pp. 549-576, Elsevier Science, Ebsco).

Sanchez R, Mahoney J. (1996). “Modularity, Flexibility, and Knowledge Management in Product and Organization Design”, (Strategic Management Journal, 17(10), pp. 63-76).

Sanchez Ron,(2000) “International Institute for Management Development - Lausanne. Interview, Alan McCluskey”,

Sanchez, R. (May 2002) “Fitting together a modular approach” (Manufacturing Engineer year, vol: 81 issue: 5 pages: 216-218 publisher: IEE/IEEE provider: IEEE doc type: Journal paper).

Schilling, Melissa A. (April 2000). “Toward a General Modular System Theory and its Application to Interfirm Product Modularity.”

Shirley, G. V. (1990) “Models for managing the redesign and manufacture of product sets”, (*Journal of Manufacturing and Operations Management*, 3(1), 85-104).

Stan Davis and Bill Davidson, (1991) “2020 Vision” (New York: Simon&Shuster, 1991, pp:15-16)

Tseng, M. and Jiao, J., (1998), "Design for Mass Customization by Developing Product Family Architecture," (*ASME Design for Manufacture Conference*, Atlanta, GA. Paper Number DETC98/DFM-5717).

Ulrich, K. and K. Tung (1991) “Fundamentals of product modularity”, (In: *Issues in Design/Manufacture Integration 1991*, pp. 73-79. A. Sharon Ed. ASME, New York, NY, U.S.A.)

Ulrich, K. T. and S. D. Eppinger (1995) “*Product Design and Development*” (McGraw-Hill, New York, NY, U.S.A.).

Uzumeri, Mustafa and Sanderson; Susan W. (1997), *Managing Product Families*. Irwin/McGraw-Hill.

WEB_1, 2005. Gerber Scientific, Corporate Overview website, http://www.mass-customization.com

WEB_2, 2005. SDPS Website Online Journals, http://www.sdpsnet.org/journals/vol3-4/gerhonson.pdf

WEB_3, 2005. 121 Time Swiss watch manufacturer for customized watch and personalized gift: buy watch online website, http://www.factory121.com

WEB_4, 2005. Official Swatch e-store web site, http://www.store.swatch.com

WEB_5, 2005. Ford Motor Company – Design, http://www.ford.com

WEB_6, 2005. IKEA Türkiye Online Katalog, http://www.ikea.com.tr/catalogue06

WEB_7, 2004. Schmal Online Katalog, http://www.csschmal.com

WEB_8, 2005. Modular architecture "Interview with Ron Sanchez", http://www.connected.org/media/modular.html

WEB_9, 2005. Strategic Horizons LLP website; http://www.customization.com

WEB_10, 2000. Herman Miller - for Business - Resolve System, http://www.hermanmiller.com

WEB_11, 2005. Otabo Fine Custom Fit Shoes, http://www.otabo.com

WEB_12, 2005. Vending Machine Website, http://www.e-vending.com/coffee_ vending_machines.htm

WEB_13, 2005. Asymptote Website, http://www.asymptote.net/downloads/fullscreen_images/a3.pdf

WEB_14, 2005. T-Shirts, Custom T-Shirts, Shirt Screen Printers, Design Online at Custom Ink Website, Service for Customized Materials; http://www.customink.com