

Industrial Design Engineering



Nicolas Cooley

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Chapter 1

Industrial Design



An iPod, an industrially designed product.



KitchenAid 5 qt. Stand Mixer, designed in 1937 by Egmont Arens, remains very successful today

Industrial design is a combination of applied art and applied science, whereby the aesthetics, ergonomics and usability of products may be improved for marketability and production. The role of an industrial designer is to create and execute design solutions towards problems of form, usability, physical ergonomics, marketing, brand development and sales.

The term "industrial design" is often attributed to the designer Joseph Claude Sinel in 1919 (although he himself denied it in later interviews) but the discipline predates that by at least a decade. Its origins lay in the industrialization of consumer products. For instance the Deutscher Werkbund, founded in 1907 and a precursor to the Bauhaus, was a state-sponsored effort to integrate traditional crafts and industrial mass-production techniques, to put Germany on a competitive footing with England and the United States.

Definition of industrial design



Western Electric model 302 Telephone, found almost universally in the United States from 1937 until the introduction of touch-tone dialing, as the Family's life was extended into the 1960s

General

The objective of this area is to study both function and form, and the connection between product and the user - product as it happens in any other architecture area, being the only difference, that here the professionals that participate in the process are all specialized in small scale design, rather than in other massive colossal equipments like buildings or ships. Architects do not design the gears or motors that make machines move, or the circuits that control the movement (that task is usually attributed to engineers), but they can affect technical aspects through usability design and form relationships. And usually, they partner a whole of other professionals like marketers, to identify and fulfill needs, wants and expectations.

In Depth

"Industrial Design (ID) is the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer".

Design, itself, is often difficult to define to non-designers because the meaning accepted by the design community is not one made of words. Instead, the definition is created as a result of acquiring a critical framework for the analysis and creation of artifacts. One of the many accepted (but intentionally unspecific) definitions of design originates from Carnegie Mellon's School of Design, "Design is the process of taking something from its existing state and moving it to a preferred state." This applies to new artifacts, whose existing state is undefined, and previously created artifacts, whose state stands to be improved.

According to the Chartered Society of Designers, design is a force that delivers innovation that in turn has exploited creativity. Their design framework known as the Design Genetic Matrix determines a set of competences in 4 key genes that are identified to define the make up of designers and communicate to a wide audience what they do. Within these genes the designer demonstrates the core competences of a designer and specific competences determine the designer as an 'industrial designer'. This is normally within the context of delivering innovation in the form of a three dimensional product that is produced in quantity. However the definition also extends to products that have been produced using an industrial process.

According to the ICSID (International Council of Societies of Industrial Design), "Design is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life-cycles. Therefore, design is the central factor of innovative humanization of technologies and the crucial factor of cultural and economic exchange."

It is critical to the product development process that the industrial design and engineering aspects of a product are considered simultaneously. This can occur via two methods. The most streamlined method is for the product designer to have an education and/or background that encompasses both industrial design and engineering. Unfortunately, there are very few educational establishments (especially in the United States) that embrace this educational ideology. A survey of engineering and industrial design curricula clearly demonstrates this fault. The other method, which is utilized by most U.S. companies, is to employ or contract with separate teams that focus somewhat independently, with occasional meetings to ensure the primary goals of each team are met or exceeded. The difficulty with the latter process is that there is sometimes a vast disconnect behind the skills, education, and understanding of the two groups. This disconnect can sometimes become extremely cumbersome to the design process, and possibly fatal to the ultimate success of the product.

Process of design



A Fender Stratocaster with sunburst finish, one of the most widely recognized electric guitars in the world.



Model 1300 Volkswagen Beetle

Although the process of design may be considered 'creative', many analytical processes also take place. In fact, many industrial designers often use various design methodologies in their creative process. Some of the processes that are commonly used are user research, sketching, comparative product research, model making, prototyping and testing. These processes can be chronological, or as best defined by the designers and/or other team members. Industrial designers often utilize 3D software, computer-aided industrial design and CAD programs to move from concept to production. Product characteristics specified by the industrial designer may include the overall form of the object, the location of details with respect to one another, colors, texture, sounds, and aspects concerning the use of the product ergonomics. Additionally the industrial designer may specify aspects concerning the production process, choice of materials and the way the product is presented to the consumer at the point of sale. The use of industrial designers in a product development process may lead to added values by improved usability, lowered production costs and more appealing products. However, some classic industrial designs are considered as much works of art as works of engineering: the iPod, the Jeep, the Fender Stratocaster, the Coke bottle, and the VW Beetle are frequently cited examples.

Industrial design also has a focus on technical concepts, products and processes. In addition to considering aesthetics, usability, and ergonomics, it can also encompass the engineering of objects, usefulness as well as usability, market placement, and other concerns such as seduction, psychology, desire, and the emotional attachment of the user to the object. These values and accompanying aspects on which industrial design is based can vary, both between different schools of thought and among practicing designers.

Product design and industrial design can overlap into the fields of user interface design, information design and interaction design. Various schools of industrial design and/or product design may specialize in one of these aspects, ranging from pure art colleges (product styling) to mixed programs of engineering and design, to related disciplines like

exhibit design and interior design, to schools where aesthetic design is almost completely subordinated to concerns of function and ergonomics of use (the so-called *functionalist* school).

Also used to describe a technically competent product designer or industrial designer is the term *Industrial Design Engineer*. The Cyclone vacuum cleaner inventor James Dyson for example could be considered to be in this category.

Industrial design rights

Industrial design rights are intellectual property rights that make exclusive the visual design of objects that are not purely utilitarian. An industrial design consists of the creation of a shape, configuration or composition of pattern or color, or combination of pattern and color in three dimensional form containing aesthetic value. An industrial design can be a two- or three-dimensional pattern used to produce a product, industrial commodity or handicraft. Under the Hague Agreement Concerning the International Deposit of Industrial Designs, a WIPO-administered treaty, a procedure for an international registration exists. An applicant can file for a single international deposit with WIPO or with the national office in a country party to the treaty. The design will then be protected in as many member countries of the treaty as desired.

Notable industrial designers

A number of industrial designers have made such a significant impact on culture and daily life that they have attained a level of notability beyond that of an average designer. Alvar Aalto, renowned as an architect, also designed a significant number of household items, such as chairs, stools, lamps, a tea-cart, and vases. Raymond Loewy was a prolific American designer who is responsible for the Royal Dutch Shell corporate logo, the original BP logo (in use until 2000), the PRR S1 steam locomotive, the Studebaker Starlight (including the later iconic bulletnose), as well as Schick electric razors, Electrolux refrigerators, short-wave radios, Le Creuset French ovens, and a complete line of modern furniture, among many other items. Richard A. Teague, who spent most of his career with the American Motor Company, originated the concept of using interchangeable body panels so as to create a wide array of different vehicles using the same stampings. He was responsible for such unique automotive designs as the Pacer, Gremlin, Matador coupe, Jeep Cherokee, and the complete interior of the Eagle Premier. Viktor Schreckengost designed bicycles manufactured by Murray bicycles for Murray and Sears, Roebuck and Company. With engineer Ray Spiller, he designed the first truck with a cab-over-engine configuration, a design in use to this day. Schreckengost also founded The Cleveland Institute of Art's school of industrial design. Charles and Ray Eames were most famous for their unique furniture design, such as the Eames Lounge Chair Wood and Eames Lounge Chair.

Another example is German industrial designer Dieter Rams, who is closely associated with the consumer products company Braun (where he worked until 1995) and the Functionalist school of industrial design. He is famous for his "ten principles to good

design", in addition to designing many iconic products at Braun. More recently, Jonathan Ive, the Senior Vice President of Design at Apple Inc., is credited for designing products for the company, which has a strong philosophy in aesthetics. His designs include the iPod and iPhone.

Chapter 2

Electric Guitar Design

Electric Guitar Design is a type of industrial design where the looks and efficiency of the shape as well as the acoustical aspects of the guitar are important factors. In the past many guitars have been designed with all kinds of odd shapes as well as very practical and convenient solutions to improve the usability of the object.

History

George Beauchamp invented the electric guitar or some may call the lap steel guitar. Initially, electric guitars consisted primarily of hollow archtop acoustic guitar bodies to which electromagnetic transducers had been attached.

Early years

Aug. 10, 1937.

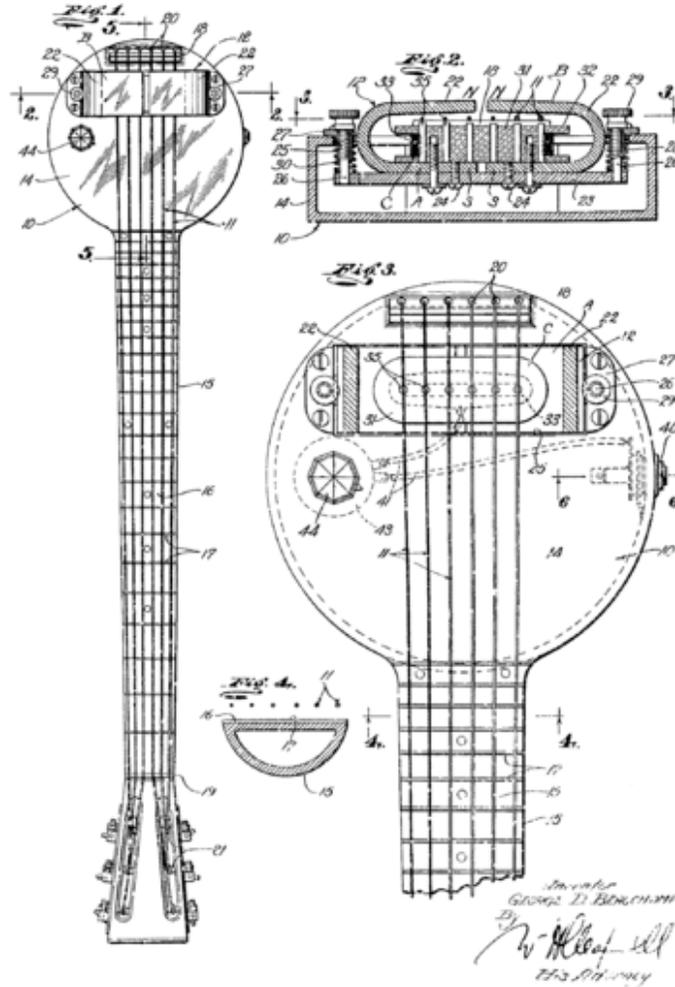
G. D. BEAUCHAMP

2,089,171

ELECTRICAL STRINGED MUSICAL INSTRUMENT

Filed June 2, 1934

3 Sheets-Sheet 1



Sketch of Rickenbacker "frying pan" lap steel guitar from 1934 patent application.

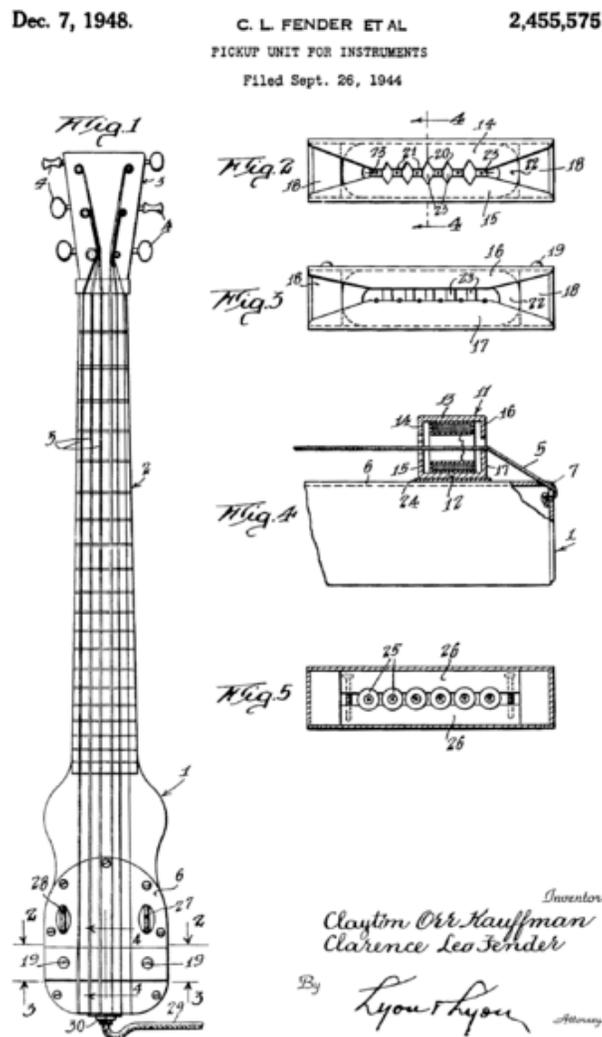
Electric guitars were originally designed by an assortment of luthiers, electronics enthusiasts, and instrument manufacturers, in varying combinations. Some of the earliest electric guitars, then essentially adapted hollow bodied acoustic instruments, used tungsten pickups and were manufactured in the 1930s by Rickenbacker. In 1935, a Soviet scientist working separately from his western colleagues was known to have produced an electric Russian guitar called the "Kuznetsov electromagnetic guitar". It was exhibited at a technology expo in Moscow, but its development was halted since the Stalin regime was hostile to guitar music.

At least one company, Audiovox, built and may have offered an electric solid-body as early as the mid-1930s. Rickenbacker, later spelled *Rickenbacker* offered a cast

aluminum electric guitar, nicknamed **The Frying Pan** or **The Pancake Guitar**, beginning in 1933.

Another early solid body electric guitar was designed and built by musician and inventor Les Paul in the early 1940s, working after hours in the Epiphone Guitar factory. His **log guitar** (so called because it consisted of a simple 4x4 wood post with a neck attached to it and homemade pickups and hardware, with two detachable Swedish hollow body halves attached to the sides for appearance only) was patented and is often considered to be the first of its kind, although it shares nothing in design or hardware with the solid body "Les Paul" model sold by Gibson.

Fender



Sketch of Fender lap steel guitar from 1944 patent application.

In 1950 and 1951, electronics and instrument amplifier maker Leo Fender through his company, designed the first commercially successful solid-body electric guitar with a

single magnetic pickup, which was initially named the "Esquire". The two-pickup version of the Esquire was called the "Broadcaster". The bolt-on neck was consistent with Leo Fender's belief that the instrument design should be modular to allow cost-effective and consistent manufacture and assembly, as well as simple repair or replacement.

In 1954, Fender introduced the Fender Stratocaster, or "Strat". It was positioned as a deluxe model and offered various product improvements and innovations over the Telecaster. These innovations included an ash or alder double-cutaway body design for badge assembly with an integrated vibrato mechanism (called a *synchronized tremolo* by Fender, thus beginning a confusion of the terms that still continues), three single-coil pickups, and body comfort contours. Leo Fender is also credited with developing the first commercially-successful electric bass called the Fender Precision Bass, introduced in 1951.

Gibson

Gibson, like many guitar manufacturers, had long offered semi-acoustic guitars with pickups, and previously rejected Les Paul and his "log" electric in the 1940s. In apparent response to the Telecaster, Gibson introduced the first Gibson Les Paul solid body guitar in 1952 (although Les Paul was actually brought in only towards the end of the design process for expert fine tuning of the nearly complete design and for marketing endorsement). Features of the Les Paul include a solid mahogany body with a carved maple top (much like a violin and earlier Gibson archtop hollow body electric guitars) and contrasting edge binding, two single-coil "soapbar" pickups, a 24¾" scale mahogany neck with a more traditional glued-in "set" neck joint, binding on the edges of the fretboard, and a tilt-back headstock with three machine heads (tuners) to a side. The earliest models had a combination bridge and trapeze-tailpiece design that was in fact designed by Les Paul himself, but was largely disliked and discontinued after the first year. Gibson then developed the Tune-o-matic bridge and separate stop tailpiece, an adjustable non-vibrato design that has endured. By 1957, Gibson had made the final major change to the Les Paul as we know it today - the humbucking pickup, or humbucker. The humbucker, invented by Seth Lover, was a dual-coil pickup which featured two windings connected out of phase and reverse-wound, in order to cancel the 60-cycle hum associated with single-coil pickups; as a byproduct, however, it also produces a distinctive, more "mellow" tone which appeals to many guitarists. The more traditionally designed and styled Gibson solid-body instruments were a contrast to Leo Fender's modular designs, with the most notable differentiator being the method of neck attachment and the scale of the neck (Gibson-24.75", Fender-25.5"). Each design has its own merits. To this day, the basic design of many solid-body electric guitar available today are derived from the original designs - the Telecaster, Stratocaster and the Les Paul.

Vox

In 1962 Vox introduced the pentagonal Phantom guitar, originally made in England but soon after made by EKO of Italy. It was followed a year later by the teardrop-shaped Mark VI, the prototype of which was used by Brian Jones of The Rolling Stones. Vox

guitars also experimented with onboard effects and electronics. The Teardrop won a prize for its design. In the mid 1960s, as the sound of electric 12 string guitar became popular, Vox introduced the Phantom XII and Mark XII electric 12 string guitars. Vox produced many more traditional 6 and 12 string electric guitars in both England and Italy.

GuitarOrgan

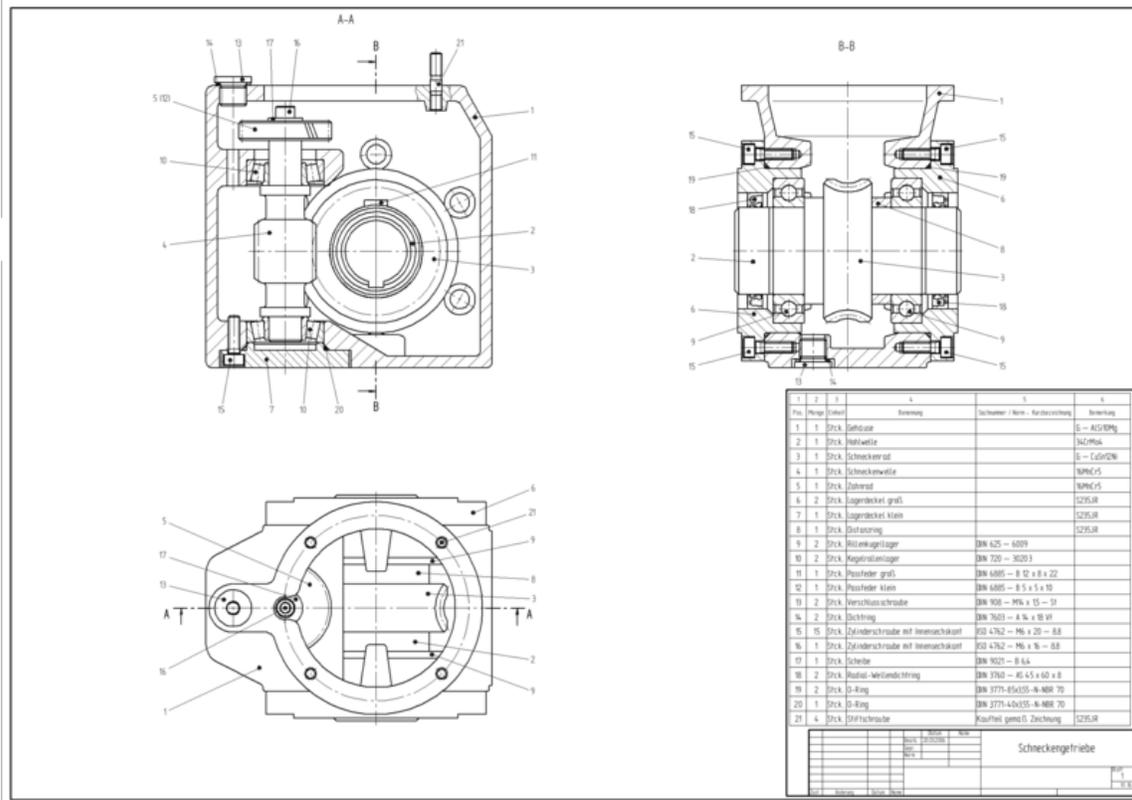
In 1966 Vox introduced the revolutionary but problematic GuitarOrgan, a Phantom VI guitar with internal organ electronics. The instrument's trigger mechanism required a specially-wired plectrum that completed circuit connections to each fret, resulting in a very wide and unwieldy neck. John Lennon was given one in a bid to secure an endorsement, though this never panned out. According to *Up-Tight: the Velvet Underground Story*, Brian Jones of the Rolling Stones also tried one; when asked by the Velvets if it "worked", his answer was negative. The instrument never became popular, but it was a precursor to the modern guitar synthesizer.

Other guitars

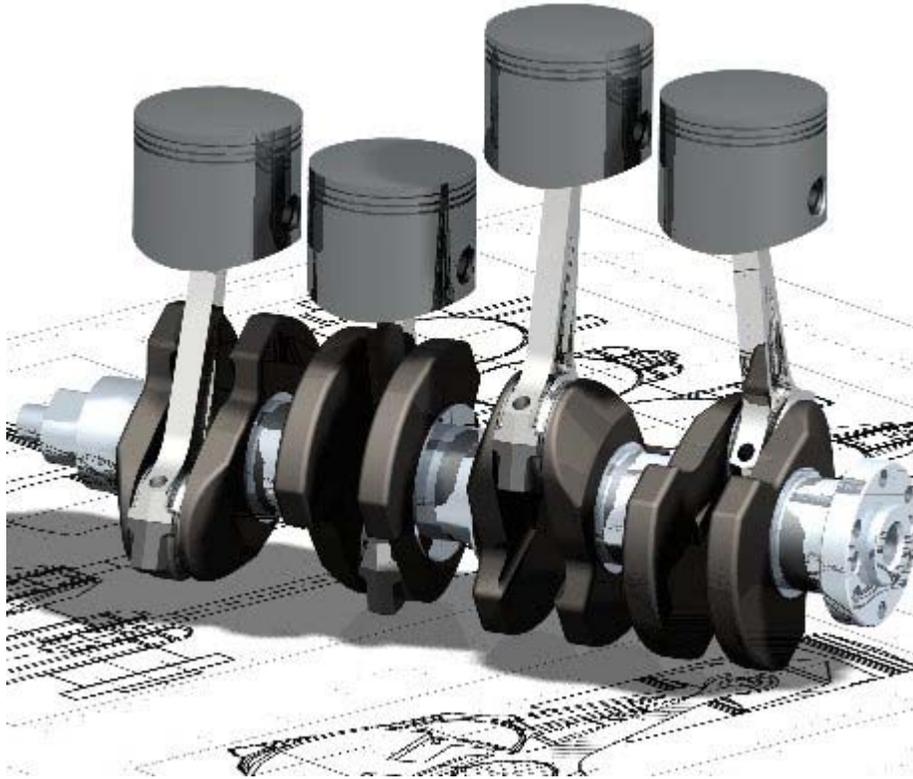
Also other materials than wood were used. Travis Bean as well as Kremer built guitars with aluminium necks. Danelectro used masonite bodies. Also plastic and carbon bodied guitars have been made in the past. The Gittler guitar was a design guitar made in the 80s. 1991 saw the introduction of guitar designer Jol Dantzig's first truly workable acoustic-electric hybrid guitar design. The instrument, called the DuoTone, was conceived while Dantzig was at Hamer Guitars. (Dantzig was also the designer of the first 12 string bass.) Adapted by players like Ty Tabor, Stone Gossard, Elvis Costello and Jeff Tweedy, the DuoTone was a full "duplex" instrument that could switch between acoustic and electric tones. Recently there have been many entries in the hybrid category (capable of both acoustic and electric tones) including the T5 by Taylor, Michael Kelly's "Hybrid," the Parker Fly and the Anderson Crowdster. In the 90s the band Neptune began building weird looking metal guitar with 3rd Bridge options incorporated. A predecessor of this type of guitars is the Pencilina. Linda Manzer designed the Picasso guitar with multiple necks.

Chapter 3

Computer-Aided Design



Example 2D CAD drawing



Example 3D CAD model

Computer-aided design (CAD), also known as **computer-aided design and drafting (CADD)**, is the use of computer technology for the process of design and design-documentation. Computer Aided Drafting describes the process of drafting with a computer. CADD software, or environments, provides the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CADD output is often in the form of electronic files for print or machining operations. The development of CADD-based software is in direct correlation with the processes it seeks to economize; industry-based software (construction, manufacturing, etc.) typically uses vector-based (linear) environments whereas graphic-based software utilizes raster-based (pixelated) environments.

CADD environments often involve more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions.

CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) objects.

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for

special effects in movies, advertising and technical manuals. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

The design of geometric models for object shapes, in particular, is often called *computer-aided geometric design (CAGD)*.

Overview

Beginning in the 1980s Computer-Aided Design programs reduced the need of draftsmen significantly, especially in small to mid-sized companies. Their affordability and ability to run on personal computers also allowed engineers to do their own drafting work, eliminating the need for entire departments. In today's world most, if not all, students in universities do not learn drafting techniques because they are not required to do so. The days of hand drawing for final drawings are almost obsolete. Universities no longer require the use of protractors and compasses to create drawings, instead there are several classes that focus on the use of CAD software such as Pro Engineer or IEAS-MS.

Current computer-aided design software packages range from 2D vector-based drafting systems to 3D solid and surface modellers. Modern CAD packages can also frequently allow rotations in three dimensions, allowing viewing of a designed object from any desired angle, even from the inside looking out. Some CAD software is capable of dynamic mathematic modeling, in which case it may be marketed as **CADD** — *computer-aided design and drafting*.

CAD is used in the design of tools and machinery and in the drafting and design of all types of buildings, from small residential types (houses) to the largest commercial and industrial structures (hospitals and factories).

CAD is mainly used for detailed engineering of 3D models and/or 2D drawings of physical components, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to definition of manufacturing methods of components. It can also be used to design objects.

CAD has become an especially important technology within the scope of computer-aided technologies, with benefits such as lower product development costs and a greatly shortened design cycle. CAD enables designers to lay out and develop work on screen, print it out and save it for future editing, saving time on their drawings.

Uses

Computer-aided design is one of the many tools used by engineers and designers and is used in many ways depending on the profession of the user and the type of software in question.

CAD is one part of the whole Digital Product Development (DPD) activity within the Product Lifecycle Management (PLM) process, and as such is used together with other tools, which are either integrated modules or stand-alone products, such as:

- Computer-aided engineering (CAE) and Finite element analysis (FEA)
- Computer-aided manufacturing (CAM) including instructions to Computer Numerical Control (CNC) machines
- Photo realistic rendering
- Document management and revision control using Product Data Management (PDM).

CAD is also used for the accurate creation of photo simulations that are often required in the preparation of Environmental Impact Reports, in which computer-aided designs of intended buildings are superimposed into photographs of existing environments to represent what that locale will be like were the proposed facilities allowed to be built. Potential blockage of view corridors and shadow studies are also frequently analyzed through the use of CAD.

Types

There are several different types of CAD. Each of these different types of CAD systems require the operator to think differently about how he or she will use them and he or she must design their virtual components in a different manner for each.

There are many producers of the lower-end 2D systems, including a number of free and open source programs. These provide an approach to the drawing process without all the fuss over scale and placement on the drawing sheet that accompanied hand drafting, since these can be adjusted as required during the creation of the final draft.

3D wireframe is basically an extension of 2D drafting (not often used today). Each line has to be manually inserted into the drawing. The final product has no mass properties associated with it and cannot have features directly added to it, such as holes. The operator approaches these in a similar fashion to the 2D systems, although many 3D systems allow using the wireframe model to make the final engineering drawing views.

3D "dumb" solids are created in a way analogous to manipulations of real world objects (not often used today). Basic three-dimensional geometric forms (prisms, cylinders, spheres, and so on) have solid volumes added or subtracted from them, as if assembling or cutting real-world objects. Two-dimensional projected views can easily be generated

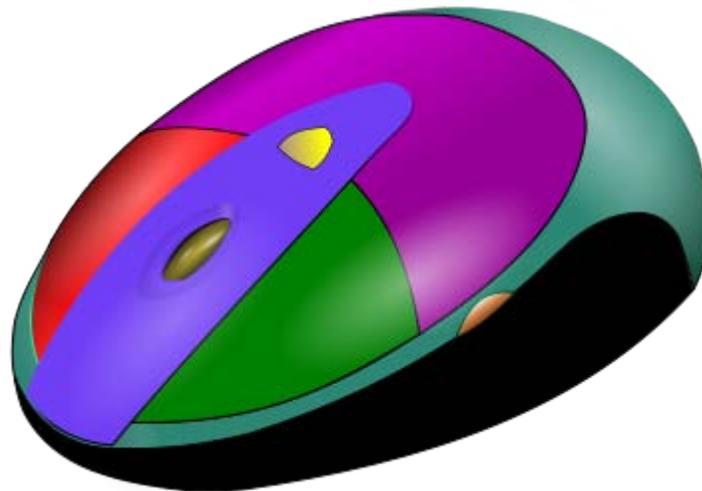
from the models. Basic 3D solids don't usually include tools to easily allow motion of components, set limits to their motion, or identify interference between components.

3D parametric solid modeling require the operator to use what is referred to as "design intent". The objects and features created are adjustable. Any future modifications will be simple, difficult, or nearly impossible, depending on how the original part was created. One must think of this as being a "perfect world" representation of the component. If a feature was intended to be located from the center of the part, the operator needs to locate it from the center of the model, not, perhaps, from a more convenient edge or an arbitrary point, as he could when using "dumb" solids. Parametric solids require the operator to consider the consequences of his actions carefully.

Some software packages provide the ability to edit parametric and non-parametric geometry without the need to understand or undo the design intent history of the geometry by use of direct modeling functionality. This ability may also include the additional ability to infer the correct relationships between selected geometry (e.g., tangency, concentricity) which makes the editing process less time and labor intensive while still freeing the engineer from the burden of understanding the model's. These kind of non history based systems are called Explicit Modellers or Direct CAD Modelers.

Top end systems offer the capabilities to incorporate more organic, aesthetics and ergonomic features into designs. Freeform surface modelling is often combined with solids to allow the designer to create products that fit the human form and visual requirements as well as they interface with the machine.

Technology



A CAD model of a computer mouse.

Originally software for Computer-Aided Design systems was developed with computer languages such as Fortran, but with the advancement of object-oriented programming methods this has radically changed. Typical modern parametric feature based modeler and freeform surface systems are built around a number of key C modules with their own

APIs. A CAD system can be seen as built up from the interaction of a graphical user interface (GUI) with NURBS geometry and/or boundary representation (B-rep) data via a geometric modeling kernel. A geometry constraint engine may also be employed to manage the associative relationships between geometry, such as wireframe geometry in a sketch or components in an assembly.

Unexpected capabilities of these associative relationships have led to a new form of prototyping called digital prototyping. In contrast to physical prototypes, which entail manufacturing time in the design.

Today, CAD systems exist for all the major platforms (Windows, Linux, UNIX and Mac OS X); some packages even support multiple platforms.

Right now, no special hardware is required for most CAD software. However, some CAD systems can do graphically and computationally expensive tasks, so a good graphics card, high speed (and possibly multiple) CPUs and large amounts of RAM are recommended.

The human-machine interface is generally via a computer mouse but can also be via a pen and digitizing graphics tablet. Manipulation of the view of the model on the screen is also sometimes done with the use of a Spacemouse/SpaceBall. Some systems also support stereoscopic glasses for viewing the 3D model.

History

Designers have long used computers for their calculations. Initial developments were carried out in the 1960s within the aircraft and automotive industries in the area of 3D surface construction and NC programming, most of it independent of one another and often not publicly published until much later. Some of the mathematical description work on curves was developed in the early 1940s by Robert Isaac Newton from Pawtucket, Rhode Island. Robert A. Heinlein in his 1957 novel *The Door into Summer* suggested the possibility of a robotic *Drafting Dan*. However, probably the most important work on polynomial curves and sculptured surface was done by Pierre Bezier (Renault), Paul de Casteljau (Citroen), Steven Anson Coons (MIT, Ford), James Ferguson (Boeing), Carl de Boor (GM), Birkhoff (GM) and Garibedian (GM) in the 1960s and W. Gordon (GM) and R. Riesenfeld in the 1970s.

It is argued that a turning point was the development of the SKETCHPAD system at MIT in 1963 by Ivan Sutherland (who later created a graphics technology company with Dr. David Evans). The distinctive feature of SKETCHPAD was that it allowed the designer to interact with his computer graphically: the design can be fed into the computer by drawing on a CRT monitor with a light pen. Effectively, it was a prototype of graphical user interface, an indispensable feature of modern CAD.

The first commercial applications of CAD were in large companies in the automotive and aerospace industries, as well as in electronics. Only large corporations could afford the computers capable of performing the calculations. Notable company projects were at GM

(Dr. Patrick J. Hanratty) with DAC-1 (Design Augmented by Computer) 1964; Lockheed projects; Bell GRAPHIC 1 and at Renault (Bezier) – UNISURF 1971 car body design and tooling.

One of the most influential events in the development of CAD was the founding of MCS (Manufacturing and Consulting Services Inc.) in 1971 by Dr. P. J. Hanratty, who wrote the system ADAM (Automated Drafting And Machining) but more importantly supplied code to companies such as McDonnell Douglas (Unigraphics), Computervision (CADD5), Calma, Gerber, Autotrol and Control Data.

As computers became more affordable, the application areas have gradually expanded. The development of CAD software for personal desktop computers was the impetus for almost universal application in all areas of construction.

Other key points in the 1960s and 1970s would be the foundation of CAD systems United Computing, Intergraph, IBM, Intergraph IGDS in 1974 (which led to Bentley Systems MicroStation in 1984)

CAD implementations have evolved dramatically since then. Initially, with 3D in the 1970s, it was typically limited to producing drawings similar to hand-drafted drawings. Advances in programming and computer hardware, notably solid modeling in the 1980s, have allowed more versatile applications of computers in design activities.

Key products for 1981 were the solid modelling packages -Romulus (ShapeData) and Uni-Solid (Unigraphics) based on PADL-2 and the release of the surface modeler CATIA (Dassault Systemes). Autodesk was founded 1982 by John Walker, which led to the 2D system AutoCAD. The next milestone was the release of Pro/ENGINEER in 1988, which heralded greater usage of feature-based modeling methods and parametric linking of the parameters of features. Also of importance to the development of CAD was the development of the B-rep solid modeling kernels (engines for manipulating geometrically and topologically consistent 3D objects) Parasolid (ShapeData) and ACIS (Spatial Technology Inc.) at the end of the 1980s and beginning of the 1990s, both inspired by the work of Ian Braid. This led to the release of mid-range packages such as SolidWorks in 1995, Solid Edge (then Intergraph) in 1996 and Autodesk Inventor in 1999.

Chapter 4

3D Printing

Part of the series on the

History of printing

Woodblock printing	200
Movable type	1040
Printing press	1454
Lithography	1796
Laser printing	1969
Thermal printing	circa 1972

3D printing is a form of additive manufacturing technology where a three dimensional object is created by laying down successive layers of material. 3D printers are generally faster, more affordable and easier to use than other additive manufacturing technologies. 3D printers offer product developers the ability to print parts and assemblies made of several materials with different mechanical and physical properties in a single build process. Advanced 3D printing technologies yield models that closely emulate the look, feel and functionality of product prototypes.

A 3D printer works by taking a 3D computer file and using and making a series of cross-sectional slices. Each slice is then printed one on top of the other to create the 3D object.

“ Three-dimensional printing makes it as cheap to create single items as it is to produce thousands and thus undermines

economies of scale. It may have as profound an impact on the world as the coming of the factory did....Just as nobody could have predicted the impact of the steam engine in 1750—or the printing press in 1450, or the transistor in 1950—it is impossible to foresee the long-term impact of 3D printing. But the technology is coming, and it is likely to disrupt every field it touches.

—*The Economist*, in a February 10, 2011 leader

Since 2003 there has been large growth in the sale of 3D printers. Additionally, the cost of 3D printers has declined. The technology also finds use in the jewellery, footwear, industrial design, architecture, engineering and construction (AEC), automotive, aerospace, dental and medical industries.

Methods

A large number of competing technologies are available to do 3D printing. Their main differences are found in the way layers are built to create parts. Some methods use melting or softening material to produce the layers, e.g. selective laser sintering (SLS) and fused deposition modeling (FDM), while others lay liquid materials that are cured with different technologies. In the case of lamination systems, thin layers are cut to shape and joined together.



A comparison of two ceramic art objects. The original was created by John Balistreri and then duplicated using a 3D scanner and printed using 3D ceramic rapid prototyping.

Each method has its advantages and drawbacks, and consequently some companies offer a choice between powder and polymer as the material from which the object emerges. Generally, the main considerations are speed, cost of the printed prototype, cost of the 3D printer, choice of materials, colour capabilities, etc.

One method of 3D printing consists of an inkjet printing system. The printer creates the model one layer at a time by spreading a layer of powder (plaster, or resins) and inkjet printing a binder in the cross-section of the part. The process is repeated until every layer is printed. This technology is the only one that allows for the printing of full colour prototypes. This method also allows overhangs. It is also recognized as the fastest method.

In digital light processing (DLP), a vat of liquid polymer is exposed to light from a DLP projector under safelight conditions. The exposed liquid polymer hardens. The build plate then moves down in small increments and the liquid polymer is again exposed to light.

The process repeats until the model is built. The liquid polymer is then drained from the vat, leaving the solid model. The ZBuilder Ultra is an example of a DLP rapid prototyping system.

Fused deposition modeling, a technology developed by Stratasys that is used in traditional rapid prototyping, uses a nozzle to deposit molten polymer onto a support structure, layer by layer.

Another approach is selective fusing of print media in a granular bed. In this variation, the unfused media serves to support overhangs and thin walls in the part being produced, reducing the need for auxiliary temporary supports for the workpiece. Typically a laser is used to sinter the media and form the solid. Examples of this are selective laser sintering and direct metal laser sintering (DMLS) using metals.

Finally, ultra-small features may be made by the 3D microfabrication technique of 2-photon photopolymerization. In this approach, the desired 3D object is traced out in a block of gel by a focused laser. The gel is cured to a solid only in the places where the laser was focused, due to the nonlinear nature of photoexcitation, and then the remaining gel is washed away. Feature sizes of under 100 nm are easily produced, as well as complex structures such as moving and interlocked parts.

Unlike stereolithography, inkjet 3D printing is optimized for speed, low cost, and ease-of-use, making it suitable for visualizing during the conceptual stages of engineering design through to early-stage functional testing. No toxic chemicals like those used in stereolithography are required, and minimal post printing finish work is needed; one need only to use the printer itself to blow off surrounding powder after the printing process. Bonded powder prints can be further strengthened by wax or thermoset polymer impregnation. FDM parts can be strengthened by wicking another metal into the part.

In 2006, Sébastien Dion, John Balistreri and others at Bowling Green State University began research into 3D rapid prototyping machines, creating printed ceramic art objects. This research has led to the invention of ceramic powders and binder systems that enable clay material to be printed from a computer model and then fired for the first time.

Resolution

Resolution is given in layer thickness and X-Y resolution in dpi. Typical layer thickness is around 100 micrometres (0.1 mm), while X-Y resolution is comparable to that of laser printers. The particles (3D dots) are around 50 to 100 micrometres (0.05-0.1 mm) in diameter.

Applications



An example of real object replication by means of 3D scanning and 3D printing: the gargoyle model on the left was digitally acquired by using a 3D scanner and the produced 3D data was processed using MeshLab. The resulting digital 3D model, shown on the laptop's screen, was used by a rapid prototyping machine to create a real resin replica of the original object

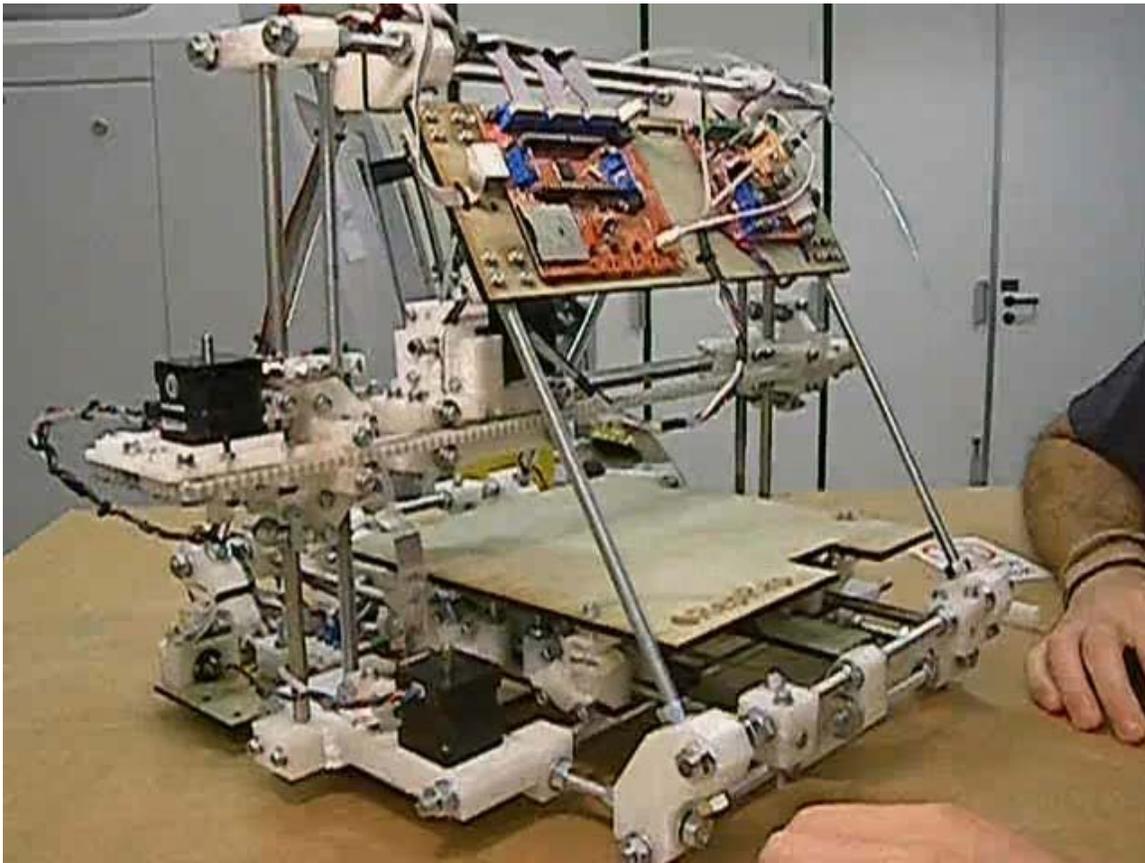
Standard applications include design visualization, prototyping/CAD, metal casting, architecture, education, geospatial, healthcare and entertainment/retail. Other applications would include reconstructing fossils in paleontology, replicating ancient and priceless artifacts in archaeology, reconstructing bones and body parts in forensic pathology and reconstructing heavily damaged evidence acquired from crime scene investigations.

More recently, the use of 3D printing technology for artistic expression has been suggested. Artists have been using 3D printers in various ways.

3D printing technology is currently being studied by biotechnology firms and academia for possible use in tissue engineering applications where organs and body parts are built using inkjet techniques. Layers of living cells are deposited onto a gel medium and slowly built up to form three dimensional structures. Several terms have been used to refer to this field of research: Organ printing, bio-printing, and computer-aided tissue engineering among others. 3D printing can produce a personalised hip replacement in one pass, with the ball permanently inside the socket, and even at current printing resolutions the unit will not require polishing.

The use of 3D scanning technologies allow the replication of real objects without the use of molding techniques, that in many cases can be more expensive, more difficult, or too invasive to be performed; particularly with precious or delicate cultural heritage artifacts where the direct contact of the molding substances could harm the surface of the original object.

Home 3D printers



RepRap version 2.0 (Mendel)

There have been several, often related efforts to develop 3D printers suitable for desktop use, and to make this technology available at price points affordable to many individual end-users. Much of this work was driven by and targeted on DIY/enthusiast/early adopter communities, with links to both the academic and hacker communities.

RepRap is a project that aims to produce a FLOSS 3D printer, whose full specifications are released under the GNU General Public License, and which can print a copy of itself. As of November 2010, the RepRap can only print plastic parts. Research is under way to let the device print circuit boards too, as well as metal parts.

Prototyping technologies and their base materials

1. Selective laser sintering (SLS): Thermoplastics, metals, sand, glass
2. Fused deposition modeling (FDM): Thermoplastics
3. Stereolithography (SL): Photopolymer
4. Laminated object manufacturing: Laminate sheets (often paper) and glue
5. Electron beam melting (EBM): Titanium alloys
6. 3D printing (3DP): Various materials, including resins
7. 3D ceramic printing: Various clay and ceramic materials

Chapter 5

Form Follows Function

Form follows function is a principle associated with modern architecture and industrial design in the 20th century. The principle is that the shape of a building or object should be primarily based upon its intended function or purpose.



Wainwright Building by Louis Sullivan

In the context of design professions *form follows function* intuitively seems like good sense, but on closer examination it becomes problematic and open to interpretation. Linking the relationship between the form of an object and its intended purpose is not always by itself a complete design solution. Defining the precise meaning(s) of the phrase 'form follows function' opens a discussion of design integrity that remains an important, lively debate.

Origins of the phrase

The authorship of the phrase is often, though wrongly, ascribed to the American sculptor Horatio Greenough, whose thinking to a large extent predates the later functionalist approach to architecture. It was, however, the American architect Louis Sullivan who coined the phrase, in 1896, in his article «The Tall Office Building Artistically Considered». Here Sullivan actually said 'form ever follows function', but the simpler (and less emphatic) phrase is the one usually remembered. For Sullivan this was distilled wisdom, an aesthetic credo, the single "rule that shall permit of no exception". The full quote is thus:

It is the pervading law of all things organic and inorganic,
Of all things physical and metaphysical,
Of all things human and all things super-human,
Of all true manifestations of the head,
Of the heart, of the soul,
That the life is recognizable in its expression,
That form ever follows function. This is the law.

Sullivan developed the shape of the tall steel skyscraper in late 19th Century Chicago at the very moment when technology, taste and economic forces converged violently and made it necessary to drop the established styles of the past. If the shape of the building wasn't going to be chosen out of the old pattern book something had to determine form, and according to Sullivan it was going to be the purpose of the building. It was 'form follows function', as opposed to 'form follows precedent'. Sullivan's assistant Frank Lloyd Wright adopted and professed the same principle in slightly different form—perhaps because shaking off the old styles gave them more freedom and latitude.

Is ornamentation 'functional'?

In 1908 the Austrian architect Adolf Loos famously proclaimed that architectural ornament was criminal, and his essay on that topic would become foundational to Modernism and eventually trigger the careers of Le Corbusier, Walter Gropius, Alvar Aalto, Mies van der Rohe and Gerrit Rietveld. The Modernists adopted both of these equations—form follows function, ornament is a crime—as moral principles, and they celebrated industrial artifacts like steel water towers as brilliant and beautiful examples of plain, simple design integrity.

These two principles—form follows function, ornament is crime—are often invoked on the same occasions for the same reasons, but they do not mean the same thing. If ornament on a building may have social usefulness like aiding wayfinding, announcing the identity of the building, signaling scale, or attracting new customers inside, then ornament can be seen as functional, which puts those two articles of dogma at odds with each other.

Conversely the argument ‘ornament is crime’ doesn’t say anything about function. It is an aesthetic preference inspired by the Machine Age. While human performance may be enhanced by a sense of well-being endowed by aesthetic pleasure, machines have no such need of beauty to perform their work tirelessly. Ornament becomes an unnecessary relic, or worse, an impediment to optimal engineering design and equipment maintenance. Other stylistic ‘non-functional’ features may rest untouched (*e.g.*, the feeling of space, the composition of the volumes) as we can see in the subsequent abstracted and non-ornamented styles. Much of the confusion between these two concepts comes from the fact that ornament traditionally derives from a function becoming a stylistic character (*e.g.*, the gargoyle from Gothic cathedrals).

Modernism in architecture began as a disciplined effort to allow the shape and organization of a building to be determined only by functional requirements, instead of by traditional aesthetic concepts. It assumes that the designer will determine empirically (or decide arbitrarily) what is or is not a functional requirement. The resulting architecture tended to be shockingly simpler, flatter, and lighter than its older neighbors, possibly due to the limited number of functional requirements upon which the designs were based; their functionality and refreshing nakedness looked as honest and inevitable as an airplane. Modernists believed, perhaps incorrectly, that airplane design did not involve any aesthetic decisions by the airplane designers. A recognizable Modern vocabulary began to develop.

Utilitarianism

Utilitarianism in architecture can mean several things.

1. The belief that the value of a feature is determined by its utility. The quality of being utilitarian: housing of bleak utilitarianism.
2. The aesthetic of exposing necessary materials and features, such as metal or heating pipes, which are normally included in a design for their utility rather than their aesthetic appeal.

Application in different fields

Architecture

Louis Sullivan's phrase "**form (ever) follows function**" became a battle-cry of Modernist architects after the 1930s. The credo was taken to imply that decorative elements, which architects call "ornament," were superfluous in modern buildings.

However, Sullivan himself neither thought nor designed along such dogmatic lines during the peak of his career. Indeed, while his buildings could be spare and crisp in their principal masses, he often punctuated their plain surfaces with eruptions of lush Art Nouveau and something like Celtic Revival decorations, usually cast in iron or terra cotta, and ranging from organic forms like vines and ivy, to more geometric designs, and interlace, inspired by his Irish design heritage. Probably the most famous example is the writhing green ironwork that covers the entrance canopies of the Carson Pirie Scott department store on South State Street in Chicago. These ornaments, often executed by the talented younger draftsman in Sullivan's employ, would eventually become Sullivan's trade mark; to students of architecture, they are his instantly-recognizable signature.

Product design

One episode in the history of the inherent conflict between functional design and the demands of the marketplace happened in 1935, after the introduction of the streamlined Chrysler Airflow, when the American auto industry temporarily halted attempts to introduce optimal aerodynamic forms into mass manufacture. Some carmakers thought that aerodynamic efficiency would result in a single optimal auto-body shape, a "teardrop" shape, which would not be good for unit sales. GM thereafter adopted two different positions on streamlining, one meant for its internal engineering community, the other meant for its customers. Like the annual model year change, so-called aerodynamic styling is often meaningless in terms of technical performance. Subsequently drag coefficient has become both a marketing tool and a means of improving the saleability of a car by reducing its fuel consumption, slightly, and its top speed, markedly.

The American industrial designers of the 1930s and '40s like Raymond Loewy, Norman bel Geddes and Henry Dreyfuss grappled with the inherent contradictions of 'form follows function' as they redesigned blenders and locomotives and duplicating machines for mass-market consumption. Loewy formulated his 'MAYA' (Most Advanced Yet Acceptable) principle to express that product designs are bounded by functional constraints of math and materials and logic, but their acceptance is constrained by social expectations.

By honestly applying 'form follows function', industrial designers had the potential to advance their clients right out of business. Some simple single-purpose objects like screwdrivers and pencils and teapots might be reducible to a single optimal form, and through the eyes of a teapot maker that's simply unacceptable. Some objects made too durable would prevent sales of replacements. From the standpoint of functionality some products are flatly unnecessary, and through the eyes of an electric carving knife maker that's quite unacceptable.

Victor Papanek (died 1999) was an influential recent designer and design philosopher who taught and wrote as a proponent of "form follows function."

Software engineering

It has been argued that the structure and internal quality attributes of a working, non-trivial software artifact will represent first and foremost the engineering requirements of its construction, with the influence of process being marginal, if any. This does not mean that process is irrelevant, but that processes compatible with an artifact's requirements lead to roughly similar results.

The principle can also be applied to Enterprise Application Architectures of modern business where 'function' is the Business processes which should be assisted by the enterprise architecture, or 'form'. If the architecture dictates how the business operates then the business is likely to suffer from inflexibility unable to adapt to change. SOA Service-Oriented Architecture have enabled Enterprise Architect to rearrange the 'form' of the architecture to meet the functional requirements of a business by adopting standards based communication protocols which enable interoperability.



Aerodynamic shape of Ferrari F430



1938 Type 57SC Atlantic from the Ralph Lauren collection

Automobile designing

If the design of an automobile conforms to its function, as in its aerodynamic shape or wide stance for better vehicle dynamics, then its form is said to follow its function. "Form follows function" can also be an aesthetic point of view that a design can heighten, as often seen in the work of Ettore, Rembrandt, and Jean Bugatti.

Evolution

According to Lamarck's long-discredited theory of evolution, anatomy will be structured according to functions associated with use; for instance, giraffes are taller to reach the leaves of trees. By contrast, in Darwinian evolution, form (variation) *precedes* function (as determined by selection). That is to say in Lamarckian evolution the form is altered **by** the required function, whereas in Darwinian evolution small variations in form allow some parts of the population to function 'better', and are therefore more successful reproductively.

Chapter 6

Preferred Number

In industrial design, **preferred numbers** (also called **preferred values**) are standard guidelines for choosing exact product dimensions within a given set of constraints. Product developers must choose numerous lengths, distances, diameters, volumes, and other characteristic quantities. While all of these choices are constrained by considerations of functionality, usability, compatibility, safety or cost, there usually remains considerable leeway in the *exact* choice for many dimensions.

Preferred numbers serve two purposes:

1. Using them increases the probability of compatibility between objects designed at different times by different people. In other words, it is one tactic among many in standardization, whether within a company or within an industry, and it is usually desirable in industrial contexts. (The opposite motive can also apply, if it is in a manufacturer's financial interest: for example, manufacturers of consumer products often have a financial interest in lack of compatibility, in planned obsolescence, and in selling name-brand and model-specific replacement parts.)
2. They are chosen such that when a product is manufactured in many different sizes, these will end up roughly equally spaced on a logarithmic scale. They therefore help to minimize the number of different sizes that need to be manufactured or kept in stock.

Renard numbers

The French army engineer Col. Charles Renard proposed in the 1870s a set of preferred numbers for use with the metric system. His system was adopted in 1952 as international standard ISO 3. Renard's system of preferred numbers divides the interval from 1 to 10 into 5, 10, 20, or 40 steps. The factor between two consecutive numbers in a Renard series is constant (before rounding), namely the 5th, 10th, 20th, or 40th root of 10 (1.58, 1.26, 1.12, and 1.06, respectively), which leads to a geometric sequence. This way, the

maximum relative error is minimized if an arbitrary number is replaced by the nearest Renard number multiplied by the appropriate power of 10.

These numbers may be rounded to any arbitrary precision, as they are irrational. R5, to various precisions:

Ones:	1	2	3	4	6
Tenths:	1.0	1.6	2.5	4.0	6.3
Hundredths:	1.00	1.58	2.51	3.98	6.31

Example: If our design constraints tell us that the two screws in our gadget should be placed between 32 mm and 55 mm apart, we make it 40 mm, because 4 is in the R5 series of preferred numbers.

Example: If you want to produce a set of nails with lengths between roughly 15 and 300 mm, then the application of the R5 series would lead to a product repertoire of 16 mm, 25 mm, 40 mm, 63 mm, 100 mm, 160 mm, and 250 mm long nails.

If a finer resolution is needed, another five numbers are added to the series, one after each of the original R5 numbers, and we end up with the R10 series:

R10: 1.00 1.25 1.60 2.00 2.50 3.15 4.00 5.00 6.30 8.00

Where an even finer grading is needed, the R20, R40, and R80 series can be applied:

R20: 1.00 1.25 1.60 2.00 2.50 3.15 4.00 5.00 6.30 8.00
 1.12 1.40 1.80 2.24 2.80 3.55 4.50 5.60 7.10 9.00

R40: 1.00 1.25 1.60 2.00 2.50 3.15 4.00 5.00 6.30 8.00
 1.06 1.32 1.70 2.12 2.65 3.35 4.25 5.30 6.70 8.50
 1.12 1.40 1.80 2.24 2.80 3.55 4.50 5.60 7.10 9.00
 1.18 1.50 1.90 2.36 3.00 3.75 4.75 6.00 7.50 9.50

R80: 1.00 1.25 1.60 2.00 2.50 3.15 4.00 5.00 6.30 8.00
 1.03 1.28 1.65 2.06 2.58 3.25 4.12 5.15 6.50 8.25
 1.06 1.32 1.70 2.12 2.65 3.35 4.25 5.30 6.70 8.50
 1.09 1.36 1.75 2.18 2.72 3.45 4.37 5.45 6.90 8.75
 1.12 1.40 1.80 2.24 2.80 3.55 4.50 5.60 7.10 9.00
 1.15 1.45 1.85 2.30 2.90 3.65 4.62 5.80 7.30 9.25
 1.18 1.50 1.90 2.36 3.00 3.75 4.75 6.00 7.50 9.50
 1.22 1.55 1.95 2.43 3.07 3.87 4.87 6.15 7.75 9.75

In some applications more rounded values are desirable, either because the numbers from the normal series would imply an unrealistically high accuracy, or because an integer value is needed (e.g., the number of teeth in a gear). For these needs, more rounded versions of the Renard series have been defined in ISO 3:

R5":	1		1.5		2.5		4		6	
R10':	1	1.25	1.6	2	2.5	3.2	4	5	6.3	8
R10":	1	1.2	1.5	2	2.5	3	4	5	6	8

R20':	1	1.25	1.6	2	2.5	3.2	4	5	6.3	8
	1.1	1.4	1.8	2.2	2.8	3.6	4.5	5.6	7.1	9
R20":	1	1.2	1.5	2	2.5	3	4	5	6	8
	1.1	1.4	1.8	2.2	2.8	3.5	4.5	5.5	7	9
R40':	1	1.25	1.6	2	2.5	3.2	4	5	6.3	8
	1.05	1.3	1.7	2.1	2.6	3.4	4.2	5.3	6.7	8.5
	1.1	1.4	1.8	2.2	2.8	3.6	4.5	5.6	7.1	9
	1.2	1.5	1.9	2.4	3	3.8	4.8	6	7.5	9.5

As the Renard numbers repeat after every 10-fold change of the scale, they are particularly well-suited for use with SI units. It makes no difference whether the Renard numbers are used with metres or kilometres. But one would end up with two incompatible sets of nicely spaced dimensions if they were applied, for instance, with both yards and miles.

Renard numbers are rounded results of the formula

$$R(i, b) = 10^{\frac{i}{b}}$$

where b is the selected series value (for example $b = 40$ for the R40 series), and i is the i -th element of this series (with $i = 0$ through $i = b$).

Rail gauges

Virtually no rail gauges are preferred numbers, with two exceptions. These are likely accidental, but remarkable in that they are in the R10 series whether expressed in inches or millimeters.

The more common gauge is the Irish gauge, 63 inches, which rounds to 1600 millimeters, both numbers in the R10 series. It is also used in Australia and Brazil. The other gauge is just half this, 800 millimeters or 31.5 inches, and is used by the Wengernalpbahn in Switzerland, between Lauterbrunnen and Grindelwald by way of Kleine Scheidegg.

1-2-5 series

In applications for which the R5 series provides a too fine graduation, the 1-2-5 series is sometimes used as a cruder alternative:

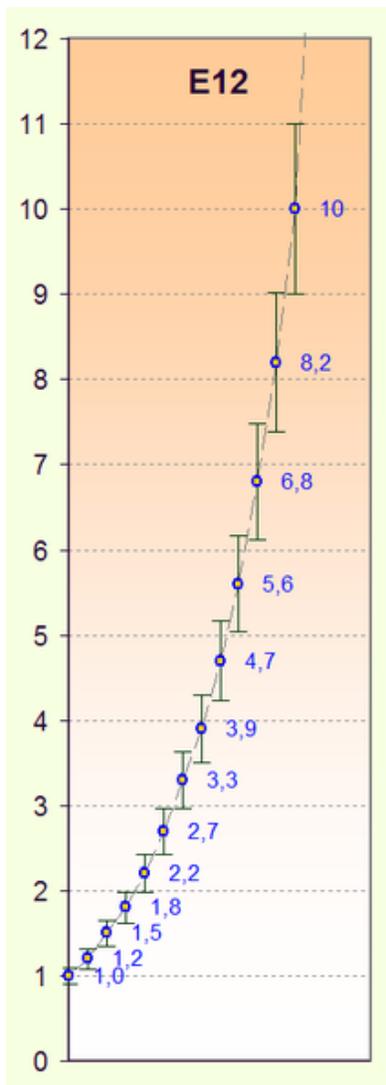
... 0.1 0.2 0.5 1 2 5 10 20 50 100 200 500 1000 ...

This series covers a decade (1:10 ratio) in three steps. Adjacent values differ by factors 2 or 2.5. Unlike the Renard series, the 1-2-5 series has not been formally adopted as an international standard. However, the Renard series R10 can be used to extend the 1-2-5 series to a finer graduation.

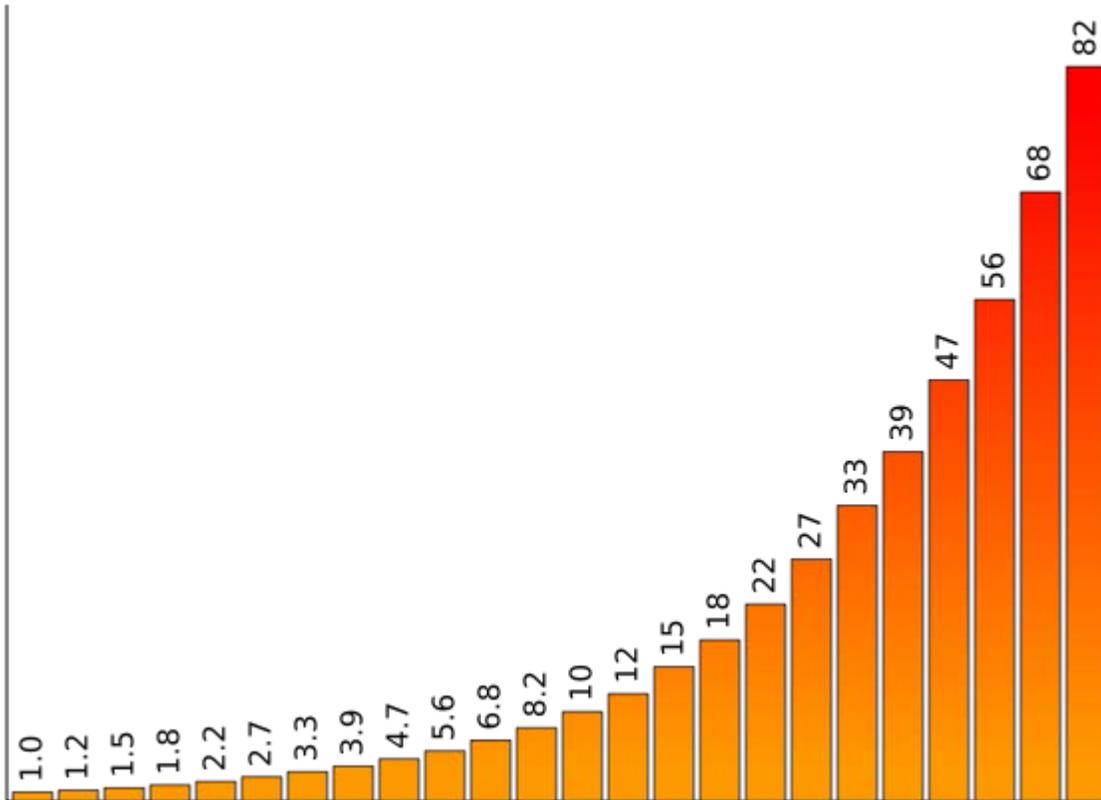
This series is used to define the scales for graphs and for instruments that display in a two-dimensional form with a graticule, such as oscilloscopes.

The denominations of most modern currencies follow a 1-2-5 series. An exception are some quarter-value coins, such as those of Canada and the United States (the latter denominated as "quarter dollar" rather than 25 cents). A $\frac{1}{4}$ - $\frac{1}{2}$ -1 series (... 0.1 0.25 0.5 1 2.5 5 10 ...) is used by currencies derived from the former Dutch gulden (Aruban florin, Netherlands Antillean gulden, Surinamese dollar), some Middle Eastern currencies (Iraqi and Jordanian dinars, Lebanese pound, Syrian pound), and the Seychellois rupee. However, newer notes introduced in Lebanon and Syria due to inflation follow the standard 1-2-5 series instead.

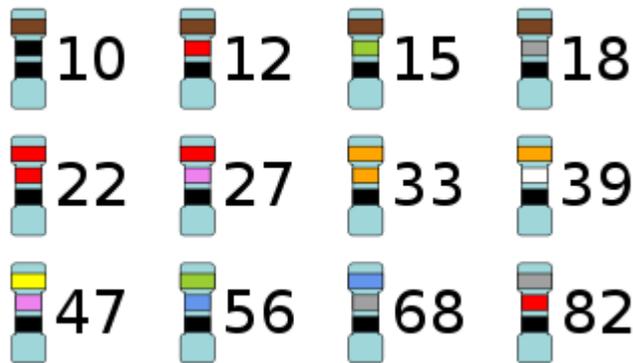
E series: Capacitors and resistors



This graph shows how the values of the E12 series (with a tolerance of 10%) nicely cover one decade (1-10)



Two decades of E12 values, which would give resistor values of 1 Ω to 82 Ω



A decade of the E12 values shown with their electronic color codes on resistors.

In electronics, international standard IEC 60063 defines another preferred number series for resistors, capacitors, inductors and zener diodes. It works similarly to the Renard series, except that it subdivides the interval from 1 to 10 into 6, 12, 24, etc. steps. These subdivisions ensure that when some arbitrary value is replaced with the nearest preferred number, the maximum relative error will be on the order of 20%, 10%, 5%, etc.

Use of the E series is mostly restricted to resistors, capacitors and inductors. Commonly produced dimensions for other types of electrical components are either chosen from the Renard series instead (for example fuses) or are defined in relevant product standards (for example wires).

The IEC 60063 numbers are as follows. The E6 series is every other element of the E12 series, which is in turn every other element of the E24 series:

```

E6 ( 20%): 10      15      22      33      47      68
E12 ( 10%): 10  12  15  18  22  27  33  39  47  56  68  82
E24 ( 5%):  10  12  15  18  22  27  33  39  47  56  68  82
              11  13  16  20  24  30  36  43  51  62  75  91
    
```

With the E48 series, a third decimal place is added, and the values are slightly adjusted. Again, the E48 series is every other value of the E96 series, which is every other value of the E192 series:

```

E48 ( 2%): 100  121  147  178  215  261  316  383  464  562  681  825
            105  127  154  187  226  274  332  402  487  590  715  866
            110  133  162  196  237  287  348  422  511  619  750
909
            115  140  169  205  249  301  365  442  536  649  787
953
E96 ( 1%): 100  121  147  178  215  261  316  383  464  562  681  825
            102  124  150  182  221  267  324  392  475  576  698  845
            105  127  154  187  226  274  332  402  487  590  715
866
            107  130  158  191  232  280  340  412  499  604  732
887
            110  133  162  196  237  287  348  422  511  619  750
909
            113  137  165  200  243  294  357  432  523  634  768
931
            115  140  169  205  249  301  365  442  536  649  787
953
            118  143  174  210  255  309  374  453  549  665
806  976
E192 (0.5%) 100  121  147  178  215  261  316  383  464  562  681  825
            101  123  149  180  218  264  320  388  470  569  690  835
            102  124  150  182  221  267  324  392  475  576  698
845
            104  126  152  184  223  271  328  397  481  583  706
856
            105  127  154  187  226  274  332  402  487  590  715
866
            106  129  156  189  229  277  336  407  493  597  723
876
            107  130  158  191  232  280  340  412  499  604  732
887
            109  132  160  193  234  284  344  417  505  612
741  898
            110  133  162  196  237  287  348  422  511  619
750  909
    
```

			111	135	164	198	240	291	352	427	517	626
759	920											
			113	137	165	200	243	294	357	432	523	634
768	931											
			114	138	167	203	246	298	361	437	530	642
777	942											
			115	140	169	205	249	301	365	442	536	
649	787	953										
			117	142	172	208	252	305	370	448	542	
657	796	965										
			118	143	174	210	255	309	374	453	549	
665	806	976										
			120	145	176	213	258	312	379	459	556	
673	816	988										

The E192 series is also used for 0.25% and 0.1% tolerance resistors.

1% resistors are available in both the E24 values and the E96 values.

Buildings

In the construction industry, it was felt that typical dimensions must be easy to use in mental arithmetic. Therefore, rather than using elements of a geometric series, a different system of preferred dimensions has evolved in this area, known as "modular coordination".

Major dimensions (e.g., grid lines on drawings, distances between wall centers or surfaces, widths of shelves and kitchen components) are multiples of 100 mm, i.e. one decimetre. This size is called the "basic module" (and represented in the standards by the letter M). Preference is given to the multiples of 300 mm (3 M) and 600 mm (6 M) of the basic module. For larger dimensions, preference is given to multiples of the modules 12 M (= 1.2 m), 15 M (= 1.5 m), 30 M (= 3 m), and 60 M (= 6 m). For smaller dimensions, the submodular increments 50 mm or 25 mm are used. (ISO 2848, BS 6750)

Dimensions chosen this way can easily be divided by a large number of factors without ending up with millimetre fractions. For example, a multiple of 600 mm (6 M) can always be divided into 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 24, 25, 30, etc. parts, each of which is again an integral number of millimetres.

Paper documents, envelopes, and drawing pens

Standard metric paper sizes use the square root of two and related numbers ($\sqrt{\sqrt{2}}$, $\sqrt{2}$, 2, or $2\sqrt{2}$) as factors between neighbor dimensions (Lichtenberg series, ISO 216). The $\sqrt{2}$ factor also appears between the standard pen thicknesses for technical drawings (0.13, 0.18, 0.25, 0.35, 0.50, 0.70, 1.00, 1.40, and 2.00 mm). This way, the right pen size is available to continue a drawing that has been magnified to a different standard paper size.

Computer engineering

When dimensioning computer components, the powers of two are frequently used as preferred numbers:

1 2 4 8 16 32 64 128 256 512 1024 ...

Where a finer grading is needed, additional preferred numbers are obtained by multiplying a power of two with a small odd integer:

(×3) 6 12 24 48 96 192 384 768 1536 ...
(×5) 10 20 40 80 160 320 640 1280 2560 ...
(×7) 14 28 56 112 224 448 896 1792 3584 ...

These correspond to binary numbers that consist mostly of trailing zero bits, which are particularly easy to add and subtract in hardware.

Preferred aspect ratios

16: **15:** **12:**
:8 2:1 3:2
:9 16:9 5:3 4:3
:10 8:5 3:2
:12 4:3 5:4 1:1

In computer graphics, widths and heights of raster images are preferred to be multiples of 16, as many compression algorithms (JPEG, MPEG) divide *color* images into square blocks of that size. Black-and-white JPEG images are divided into 8x8 blocks. Screen resolutions often follow the same principle. Preferred aspect ratios have also an important influence here, e.g. 2:1, 3:2, 4:3, 5:3, 5:4, 8:5, 16:9.

Retail packaging

In some countries, consumer-protection laws restrict the number of different prepackaged sizes in which certain products can be sold, in order to make it easier for consumers to compare prices.

An example of such a regulation is the European Union directive on the volume of certain prepackaged liquids (75/106/EEC). It restricts the list of allowed wine-bottle sizes to 0.1, 0.25 (1/4), 0.375 (3/8), 0.5 (1/2), 0.75 (3/4), 1, 1.5, 2, 3, and 5 litres. Similar lists exist for several other types of products. They vary and often deviate significantly from any geometric series in order to accommodate traditional sizes when feasible. Adjacent package sizes in these lists differ typically by factors 2/3 or 3/4, in some cases even 1/2, 4/5, or some other ratio of two small integers.

Music

While some instruments (trombone, theremin, etc.) can play a tone at any arbitrary frequency, other instruments (such as pianos) can only play a limited set of tones. The very popular "twelve-tone equal temperament" selects tones from the geometric sequence

$$f(i) = k \text{ Hz} \times 2^{\frac{i}{12}}.$$

where k is typically 440, though other standards have been used in the past. However, other less common tuning systems have also been historically important as preferred audio frequencies.

Since $2^{10} \approx 10^3$, $2^{1/12} \approx 10^{3/120} = 10^{1/40}$, and the resultant frequency spacing is very similar to the R40 series.

Photography

In photography, aperture, exposure, and film speed generally follow powers of 2:

The aperture size controls how much light enters the camera. It's measured in f-stops: $f/1.4$, $f/2$, $f/2.8$, $f/4$, etc. Full f-stops are a square root of 2 apart. Digital cameras often subdivide these into thirds, so each f-stop is a sixth root of 2, rounded to two significant digits: 1.0, 1.1, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.2, 3.5, 4.0.

The film speed (or digital equivalent) controls how quickly light is recorded. It's expressed as ISO values such as ISO 100, ISO 200, ISO 400, ISO 800. These are usually a power of 2 apart from each other, although other film speeds do exist.

The shutter speed controls how long the camera records light. These are expressed as fractions of a second, roughly but not exactly based on powers of 2: 1 second, $1/2$, $1/4$, $1/8$, $1/15$, $1/30$, $1/60$, $1/125$, $1/250$, $1/500$, $1/1000$ of a second.

Chapter 7

Packaging and Labeling

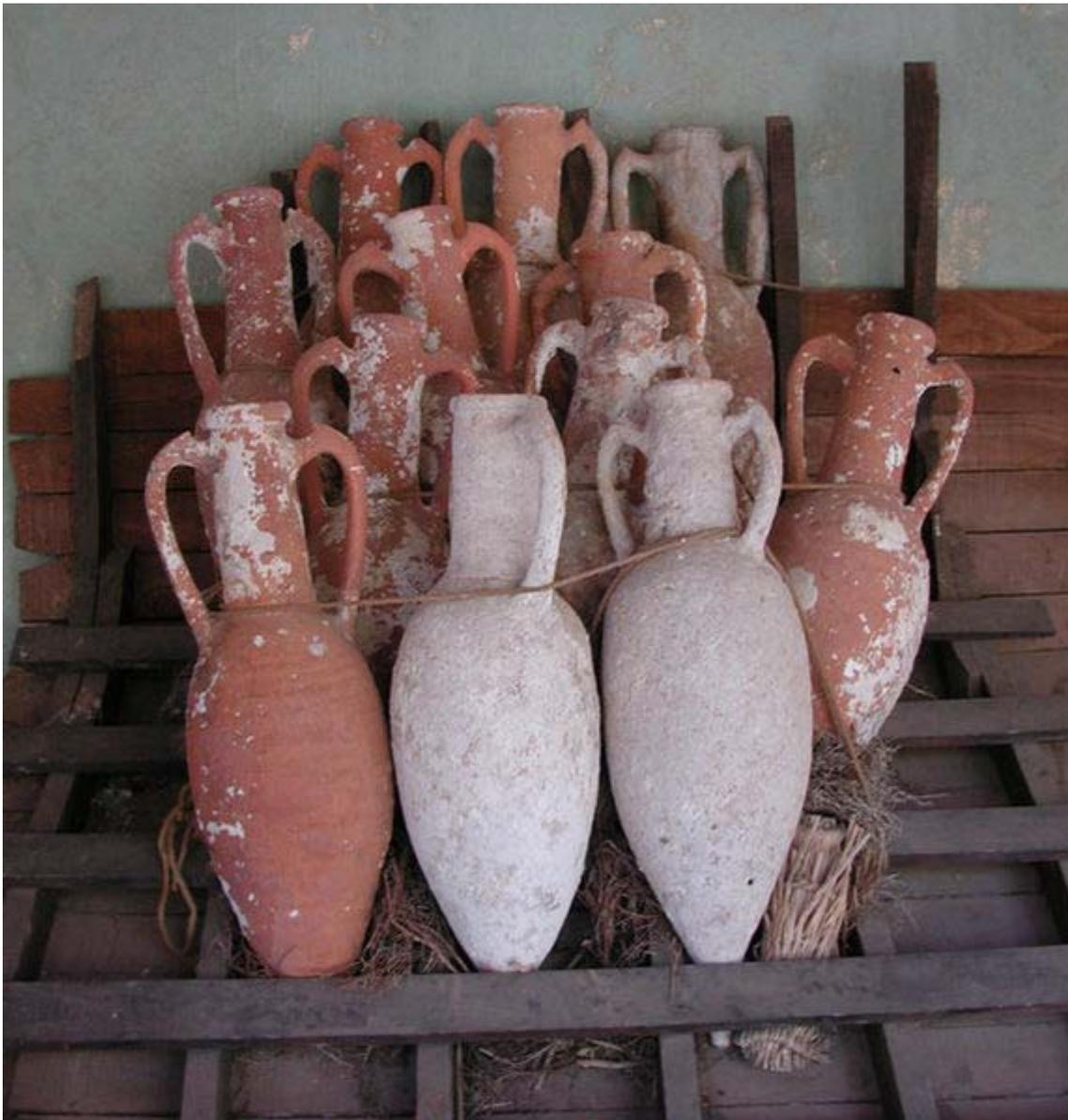


Tablets in a blister pack, which was itself packaged in a folding carton made of paperboard.

Packaging is the science, art and technology of enclosing or protecting products for distribution, storage, sale, and use. Packaging also refers to the *process* of design, evaluation, and production of packages. Packaging can be described as a *coordinated system* of preparing goods for transport, warehousing, logistics, sale, and end use. Packaging contains, protects, preserves, transports, informs, and sells. In many countries it is fully integrated into government, business, institutional, industrial, and personal use.

Package labelling (en-GB) or **labeling** (en-US) is any written, electronic, or graphic communications on the packaging or on a separate but associated label.

History



Amphorae on display in Bodrum Castle, Turkey

The first packages used the natural materials available at the time: Baskets of reeds, wineskins (Bota bags), wooden boxes, pottery vases, ceramic amphorae, wooden barrels, woven bags, etc. Processed materials were used to form packages as they were developed: for example, early glass and bronze vessels. The study of old packages is an important aspect of archaeology.

The earliest recorded use of paper for packaging dates back to 1035, when a Persian traveler visiting markets in Cairo noted that vegetables, spices and hardware were wrapped in paper for the customers after they were sold.

Iron and tin plated steel were used to make cans in the early 19th century. Paperboard cartons and corrugated fiberboard boxes were first introduced in the late 19th century.

Packaging advancements in the early 20th century included Bakelite closures on bottles, transparent cellophane overwraps and panels on cartons, increased processing efficiency and improved food safety. As additional materials such as aluminum and several types of plastic were developed, they were incorporated into packages to improve performance and functionality.

In-plant recycling has long been common for production of packaging materials. Post-consumer recycling of aluminum and paper based products has been economical for many years: since the 1980s, post-consumer recycling has increased due to curbside recycling, consumer awareness, and regulatory pressure.

As of 2003, the packaging sector accounted for about two percent of the gross national product in developed countries. About half of this market was related to food packaging.

The purposes of packaging and package labels



Diced pork in tray and film overwrap. Label indicates net weight, composition, preparation, etc. The Union Flag, British Farm Standard tractor logo, and British Meat Quality Standard logo are also present.

Packaging and package labeling have several objectives

- **Physical protection** - The objects enclosed in the package may require protection from, among other things, mechanical shock, vibration, electrostatic discharge, compression, temperature, etc.
- **Barrier protection** - A barrier from oxygen, water vapor, dust, etc., is often required. Permeation is a critical factor in design. Some packages contain desiccants or Oxygen absorbers to help extend shelf life. Modified atmospheres or controlled atmospheres are also maintained in some food packages. Keeping the contents clean, fresh, sterile and safe for the intended shelf life is a primary function.
- **Containment or agglomeration** - Small objects are typically grouped together in one package for reasons of efficiency. For example, a single box of 1000 pencils requires less physical handling than 1000 single pencils. Liquids, powders, and granular materials need containment.

- **Information transmission** - Packages and labels communicate how to use, transport, recycle, or dispose of the package or product. With pharmaceuticals, food, medical, and chemical products, some types of information are required by governments. Some packages and labels also are used for track and trace purposes.
- **Marketing** - The packaging and labels can be used by marketers to encourage potential buyers to purchase the product. Package graphic design and physical design have been important and constantly evolving phenomenon for several decades. Marketing communications and graphic design are applied to the surface of the package and (in many cases) the point of sale display.
- **Security** - Packaging can play an important role in reducing the security risks of shipment. Packages can be made with improved tamper resistance to deter tampering and also can have tamper-evident features to help indicate tampering. Packages can be engineered to help reduce the risks of package pilferage: Some package constructions are more resistant to pilferage and some have pilfer indicating seals. Packages may include authentication seals and use security printing to help indicate that the package and contents are not counterfeit. Packages also can include anti-theft devices, such as dye-packs, RFID tags, or electronic article surveillance tags that can be activated or detected by devices at exit points and require specialized tools to deactivate. Using packaging in this way is a means of loss prevention.
- **Convenience** - Packages can have features that add convenience in distribution, handling, stacking, display, sale, opening, reclosing, use, dispensing, and reuse.
- **Portion control** - Single serving or single dosage packaging has a precise amount of contents to control usage. Bulk commodities (such as salt) can be divided into packages that are a more suitable size for individual households. It also aids the control of inventory: selling sealed one-liter-bottles of milk, rather than having people bring their own bottles to fill themselves.



Aluminium can with a pull tab

It is sometimes convenient to categorize packages by layer or function: "primary", "secondary", etc.

- Primary packaging is the material that first envelops the product and holds it. This usually is the smallest unit of distribution or use and is the package which is in direct contact with the contents.
- Secondary packaging is outside the primary packaging, perhaps used to group primary packages together.
- Tertiary packaging is used for bulk handling, warehouse storage and transport shipping. The most common form is a palletized unit load that packs tightly into containers.

These broad categories can be somewhat arbitrary. For example, depending on the use, a shrink wrap can be primary packaging when applied directly to the product, secondary packaging when combining smaller packages, and tertiary packaging on some distribution packs.

Symbols used on packages and labels

Many types of symbols for package labeling are nationally and internationally standardized. For consumer packaging, symbols exist for product certifications, trademarks, proof of purchase, etc. Some requirements and symbols exist to communicate aspects of consumer use and safety, for example the estimated sign that notes conformance to EU weights and measures accuracy regulations. Examples of environmental and recycling symbols include the recycling symbol, the resin identification code and the "Green Dot".

Bar codes , Universal Product Codes, and RFID labels are common to allow automated information management in logistics and retailing. Country of Origin Labeling is often used.

Shipping container labeling



"Print & Apply" corner wrap UCC (GS1-128) label application to a pallet load

Technologies related to shipping containers are identification codes, bar codes, and electronic data interchange (EDI). These three core technologies serve to enable the

business functions in the process of shipping containers throughout the distribution channel. Each has an essential function: identification codes either relate product information or serve as keys to other data, bar codes allow for the automated input of identification codes and other data, and EDI moves data between trading partners within the distribution channel.

Elements of these core technologies include UPC and EAN item identification codes, the SCC-14 (UPC shipping container code), the SSCC-18 (Serial Shipping Container Codes), Interleaved 2-of-5 and UCC/EAN-128 (newly designated GS1-128) bar code symbologies, and ANSI ASC X12 and UN/EDIFACT EDI standards.

Small parcel carriers often have their own formats. For example, United Parcel Service has a MaxiCode 2-D code for parcel tracking.

RFID labels for shipping containers are also increasing in usage. A Wal-Mart division, Sam's Club, has also moved in this direction and is putting pressure on its suppliers for compliance.

Shipments of hazardous materials or dangerous goods have special information and symbols (labels, placards, etc.) as required by UN, country, and specific carrier requirements. Two examples are below:



With transport packages, standardised symbols are also used to communicate handling needs. Some common ones are shown below while others are listed in ASTM D5445 "Standard Practice for Pictorial Markings for Handling of Goods" and ISO 780 "Pictorial marking for handling of goods".



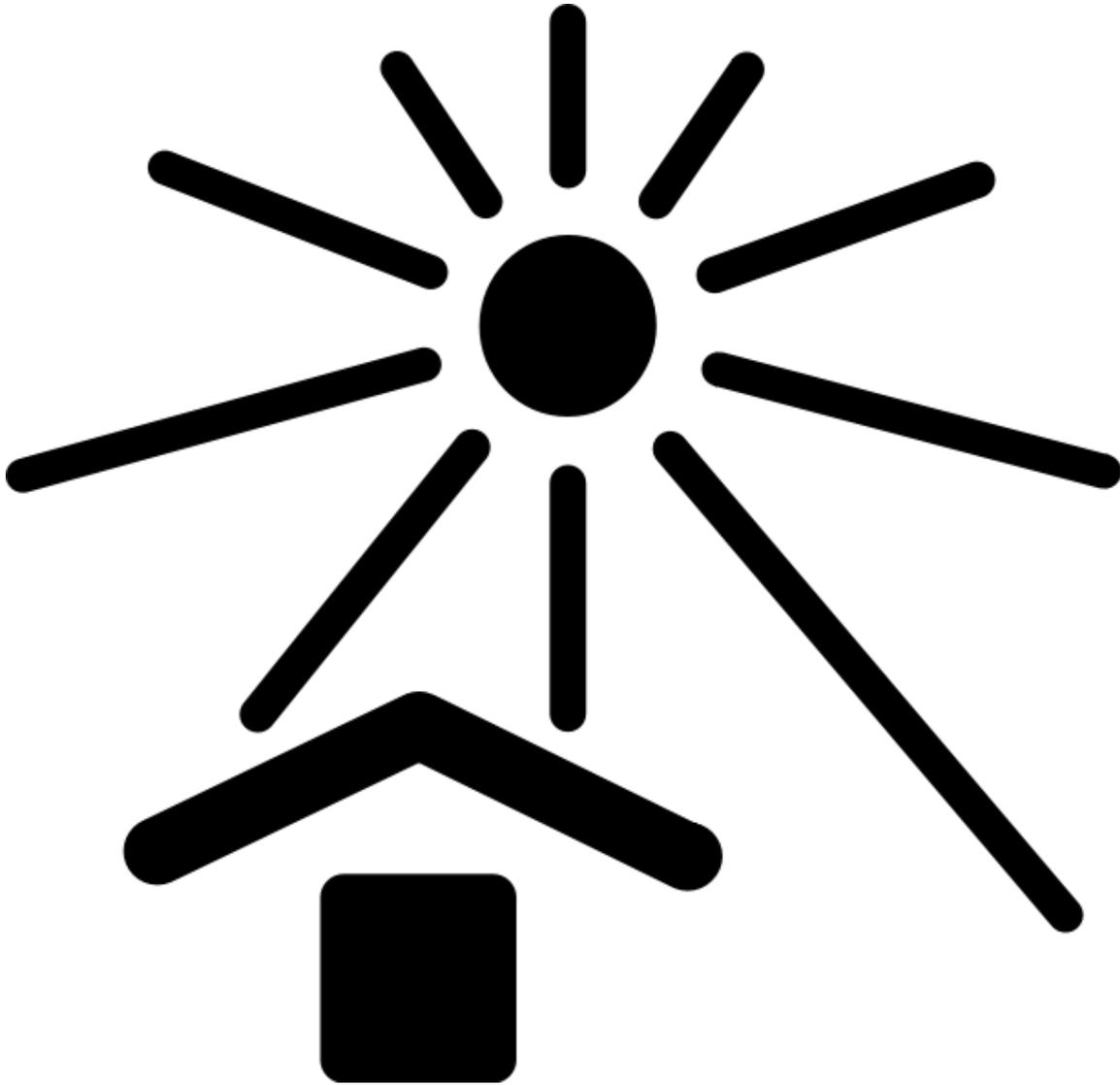
Fragile



Do not use hand hooks



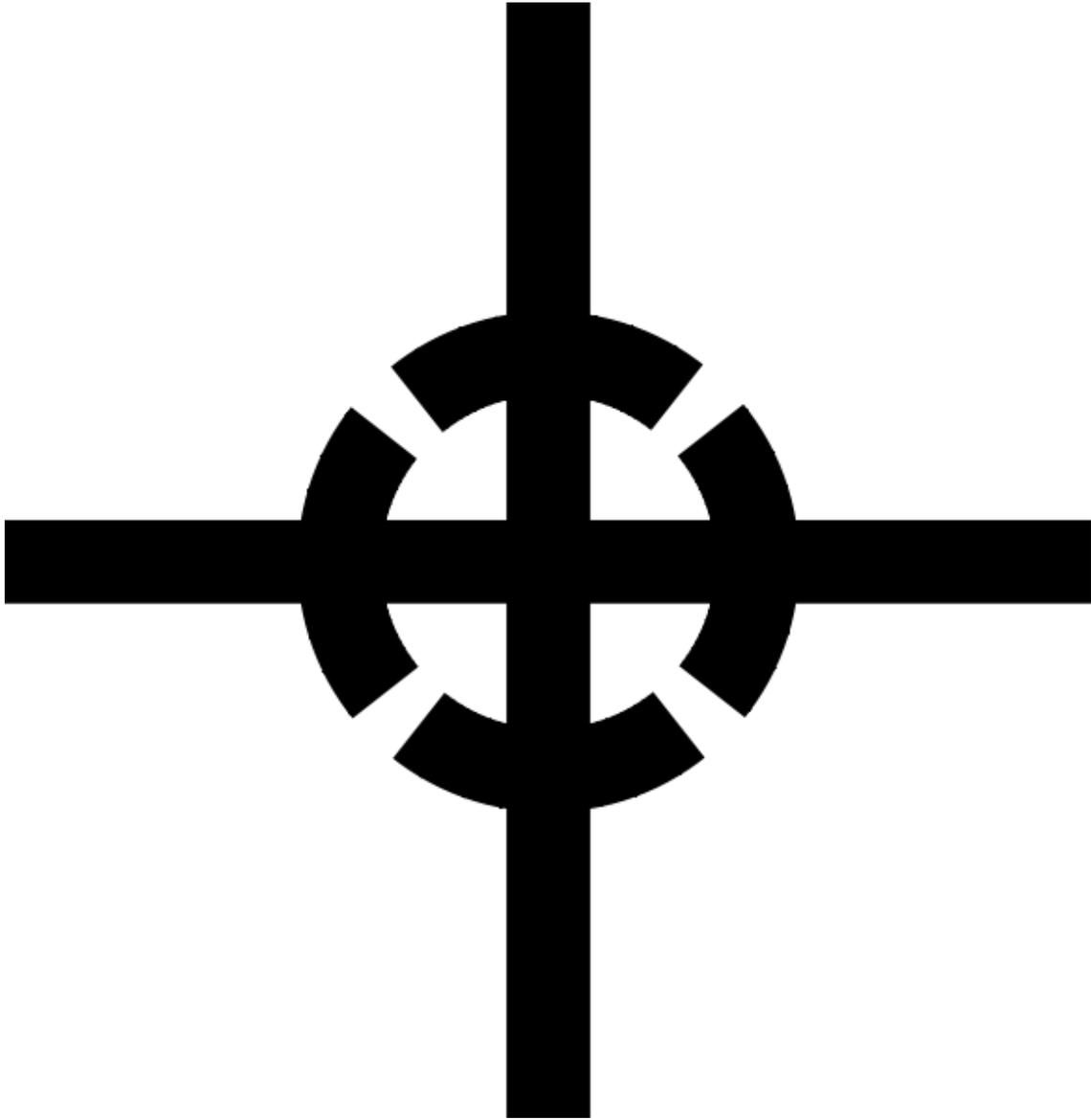
This way up



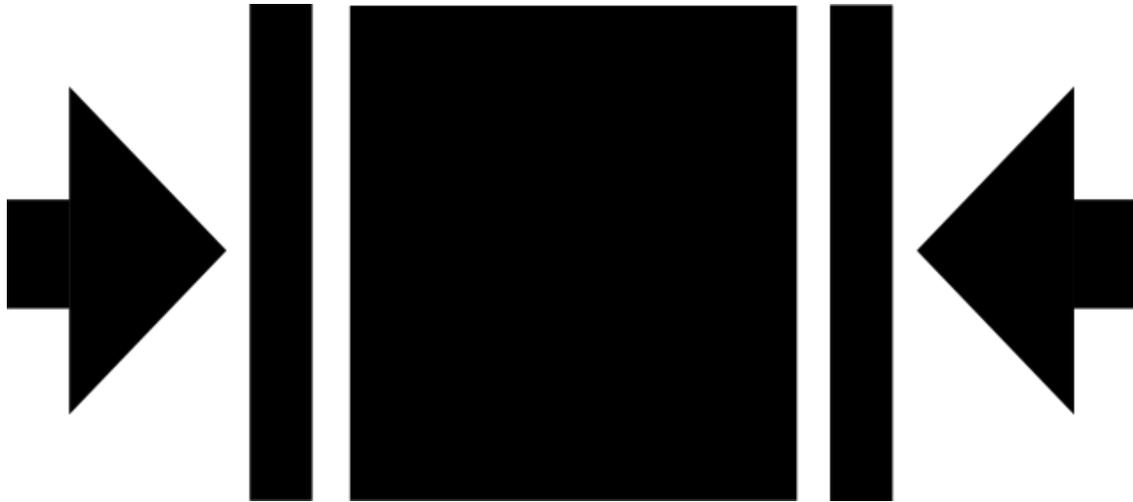
Keep away from sunlight



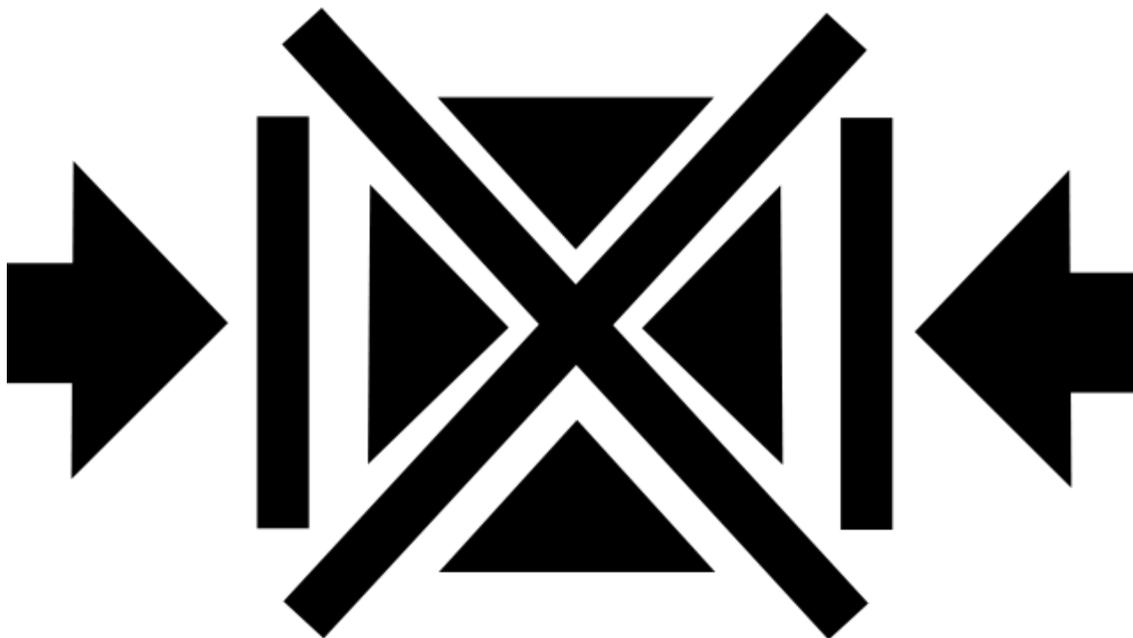
Keep away from water



Centre of gravity



Clamp as indicated



Do not clamp as indicated

Package development considerations

Package design and development are often thought of as an integral part of the new product development process. Alternatively, development of a package (or component) can be a separate process, but must be linked closely with the product to be packaged. Package design starts with the identification of all the requirements: structural design, marketing, shelf life, quality assurance, logistics, legal, regulatory, graphic design, end-

use, environmental, etc. The design criteria, performance (specified by package testing), completion time targets, resources, and cost constraints need to be established and agreed upon.



Palletized and unitized load



**Express air shipment
of mixed parcels**

Transport packaging needs to be matched to its logistics system. Packages designed for controlled shipments of uniform pallet loads may not be suited to mixed shipments with express carriers.

An example of how package design is affected by other factors is the relationship to logistics. When the distribution system includes individual shipments by a small parcel carrier, the sortation, handling, and mixed stacking make severe demands on the strength and protective ability of the transport package. If the logistics system consists of uniform palletized unit loads, the structural design of the package can be designed to those specific needs: vertical stacking, perhaps for a longer time frame. A package designed for one mode of shipment may not be suited for another.

With some types of products, the design process involves detailed regulatory requirements for the package. For example with packaging foods, any package components that may contact the food are food contact materials. Toxicologists and food scientists need to verify that the packaging materials are allowed by applicable regulations. Packaging engineers need to verify that the completed package will keep the product safe for its intended shelf life with normal usage. Packaging processes, labeling, distribution, and sale need to be validated to comply with regulations and have the well being of the consumer in mind.

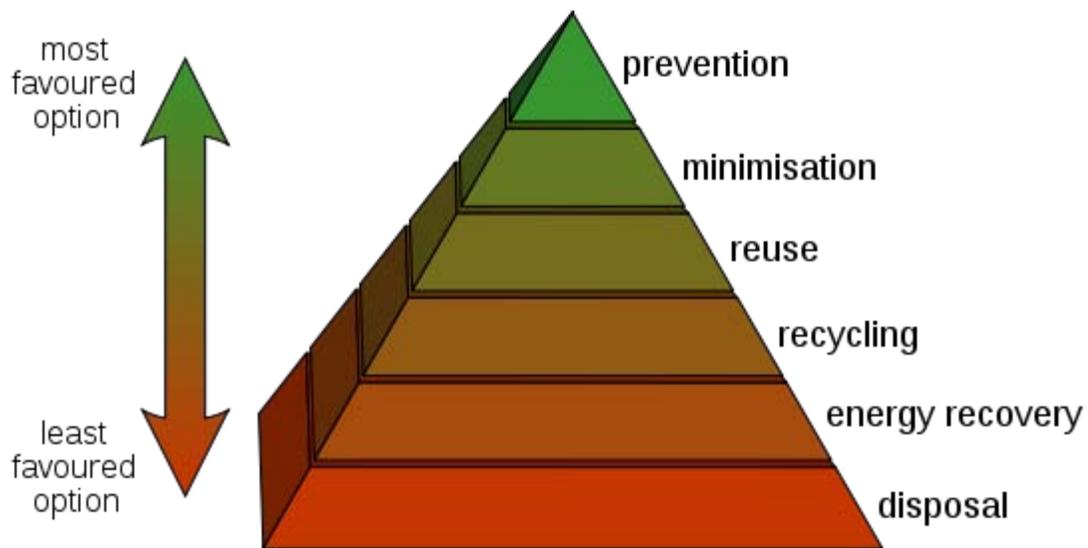
Sometimes the objectives of package development seem contradictory. For example, regulations for an over-the-counter drug might require the package to be tamper-evident and child resistant: These intentionally make the package difficult to open. The intended consumer, however, might be handicapped or elderly and be unable to readily open the package. Meeting all goals is a challenge.

Package design may take place within a company or with various degrees of external packaging engineering: independent contractors, consultants, vendor evaluations, independent laboratories, contract packagers, total outsourcing, etc. Some sort of formal Project planning and Project management methodology is required for all but the simplest package design and development programs. An effective quality management system and Verification and Validation protocols are mandatory for some types of packaging and recommended for all.

Environmental considerations

Package development involves considerations for sustainability, environmental responsibility, and applicable environmental and recycling regulations. It may involve a life cycle assessment which considers the material and energy inputs and outputs to the package, the packaged product (contents), the packaging process, the logistics system, waste management, etc. It is necessary to know the relevant regulatory requirements for point of manufacture, sale, and use.

The traditional “three R’s” of reduce, reuse, and recycle are part of a waste hierarchy which may be considered in product and package development.



The waste hierarchy

- Prevention – Waste prevention is a primary goal. Packaging should be used only where needed. Proper packaging can also help prevent waste. Packaging plays an important part in preventing loss or damage to the packaged-product (contents). Usually, the energy content and material usage of the product being packaged are much greater than that of the package. A vital function of the package is to protect the product for its intended use: if the product is damaged or degraded, its entire energy and material content may be lost.

- Minimization – (also "source reduction") The mass and volume of packaging (per unit of contents) can be measured and used as one of the criteria to minimize during the package design process. Usually “reduced” packaging also helps minimize costs. Packaging engineers continue to work toward reduced packaging.
- Reuse – The reuse of a package or component for other purposes is encouraged. Returnable packaging has long been useful (and economically viable) for closed loop logistics systems. Inspection, cleaning, repair and recouperage are often needed. Some manufacturers re-use the packaging of the incoming parts for a product, either as packaging for the outgoing product or as part of the product itself.
- Recycling – Recycling is the reprocessing of materials (pre- and post-consumer) into new products. Emphasis is focused on recycling the largest primary components of a package: steel, aluminum, papers, plastics, etc. Small components can be chosen which are not difficult to separate and do not contaminate recycling operations.
- Energy recovery – Waste-to-energy and Refuse-derived fuel in approved facilities are able to make use of the heat available from the packaging components.
- Disposal – Incineration, and placement in a sanitary landfill are needed for some materials. Certain states within the US regulate packages for toxic contents, which have the potential to contaminate emissions and ash from incineration and leachate from landfill. Packages should not be littered.

Development of sustainable packaging is an area of considerable interest by standards organizations, government, consumers, packagers, and retailers.

Packaging machines



Beer bottling lines

A choice of packaging machinery includes: technical capabilities, labor requirements, worker safety, maintainability, serviceability, reliability, ability to integrate into the packaging line, capital cost, floorspace, flexibility (change-over, materials, etc.), energy usage, quality of outgoing packages, qualifications (for food, pharmaceuticals, etc.), throughput, efficiency, productivity, ergonomics, return on investment, etc.

Packaging machinery can be:

1. purchased as standard, off-the-shelf
2. purchased custom-made or custom-tailored to specific operations
3. manufactured or modified by in-house engineers and maintenance staff

Packaging machines may be of the following general types:

- Accumulating and Collating Machines
- Blister packs, skin packs and Vacuum Packaging Machines
- Bottle caps equipment, Over-Capping, Lidding, Closing, Seaming and Sealing Machines
- Box, Case and Tray Forming, Packing, Unpacking, Closing and Sealing Machines

- Cartoning machines
- Cleaning, Sterilizing, Cooling and Drying Machines
- Coding, Printing, Marking, Stamping, and Imprinting Machines
- Converting Machines
- Conveyor belts, Accumulating and Related Machines
- Feeding, Orienting, Placing and Related Machines
- Filling Machines: Handling dry, powdered, solid, liquid, gas, or viscous products
- Inspecting, Detecting and Check weigher Machines
- Label dispenser
- Orienting, Unscrambling Machines
- Package Filling and Closing Machines
- Palletizing, Depalletizing, Unit load assembly
- Product Identification: labeling, marking, etc.
- Wrapping machines: Shrink wrap, Banding
- Form, Fill and Seal Machines
- Other speciality machinery: slitters, perforating, laser cutters, parts attachment, etc.
- Process Machinery (Product Preparation): Chopper, Crusher, Cutter, Molder, Peeler, etc.
- Process Machinery (Special Product): Coating, Enrobing, Seasoning
- Process Machinery (Product Cooking, Heating, and Cooling): Aseptic



Bakery goods shrinkwrapped by shrink film, heat sealer and heat tunnel on roller conveyer



High speed conveyor with bar code scanner for sorting transport packages



Label printer applicator applying a label to adjacent panels of a corrugated box.



Robotics used to palletize bread



Equipment used for making molded pulp components and molding packaging from straw



A semi-automatic Rotary Arm Stretch Wrapper



Equipment for thermoforming packages at NASA



Automated labeling line for wine bottles

Chapter 8

Corrugated Box Design



High graphics overlap box: die-cut for plastic handle and locking tabs

Corrugated box design is the process of matching design factors for corrugated fiberboard boxes with the functional physical, processing and end-use requirements. Packaging engineers work to control and minimize total costs throughout the system.

Functions

Corrugated boxes are used frequently as shipping containers. Boxes need to contain the product from manufacturing through distribution to sale and sometimes end-use. Boxes provide some measure of product protection by themselves but often require inner components such as cushioning, bracing and blocking to help protect fragile contents. The shipping hazards depend largely upon the particular logistics system being employed. For example, boxes unitized into a unit load on a pallet do not encounter individual handling while boxes sorted and shipped through part of their distribution cycle as mixed loads or express carriers can receive severe shocks, kicks, etc...

Ordinary shipping containers require printing and labels to identify the contents, provide legal and regulatory information, and bar codes for routing. Boxes that are used for marketing, merchandising, and point-of-sale often have high graphics to help communicate the contents. Some boxes are designed for display of contents on the shelf. Others are designed to help dispense the contents.

Stacking strength

One of the important functions of a corrugated box is to provide crush resistance (product protection) and adequate strength for stacking in warehouses.

A box can be designed by optimizing the grade of corrugated board, box design, flute direction, and inner supports. Support from the product also provides "load sharing" and can be an important factor. Box closures sometimes can have effects on box stacking strength.

If long-term storage of corrugated boxes in high humidity is expected, extra strength and moisture resistance is called for.

The method of loading boxes on pallets strongly affects stacking. Vertical columns provide the best box performance while interlocking patterns of boxes significantly reduce performance. The interaction of the boxes and pallets is also important.

Box compression testing is a means of evaluating boxes, stacks of boxes, and unit loads under controlled conditions. Field conditions of stacking and dynamic compression do not have the same degree of control. Compression strength can be estimated based on container construction, size, and use parameters: actual package testing is often conducted to verify these estimates.

Many packaging engineers find it beneficial to periodically audit warehouses and visit customer's package receiving operations. When field performance is observed or documented to have problems, a new cycle of design and testing may be justified.

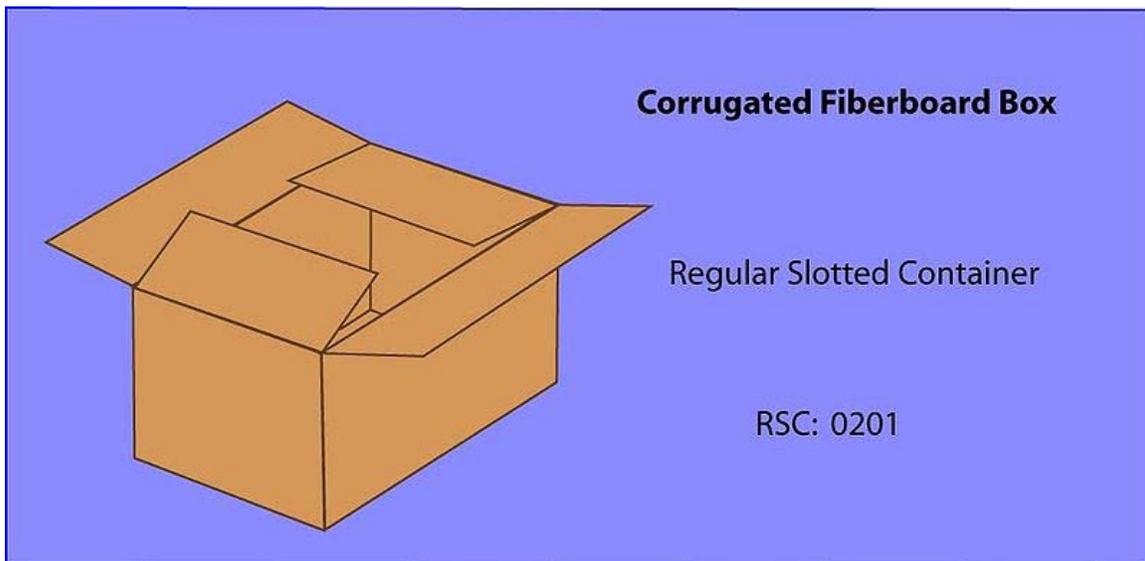
Process

Packaging engineers design corrugated boxes to meet the particular needs of the product being shipped, the hazards of the shipping environment, (shock, vibration, compression, moisture, etc), and the needs of retailers and consumers

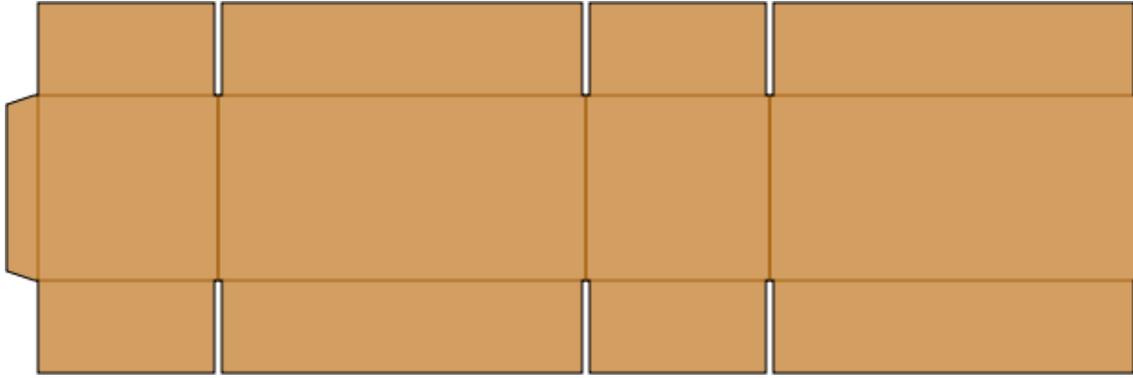
Engineers and designers start with the needs of the particular project: cost constraints, machinery capabilities, product characteristics, logistics needs, applicable regulations, consumer needs, etc. Often designs are made with Computer Aided Design programs connected to automated sample making tables. Several design and construction options might be considered. Samples are often submitted to performance testing based on ASTM or other standard test protocols such as the International Safe Transit Association. Structural design is matched with graphic design. For consumer based designs, marketing personnel sometimes use Focus groups or more quantitative means of assessing acceptance. Test markets are employed for major programs.

Design

The most common box style is the Regular Slotted Container (RSC). All flaps are the same length from score to edge. Typically the major flaps meet in the middle and the minor flaps do not.



Regular Slotted Container



Box blank for a regular slotted container showing score lines, slots, and manufacturer's joint

The manufacturer's joint is most often joined with adhesive but may also be taped or stitched. The box is shipped flat (knocked down) to the packager who sets up the box, fills it, and closes it for shipment. Box closure may be by tape, adhesive, staples, strapping, etc.

Many other styles of corrugated boxes and structures are available:

- A Full Overlap Box is similar to an RSC except the major flaps fully overlap.
- A Half Slotted Container (HSC) Bottom or top normally used as a shroud (cap) or base (btm)
- A Five Panel Folder is shipped flat to a packager without a manufacturer's joint and is often used for long items. The box has five long panels, one of which fully overlaps. The ends also fully overlap.
- A Full Telescope Box has two fully telescoping sections. The sections may be formed by staples, die-cut locks, adhesive, etc.
- A Partial Telescope Box has two sections. The top telescopes partially over the bottom.
- A corrugated tray is often used for display purposes or used with a shrink wrap
- Corrugated corner pads can be used for product support and cushioning
- Special die-cut shapes have almost endless designs and uses.
- etc

The size of a box can be measured for either internal (for product fit) or external (for handling machinery or palletizing) dimensions. Boxes are usually specified and ordered by the internal dimensions.

Box styles in Europe are typically defined by a 4-digit code specified by FEFCO: for example a regular slotted container (RSC) is coded 0201. FEFCO styles are normally the basis for more complicated special designs that incorporate, for example, locking tabs or internal fittings.



Wholesale outlet using corrugated boxes to stock shelves.



Bag-In-Box containing liquids to dispense



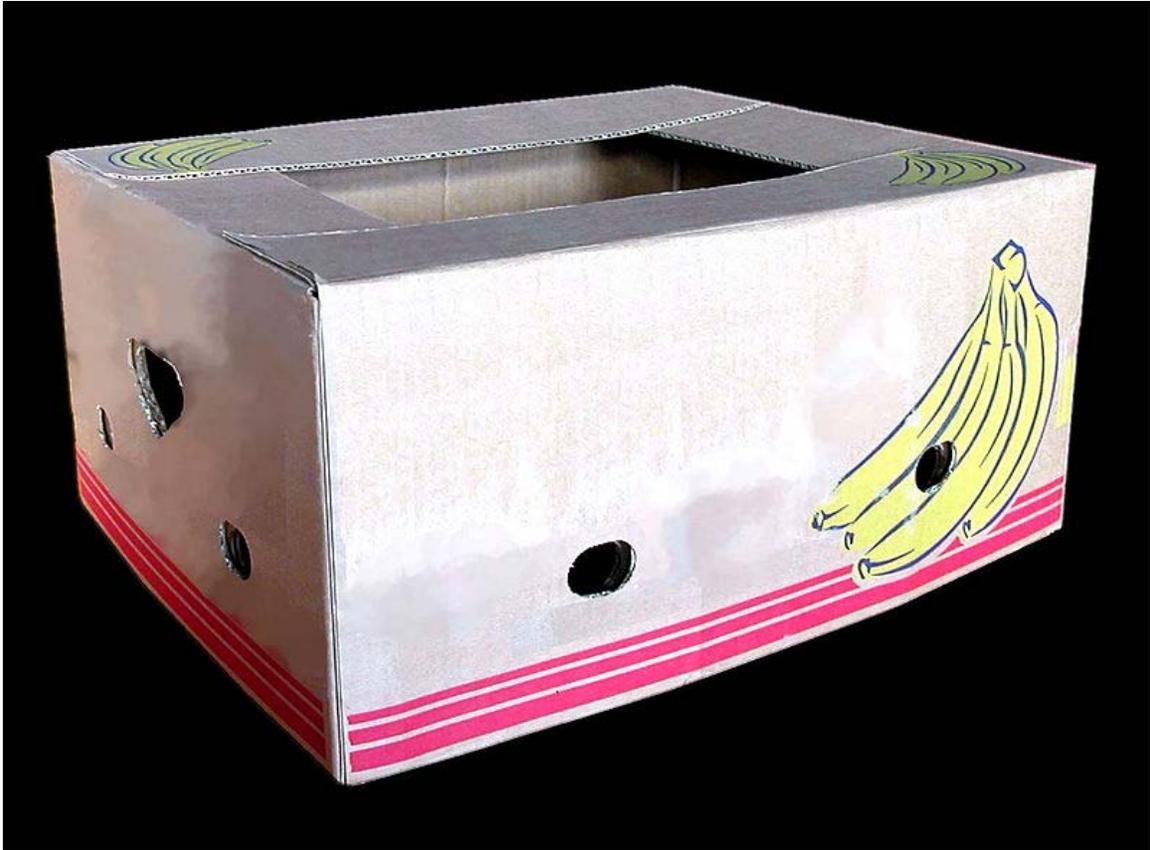
Display box for pretzels



Box (lug) used for fruit. Box needs to be open to allow respiration and access to cold chain. Tabs interlock when stacked on pallet.



Boxes of books. Note security tape used as closure



Telescope box used for bananas. Note hand holes and ventilation holes

Individual mixed shipments



Palletized and unitized load



**Express air shipment
of mixed parcels**

Box construction needs to be matched to its logistics system. Packages designed for controlled shipments of uniform pallet loads may not be suited to mixed shipments with express carriers.

Many items are shipped individually (in part or entirely) by express carrier, mail, or other mixed logistics systems. The demands of multiple manual handlings, automated sortation, and uncontrolled stacking in trucks or air containers put severe stress on boxes, box closures, and the contents. Boxes designed for unit load handling and storage may not be suited to mixed logistics systems.

Less than truckload shipping puts more stress on corrugated shipping containers than shipment by uniform pallet loads in trucks or intermodal containers. Boxes sometimes need to be heavier construction to match the needs of the distribution system.

Government, military, and export

Many items being supplied to governments are handled very well: boxes are unitized, shipped on covered trucks or intermodal containers, and storage is in warehouses. Normal “domestic boxes” and commercial packaging are acceptable.

Military materiel, field supplies, and humanitarian aid often encounter severe handling and uncontrolled storage. Special box specifications for government shipments are often applicable. Weather-resistant fiberboards, box construction, box closure, and unitizing are needed.



RSCs of MREs being off-loaded from a helicopter. Water-resistant boxes closed with strapping.



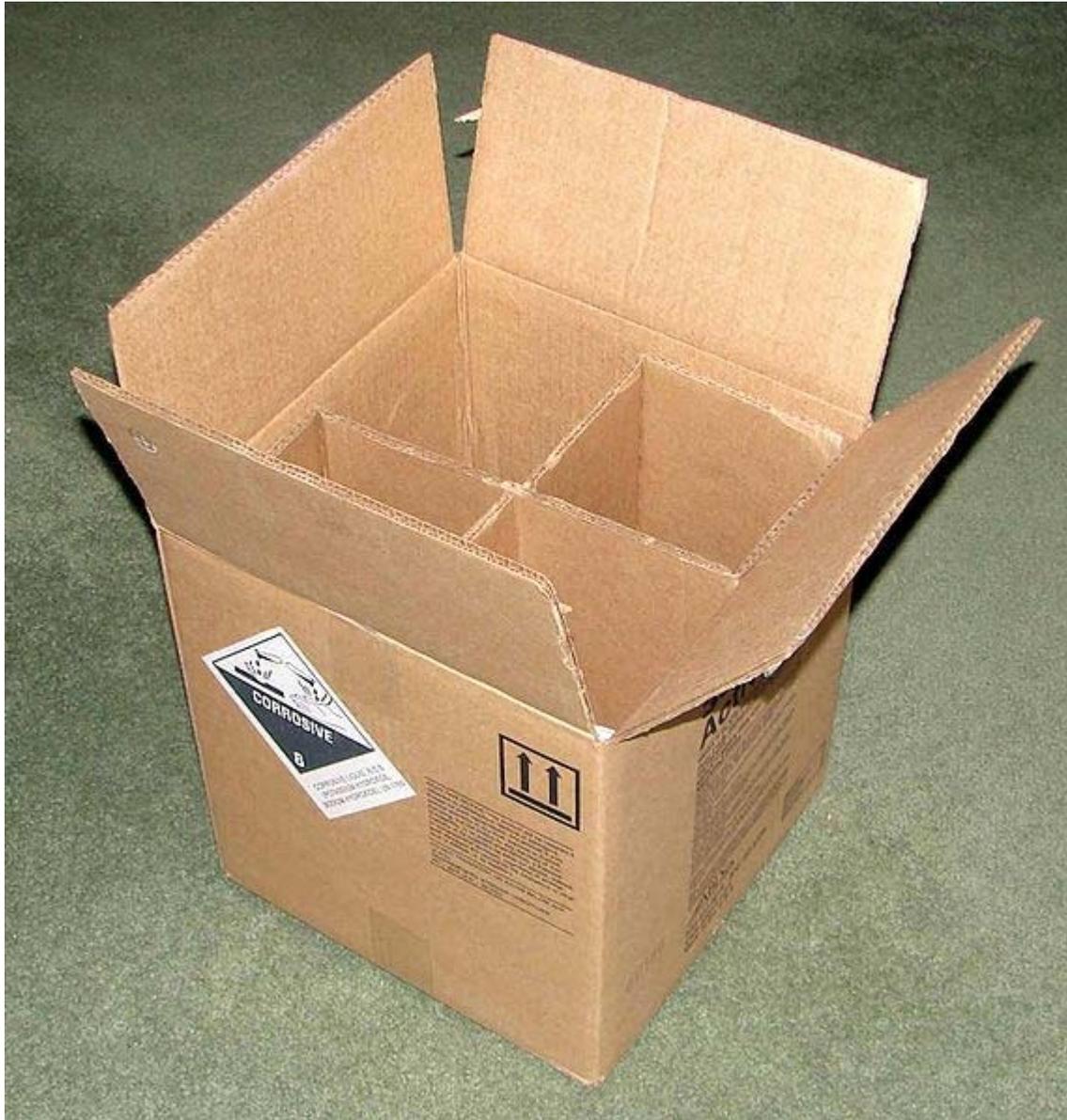
Humanitarian aid in a bulk boxes or bins

Export

Many international shipments are handled very well: boxes are unitized, shipped on covered trucks or intermodal containers, and storage is in warehouses. Normal “domestic boxes” are commonly used.

Break bulk cargo needs to be water resistant and heavy duty. Even shipments initially sent via intermodal freight transport may have subsequent logistics operations that are extreme and uncontrolled. The specific conditions in the destination port and the country of use need to be considered for design of export boxes.

Dangerous and hazardous goods



Doublewall box with dividers for shipping four bottles of corrosive liquid

Shipment of dangerous goods or hazardous materials are highly regulated. Based on the UN Recommendations on the Transport of Dangerous Goods model regulations, each country has coordinated design and performance requirements for shipment. For example, in the US, the Department of Transportation has jurisdiction and published requirements in Title 49 of the Code of Federal Regulations. Corrugated boxes are described in 4G requirements. Performance (severe drop test, etc.) needs to be certified for the box and contents.

Some carriers have additional requirements.

Box Closure

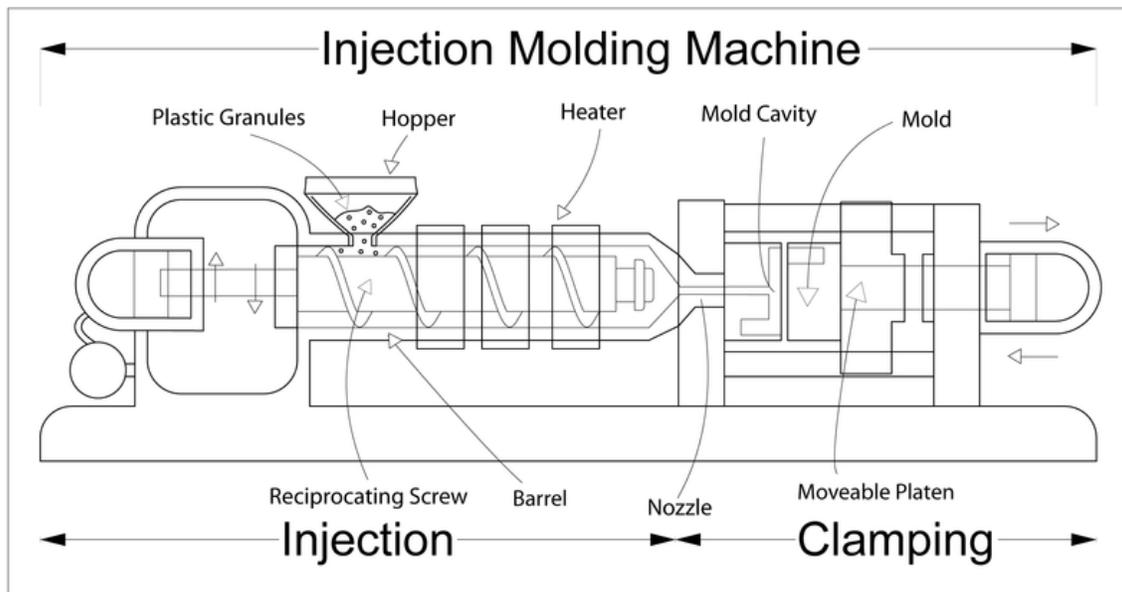
The means of closing a box is an important aspect of design. It affects the types of equipment available to production lines, the measured laboratory performance, the field performance, and the ability of end-users to easily and safely open the box.

Box closures include:

- Adhesive, water based or Hot melt adhesive
- Staples
- Box sealing tape, pressure sensitive
- Filament tape, pressure sensitive
- Water activated gummed paper
- Reinforced water activated gummed tape
- Strapping
- Shrink wrap

Chapter 9

Injection Molding



An injection molding machine

Injection molding (British English: **moulding**) is a manufacturing process for producing parts from both thermoplastic and thermosetting plastic materials. Material is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the mold cavity. After a product is designed, usually by an industrial designer or an engineer, molds are made by a moldmaker (or toolmaker) from metal, usually either steel or aluminum, and precision-machined to form the features of the

desired part. Injection molding is widely used for manufacturing a variety of parts, from the smallest component to entire body panels of cars.

Process characteristics

- Utilizes a ram or screw-type plunger to force molten plastic material into a mold cavity
- Produces a solid or open-ended shape that has conformed to the contour of the mold
- Uses thermoplastic or thermoset materials
- Produces a parting line, sprue, and gate marks
- Ejector pin marks are usually present

History

The first man-made plastic was invented in Britain in 1851 by Alexander Parkes. He publicly demonstrated it at the 1862 International Exhibition in London, calling the material he produced "Parkesine." Derived from cellulose, Parkesine could be heated, molded, and retain its shape when cooled. It was, however, expensive to produce, prone to cracking, and highly flammable.

In 1868, American inventor John Wesley Hyatt developed a plastic material he named Celluloid, improving on Parkes' invention so that it could be processed into finished form. Together with his brother Isaiah, Hyatt patented the first injection molding machine in 1872. This machine was relatively simple compared to machines in use today. It worked like a large hypodermic needle, using a plunger to inject plastic through a heated cylinder into a mold. The industry progressed slowly over the years, producing products such as collar stays, buttons, and hair combs.

The industry expanded rapidly in the 1940s because World War II created a huge demand for inexpensive, mass-produced products. In 1946, American inventor James Watson Hendry built the first screw injection machine, which allowed much more precise control over the speed of injection and the quality of articles produced. This machine also allowed material to be mixed before injection, so that colored or recycled plastic could be added to virgin material and mixed thoroughly before being injected. Today screw injection machines account for the vast majority of all injection machines. In the 1970s, Hendry went on to develop the first gas-assisted injection molding process, which permitted the production of complex, hollow articles that cooled quickly. This greatly improved design flexibility as well as the strength and finish of manufactured parts while reducing production time, cost, weight and waste.

The plastic injection molding industry has evolved over the years from producing combs and buttons to producing a vast array of products for many industries including automotive, medical, aerospace, consumer products, toys, plumbing, packaging, and construction.

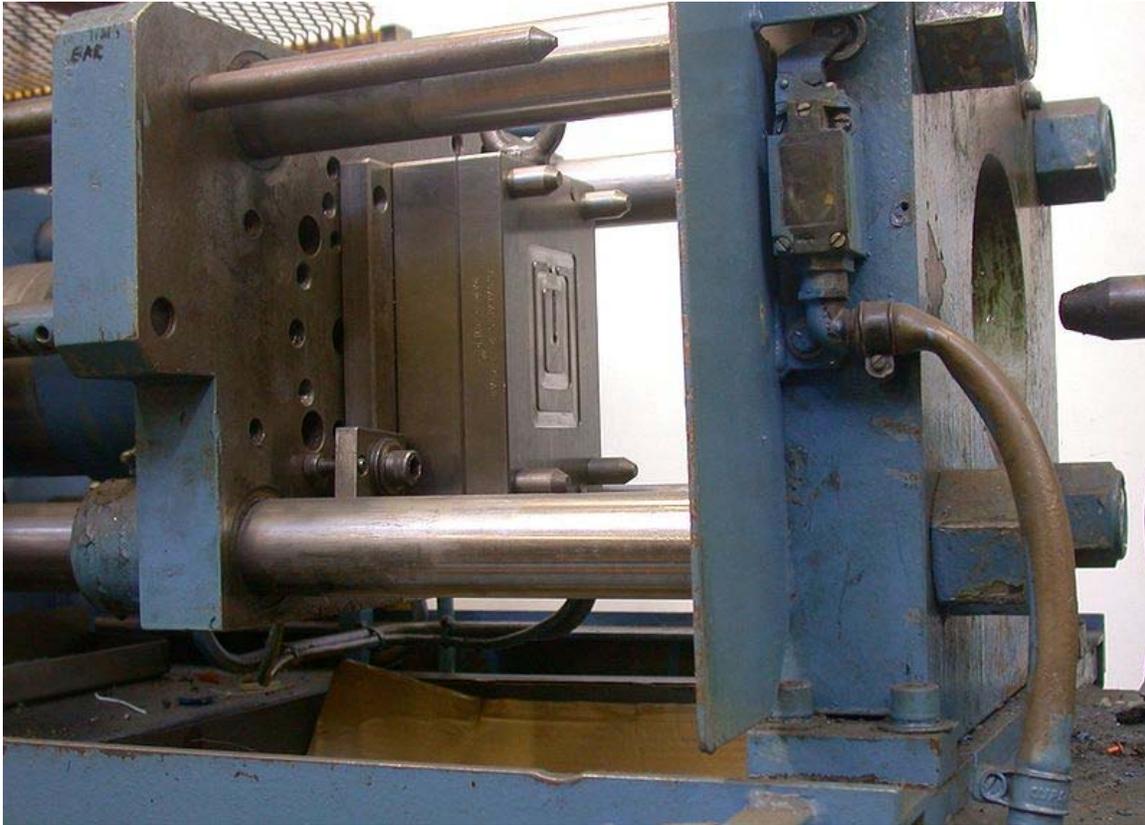
Applications

Injection molding is used to create many things such as wire spools, packaging, bottle caps, automotive dashboards, pocket combs, and most other plastic products available today. Injection molding is the most common method of part manufacturing. It is ideal for producing high volumes of the same object. Some advantages of injection molding are high production rates, repeatable high tolerances, the ability to use a wide range of materials, low labor cost, minimal scrap losses, and little need to finish parts after molding. Some disadvantages of this process are expensive equipment investment, potentially high running costs, and the need to design moldable parts.

Examples of polymers best suited for the process

Most polymers may be used, including all thermoplastics, some thermosets, and some elastomers. In 1995 there were approximately 18,000 different materials available for injection molding and that number was increasing at an average rate of 750 per year. The available materials are alloys or blends of previously developed materials meaning that product designers can choose from a vast selection of materials, one that has exactly the right properties. Materials are chosen based on the strength and function required for the final part, but also each material has different parameters for molding that must be taken into account. Common polymers like epoxy and phenolic are examples of thermosetting plastics while nylon, polyethylene, and polystyrene are thermoplastic.

Equipment



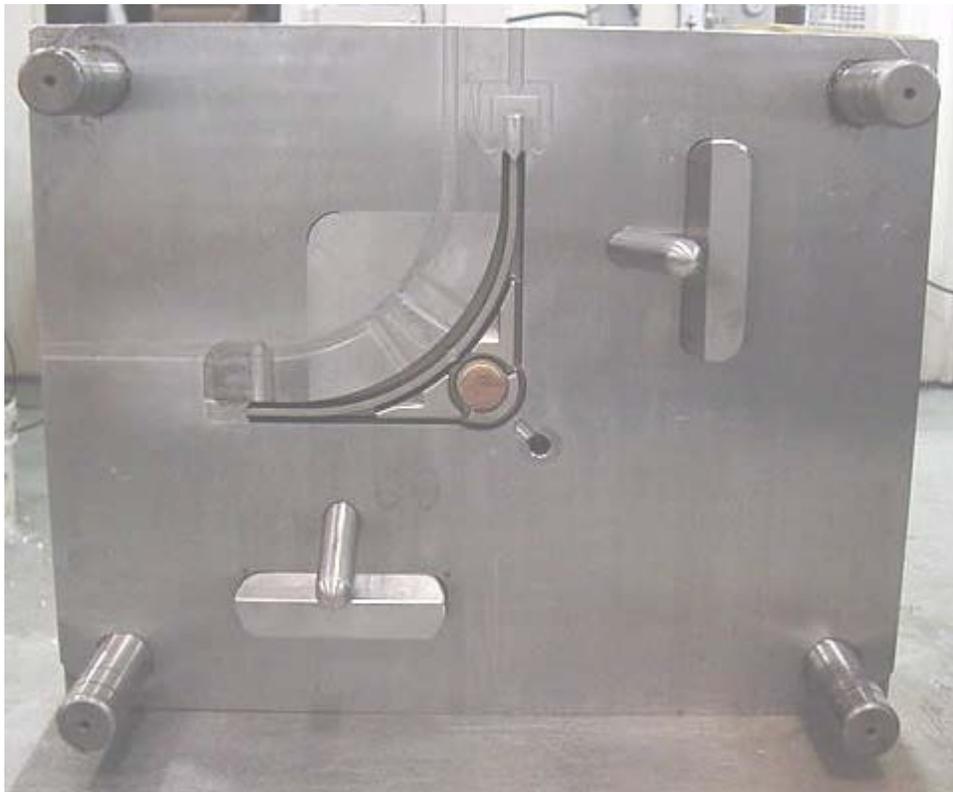
Paper clip mold opened in molding machine; the nozzle is visible at right

Injection molding machines consist of a material hopper, an injection ram or screw-type plunger, and a heating unit. They are also known as presses, they hold the molds in which the components are shaped. Presses are rated by tonnage, which expresses the amount of clamping force that the machine can exert. This force keeps the mold closed during the injection process. Tonnage can vary from less than 5 tons to 6000 tons, with the higher figures used in comparatively few manufacturing operations. The total clamp force needed is determined by the projected area of the part being molded. This projected area is multiplied by a clamp force of from 2 to 8 tons for each square inch of the projected areas. As a rule of thumb, 4 or 5 tons/in² can be used for most products. If the plastic material is very stiff, it will require more injection pressure to fill the mold, thus more clamp tonnage to hold the mold closed. The required force can also be determined by the material used and the size of the part, larger parts require higher clamping force.

Mold

Mold or **die** are the common terms used to describe the tooling used to produce plastic parts in molding.

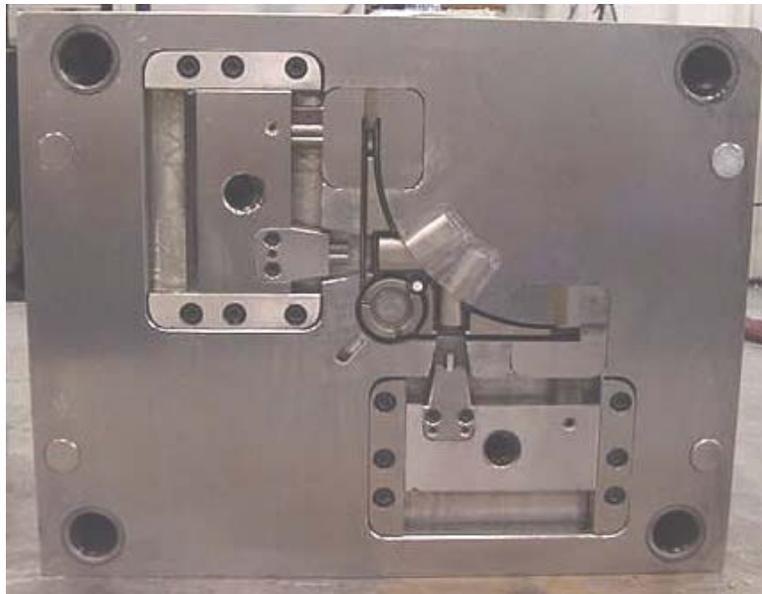
Since molds have been expensive to manufacture, they were usually only used in mass production where thousands of parts were being produced. Typical molds are constructed from hardened steel, pre-hardened steel, aluminum, and/or beryllium-copper alloy. The choice of material to build a mold from is primarily one of economics; in general, steel molds cost more to construct, but their longer lifespan will offset the higher initial cost over a higher number of parts made before wearing out. Pre-hardened steel molds are less wear-resistant and are used for lower volume requirements or larger components. The typical steel hardness is 38–45 on the Rockwell-C scale. Hardened steel molds are heat treated after machining. These are by far the superior in terms of wear resistance and lifespan. Typical hardness ranges between 50 and 60 Rockwell-C (HRC). Aluminum molds can cost substantially less, and, when designed and machined with modern computerized equipment, can be economical for molding tens or even hundreds of thousands of parts. Beryllium copper is used in areas of the mold that require fast heat removal or areas that see the most shear heat generated. The molds can be manufactured either by CNC machining or by using Electrical Discharge Machining processes



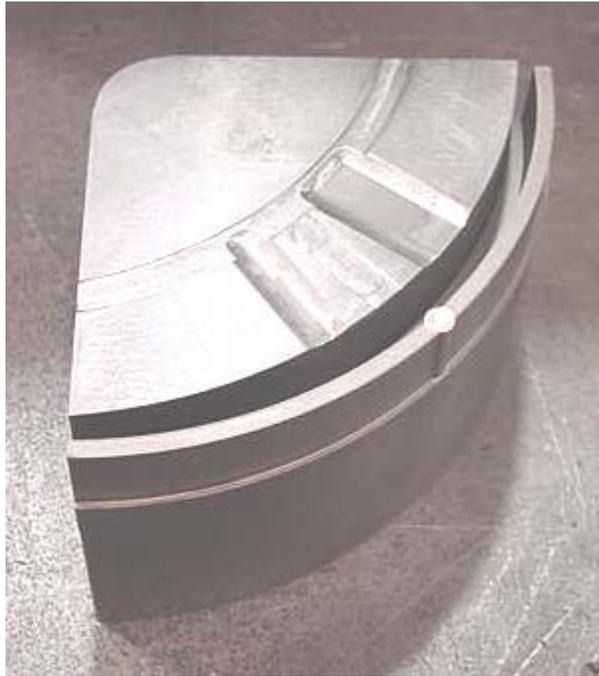
"A" side of die for 25% glass-filled acetal with 2 side pulls.



Close up of removable insert in "A" side.



"B" side of die with side pull actuators.



Insert removed from die.

Mold design



Standard two plates tooling – core and cavity are inserts in a mold base – "family mold" of five different parts

The mold consists of two primary components, the injection mold (A plate) and the ejector mold (B plate). Plastic resin enters the mold through a *sprue* in the injection mold, the sprue bushing is to seal tightly against the nozzle of the injection barrel of the molding machine and to allow molten plastic to flow from the barrel into the mold, also known as the *cavity*. The sprue bushing directs the molten plastic to the cavity images through channels that are machined into the faces of the A and B plates. These channels allow plastic to run along them, so they are referred to as runners. The molten plastic flows through the runner and enters one or more specialized gates and into the cavity geometry to form the desired part.

The amount of resin required to fill the sprue, runner and cavities of a mold is a shot. Trapped air in the mold can escape through air vents that are ground into the parting line of the mold. If the trapped air is not allowed to escape, it is compressed by the pressure of the incoming material and is squeezed into the corners of the cavity, where it prevents filling and causes other defects as well. The air can become so compressed that it ignites and burns the surrounding plastic material. To allow for removal of the molded part from the mold, the mold features must not overhang one another in the direction that the mold opens, unless parts of the mold are designed to move from between such overhangs when the mold opens (utilizing components called Lifters).

Sides of the part that appear parallel with the direction of draw (The axis of the cored position (hole) or insert is parallel to the up and down movement of the mold as it opens and closes) are typically angled slightly with (draft) to ease release of the part from the mold. Insufficient draft can cause deformation or damage. The draft required for mold release is primarily dependent on the depth of the cavity: the deeper the cavity, the more draft necessary. Shrinkage must also be taken into account when determining the draft required. If the skin is too thin, then the molded part will tend to shrink onto the cores that form them while cooling, and cling to those cores or part may warp, twist, blister or crack when the cavity is pulled away. The mold is usually designed so that the molded part reliably remains on the ejector (B) side of the mold when it opens, and draws the runner and the sprue out of the (A) side along with the parts. The part then falls freely when ejected from the (B) side. Tunnel gates, also known as submarine or mold gate, is located below the parting line or mold surface. The opening is machined into the surface of the mold on the parting line. The molded part is cut (by the mold) from the runner system on ejection from the mold. Ejector pins, also known as knockout pin, is a circular pin placed in either half of the mold (usually the ejector half), which pushes the finished molded product, or runner system out of a mold.

The standard method of cooling is passing a coolant (usually water) through a series of holes drilled through the mold plates and connected by hoses to form a continuous pathway. The coolant absorbs heat from the mold (which has absorbed heat from the hot plastic) and keeps the mold at a proper temperature to solidify the plastic at the most efficient rate.

To ease maintenance and venting, cavities and cores are divided into pieces, called *inserts*, and sub-assemblies, also called *inserts*, *blocks*, or *chase blocks*. By substituting interchangeable inserts, one mold may make several variations of the same part.

More complex parts are formed using more complex molds. These may have sections called slides, that move into a cavity perpendicular to the draw direction, to form overhanging part features. When the mold is opened, the slides are pulled away from the plastic part by using stationary “angle pins” on the stationary mold half. These pins enter a slot in the slides and cause the slides to move backward when the moving half of the mold opens. The part is then ejected and the mold closes. The closing action of the mold causes the slides to move forward along the angle pins.

Some molds allow previously molded parts to be reinserted to allow a new plastic layer to form around the first part. This is often referred to as overmolding. This system can allow for production of one-piece tires and wheels.

Two-shot or multi-shot molds are designed to "overmold" within a single molding cycle and must be processed on specialized injection molding machines with two or more injection units. This process is actually an injection molding process performed twice. In the first step, the base color material is molded into a basic shape. Then the second material is injection-molded into the remaining open spaces. That space is then filled during the second injection step with a material of a different color.

A mold can produce several copies of the same parts in a single "shot". The number of "impressions" in the mold of that part is often incorrectly referred to as cavitation. A tool with one impression will often be called a single impression(cavity) mold. A mold with 2 or more cavities of the same parts will likely be referred to as multiple impression (cavity) mold. Some extremely high production volume molds (like those for bottle caps) can have over 128 cavities.

In some cases multiple cavity tooling will mold a series of different parts in the same tool. Some toolmakers call these molds family molds as all the parts are related.

Effects on the material properties

The mechanical properties of a part are usually little affected. Some parts can have internal stresses in them. This is one of the reasons why it is desirable to have uniform wall thickness when molding. One of the physical property changes is shrinkage. A permanent chemical property change is the material thermoset, which can't be remelted to be injected again.

Tool materials

Tool steel or beryllium-copper are often used. Mild steel, aluminum, nickel or epoxy are suitable only for prototype or very short production runs. Modern hard aluminum (7075

and 2024 alloys) with proper mold design, can easily make molds capable of 100,000 or more part life.

Geometrical possibilities

The most commonly used plastic molding process, injection molding, is used to create a large variety of products with different shapes and sizes. Most importantly, they can create products with complex geometry that many other processes cannot. There are a few precautions when designing something that will be made using this process to reduce the risk of weak spots. First, streamline your product or keep the thickness relatively uniform. Second, try and keep your product between 2 to 20 inches.

The size of a part will depend on a number of factors (material, wall thickness, shape, process etc.). The initial raw material required may be measured in the form of granules, pellets or powders. Here are some ranges of the sizes:

Method	Raw materials	Maximum size	Minimum size
Injection molding (thermo-plastic)	Granules, pellets, powders	700 oz.	Less than 1 oz.
Injection molding (thermo-setting)	Granules, pellets, powders	200 oz.	Less than 1 oz.

Machining

Molds are built through two main methods: standard machining and EDM. Standard Machining, in its conventional form, has historically been the method of building injection molds. With technological development, CNC machining became the predominant means of making more complex molds with more accurate mold details in less time than traditional methods.

The electrical discharge machining (EDM) or spark erosion process has become widely used in mold making. As well as allowing the formation of shapes that are difficult to machine, the process allows pre-hardened molds to be shaped so that no heat treatment is required. Changes to a hardened mold by conventional drilling and milling normally require annealing to soften the mold, followed by heat treatment to harden it again. EDM is a simple process in which a shaped electrode, usually made of copper or graphite, is very slowly lowered onto the mold surface (over a period of many hours), which is immersed in paraffin oil. A voltage applied between tool and mold causes spark erosion of the mold surface in the inverse shape of the electrode.

Cost

The cost of manufacturing molds depends on a very large set of factors ranging from number of cavities, size of the parts (and therefore the mold), complexity of the pieces,

expected tool longevity, surface finishes and many others. The initial cost is great, however the piece part cost is low, so with greater quantities the overall price decreases.

Injection process



Small injection molder showing hopper, nozzle and die area

With injection molding, granular plastic is fed by gravity from a hopper into a heated barrel. As the granules are slowly moved forward by a screw-type plunger, the plastic is forced into a heated chamber, where it is melted. As the plunger advances, the melted plastic is forced through a nozzle that rests against the mold, allowing it to enter the mold cavity through a gate and runner system. The mold remains cold so the plastic solidifies almost as soon as the mold is filled.

Injection molding cycle

The sequence of events during the injection mold of a plastic part is called the injection molding cycle. The cycle begins when the mold closes, followed by the injection of the polymer into the mold cavity. Once the cavity is filled, a holding pressure is maintained to compensate for material shrinkage. In the next step, the screw turns, feeding the next shot to the front screw. This causes the screw to retract as the next shot is prepared. Once the part is sufficiently cool, the mold opens and the part is ejected.

Different types of injection molding processes



sandwich molded toothbrush handle

Although most injection molding processes are covered by the conventional process description above, there are several important molding variations including:

- Co-injection (sandwich) molding
- Fusible (lost, soluble) core injection molding
- Gas-assisted injection molding
- In-mold decoration and in mold lamination
- Injection-compression molding
- Insert and outsert molding
- Lamellar (microlayer) injection molding
- Low-pressure injection molding
- Metal injection molding
- Microinjection molding
- Microcellular molding
- Multicomponent injection molding
- Multiple live-feed injection molding
- Powder injection molding
- Push-Pull injection molding
- Reaction injection molding
- Resin transfer molding
- Rheomolding
- Structural foam injection molding
- Structural reaction injection molding
- Thin-wall molding
- Vibration gas injection molding
- Water assisted injection molding
- Rubber injection
- Injection molding of liquid silicone rubber

For more details about the different types injection processes.

Process troubleshooting

Optimal process settings are critical to influencing the cost, quality, and productivity of plastic injection molding. The main trouble in injection molding is to have a box of good plastics parts contaminated with scrap. For that reason process optimization studies have to be done and process monitoring has to take place. First article inspection of internal and external geometry including imperfections such as porosity can be completed using Industrial CT Scanning a 3D x-ray technology. For external geometry verification only a Coordinate-measuring machine or white light scanner can be used.

To have a constant filling rate in the cavity the switch over from injection phase to the holding phase can be made based on a cavity pressure level.

Having a stable production window the following issues are worth to investigate:

The **Metering phase** can be optimized by varying screw turns per minute and backpressure. Variation of time needed to reload the screw gives an indication of the

stability of this phase.

Injection speed can be optimized by pressure drop studies between pressure measured in the Nozzle (alternatively hydraulic pressure) and pressure measured in the cavity. Melted material with a lower viscosity has less pressure loss from nozzle to cavity than material with a higher viscosity. Varying the Injection speed changes the shear rate. Higher speed = higher shear rate = lower viscosity. Pay attention increasing the mold and melt temperature lowers the viscosity but lowers the shear rate too.

Gate seal or gate freeze / sink mark / weight and geometry studies have the approach to prevent sink marks and geometrical faults. Optimizing the high and duration of applied holding pressure based on cavity pressure curves is the appropriate way to go. The thicker the part the longer the holding pressure applied. The thinner the part the shorter the holding pressure applied.

Cooling time starts once the injection phase is finished. The hotter the melted plastics the longer the cooling time the thicker the part produced the longer the cooling time.

Molding trial

When filling a new or unfamiliar mold for the first time, where shot size for that mold is unknown, a technician/tool setter usually starts with a small shot weight and fills gradually until the mold is 95 to 99% full. Once this is achieved a small amount of holding pressure will be applied and holding time increased until gate freeze off (solidification time) has occurred. Gate freeze off time can be determined by increasing the hold time and then weighing the part when the weight of the part does not change we then know that the gate has frozen and no more material is injected into the part. Gate solidification time is important as it determines cycle time and the quality and consistency of the product, which itself is an important issue in the economics of the production process. Holding pressure is increased until the parts are free of sinks and part weight has been achieved. Once the parts are good enough and have passed any specific criteria, a setting sheet is produced for people to follow in the future. The method to setup an unknown mold the first time can be supported by installing cavity pressure sensors. Measuring the cavity pressure as a function of time can provide a good indication of the filling profile of the cavity. Once the equipment is set to successfully create the molded part, modern monitoring systems can save a reference curve of the cavity pressure. With that it is possible to reproduce the same part quality on another molding machine within a short setup time.

Molding defects

Injection molding is a complex technology with possible production problems. They can be caused either by defects in the molds or more often by part processing (molding)

Molding Defects	Alternative name	Descriptions	Causes
Blister	Blistering	Raised or layered zone on surface of the part	Tool or material is too hot, often caused by a lack of cooling around the tool or a faulty heater

Burn marks	Air burn/gas burn/dieseling	Black or brown burnt areas on the part located at furthest points from gate or where air is trapped	Tool lacks venting, injection speed is too high
Color streaks (US)	Colour streaks (UK)	Localized change of color/colour	Masterbatch isn't mixing properly, or the material has run out and it's starting to come through as natural only. Previous colored material "dragging" in nozzle or check valve. Contamination of the material e.g. PP mixed with ABS, very dangerous if the part is being used for a safety critical application as the material has very little strength when delaminated as the materials cannot bond
Delamination		Thin mica like layers formed in part wall	
Flash	Burrs	Excess material in thin layer exceeding normal part geometry	Mold is over packed or parting line on the tool is damaged, too much injection speed/material injected, clamping force too low. Can also be caused by dirt and contaminants around tooling surfaces.
Embedded contaminates	Embedded particulates	Foreign particle (burnt material or other) embedded in the part	Particles on the tool surface, contaminated material or foreign debris in the barrel, or too much shear heat burning the material prior to injection
Flow marks	Flow lines	Directionally "off tone" wavy lines or patterns	Injection speeds too slow (the plastic has cooled down too much during injection, injection speeds must be set as fast as you can get away with at all times)
Jetting		Deformed part by turbulent flow of material	Poor tool design, gate position or runner. Injection speed set too high.
Knit lines	Weld lines	Small lines on the backside of core pins or windows in parts that look like just lines.	Caused by the melt-front flowing around an object standing proud in a plastic part as well as at the end of fill where the melt-front comes together again. Can be minimized or eliminated with a mold-flow study when the mold is in design phase. Once the mold is made and the gate

is placed, one can minimize this flaw only by changing the melt and the mold temperature.

Polymer degradation		Polymer breakdown from hydrolysis, oxidation etc.	Excess water in the granules, excessive temperatures in barrel
Sink marks	[sinks]	Localized depression (In thicker zones)	Holding time/pressure too low, cooling time too short, with sprueless hot runners this can also be caused by the gate temperature being set too high. Excessive material or thick wall thickness.
Short shot	Non-fill / Short mold	Partial part	Lack of material, injection speed or pressure too low, mold too cold, lack of gas vents
Splay marks	Splash mark / Silver streaks	Circular pattern around gate caused by hot gas	Moisture in the material, usually when hygroscopic resins are dried improperly. Trapping of gas in "rib" areas due to excessive injection velocity in these areas. Material too hot.
Stringiness	Stringing	String like remain from previous shot transfer in new shot	Nozzle temperature too high. Gate hasn't frozen off
Voids		Empty space within part (Air pocket)	Lack of holding pressure (holding pressure is used to pack out the part during the holding time). Filling too fast, not allowing the edges of the part to set up. Also mold may be out of registration (when the two halves don't center properly and part walls are not the same thickness).
Weld line	Knit line / Meld line / Transfer line	Discolored line where two flow fronts meet	Mold/material temperatures set too low (the material is cold when they meet, so they don't bond). Point between injection and transfer (to packing and holding) too early.
Warping	Twisting	Distorted part	Cooling is too short, material is too hot, lack of cooling around the tool, incorrect water temperatures (the parts bow inwards towards the hot

side of the tool) Uneven shrinking between areas of the part

Tolerances and surfaces

Molding tolerance is a specified allowance on the deviation in parameters such as dimensions, weights, shapes, or angles, etc. To maximize control in setting tolerances there is usually a minimum and maximum limit on thickness, based on the process used. Injection molding typically is capable of tolerances equivalent to an IT Grade of about 9–14. The possible tolerance of a thermoplastic or a thermoset is ± 0.008 to ± 0.002 inches. Surface finishes of two to four microinches or better can be obtained. Rough or pebbled surfaces are also possible.

Molding Type	Typical [in]	Possible [in]
Thermoplastic	± 0.008	± 0.002
Thermoset	± 0.008	± 0.002

Lubrication and cooling

Obviously, the mold must be cooled in order for the production to take place. Because of the heat capacity, inexpensiveness, and availability of water, water is used as the primary cooling agent. To cool the mold, water can be channeled through the mold to account for quick cooling times. Usually a colder mold is more efficient because this allows for faster cycle times. However, this is not *always* true because crystalline materials require the opposite: a warmer mold and lengthier cycle time.

Power requirements

The power required for this process of injection molding depends on many things and varies between materials used. *Manufacturing Processes Reference Guide* states that the power requirements depend on "a material's specific gravity, melting point, thermal conductivity, part size, and molding rate." Below is a table from page 243 of the same reference as previously mentioned that best illustrates the characteristics relevant to the power required for the most commonly used materials.

Material	Specific gravity	Melting point (°F)
Epoxy	1.12 to 1.24	248
Phenolic	1.34 to 1.95	248
Nylon	1.01 to 1.15	381 to 509
Polyethylene	0.91 to 0.965	230 to 243
Polystyrene	1.04 to 1.07	338

Inserts

Metal inserts can also be injection molded into the workpiece. For large volume parts the inserts are placed in the mold using automated machinery. An advantage of using automated components is that the smaller size of parts allows a mobile inspection system that can be used to examine multiple parts in a decreased amount of time. In addition to mounting inspection systems on automated components, multiple axial robots are also capable of removing parts from the mold and place them in latter systems that can be used to ensure quality of multiple parameters. The ability of automated components to decrease the cycle time of the processes allows for a greater output of quality parts.

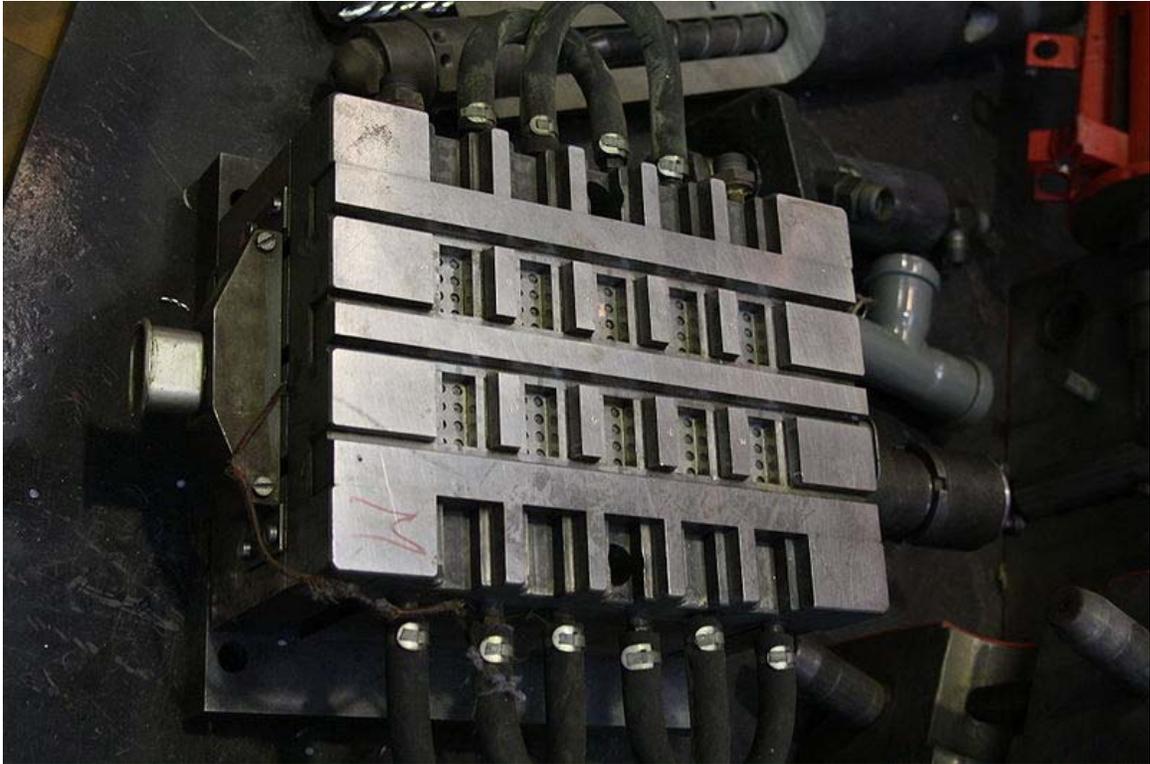
Specific instances of this increased efficiency include the removal of parts from the mold immediately after the parts are created and use in conjunction with vision systems. The removal of parts is achieved by using robots to grip the part once it has become free from the mold after in ejector pins have been raised. The robot then moves these parts into either a holding location or directly onto an inspection system, depending on the type of product and the general layout of the rest of the manufacturer's production facility. Visions systems mounted on robots are also an advancement that has greatly changed the way that quality control is performed in insert molded parts. A mobile robot is able to more precisely determine the accuracy of the metal component and inspect more locations in the same amount of time as a human inspector.



Lego injection mold, lower side



Lego injection mold, detail of lower side



Lego injection mold, upper side



Lego injection mold, detail of upper side

Chapter 10

Industrial Design Right

An **industrial design right** is an intellectual property right that protects the visual design of objects that are not purely utilitarian. An industrial design consists of the creation of a shape, configuration or composition of pattern or color, or combination of pattern and color in three dimensional form containing aesthetic value. An industrial design can be a two- or three-dimensional pattern used to produce a product, industrial commodity or handicraft.

Under the Hague Agreement Concerning the International Deposit of Industrial Designs, a WIPO-administered treaty, a procedure for an international registration exists. An applicant can file for a single international deposit with WIPO or with the national office in a country party to the treaty. The design will then be protected in as many member countries of the treaty as desired. Design rights started in the United Kingdom in 1787 with the Designing and Printing of Linen Act and have expanded from there.

An industrial design right can be viewed as a sui generis intellectual property right similar to copyright.

Legislations

Kenya

According to industrial property Act 2001, an industrial design is defined as "any composition of lines or colours or any three dimensional form whether or not associated with lines or colours, provided that such composition or form gives a special appearance to a product of industry or handicraft and can serve as pattern for a product of industry or handicraft" .

An industrial design is registrable if it is new. An industrial design is deemed to be new if it has not been disclosed to the public, anywhere in the world, by publication in tangible

form or, in Kenya by use or in any other way, prior to the filing date or, where applicable, the priority date of the application for registration. However a disclosure of the industrial design is not taken into consideration if it occurred not earlier than twelve months before the filing date or, where applicable, the priority date of the application and if it was by reason or in consequence of acts committed by the applicant or his predecessor in title; or an evident abuse committed by a third party in relation to the applicant or his predecessor in title.

India

India's Design Act, 2000 was enacted to consolidate and amend the law relating to protection of design and to comply with the articles 25 and 26 of TRIPS agreement. The new act, (earlier Patent and Design Act, 1911 was repealed by this act) now defines "design" to mean only the features of shape, configuration, pattern, ornament, or composition of lines or colours applied to any article, whether in two or three dimensional, or in both forms, by any industrial process or means, whether manual or mechanical or chemical, separate or combined, which in the finished article appeal to and are judged solely by the eye; but does not include any mode or principle of construction.

Indonesia

In Indonesia the protection of the Right to Industrial Design shall be granted for **10 (ten) years** commencing from the filing date.

- Industrial Designs that are Granted Protection

1. The Right to Industrial Design shall be granted for an Industrial Design that is novel/new
2. An Industrial Design shall be deemed new if on the filing date, such Industrial Design is not the same as any previous disclosure.
3. The previous disclosure as referred to in point 2 shall be one which before :
 - a. The filing date or
 - b. The Priority Date, if the applicant is filed with priority right.
 - c. Has been announced or used in Indonesia or out side Indonesia.

Canada

Canada's industrial design act affords ten years of protection to industrial designs that are registered; there is no protection if the design is not registered. The *Industrial Design Act* (R.S., c. I-8) defines "design" or "industrial design" to mean *features of shape, configuration, pattern or ornament and any combination of those features that, in a finished article, appeal to and are judged solely by the eye.*

During the existence of an exclusive right, no person can "make, import for the purpose of trade or business, or sell, rent, or offer or expose for sale or rent, any article in respect

of which the design is registered." The rule also applies to kits and substantial differences are in reference to previously published designs.

Europe

Registered and unregistered Community designs are available which provide a unitary right covering the European Community. Protection for a registered Community design is for up to 25 years, subject to the payment of renewal fees every five years. The unregistered Community design lasts for three years after a design is made available to the public and infringement only occurs if the protected design has been copied.

United Kingdom

In addition to the design protection available under Community designs, UK law provides its own national registered design right and an unregistered design right. The unregistered right, which exists automatically if the requirements are met can last for up to 15 years. The registered design right can last up to 25 years subject to the payment of maintenance fees.

Japan

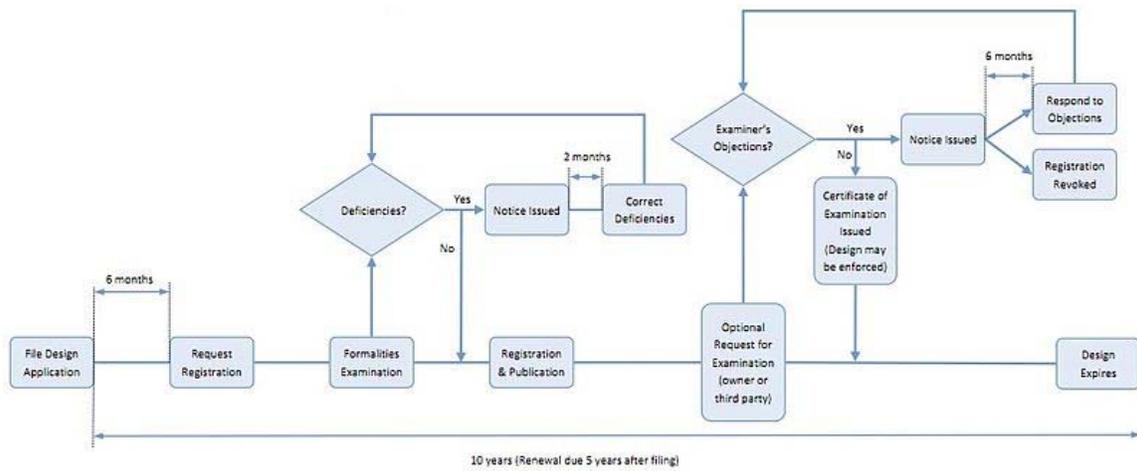
Article 1 of the Japanese **Design Law** states: "This law was designed to protect and utilize designs and to encourage creation of designs in order to contribute to industrial development". The protection period in Japan is 15 years from the day of registration.

United States

U.S. design patents last fourteen years from the date of grant and cover the ornamental aspects of utilitarian objects. Objects that lack a use beyond that conferred by their appearance or the information they convey, may be covered by copyright—a form of intellectual property of much longer duration that exists as soon as a qualifying work is created. In some circumstances, rights may also be acquired in trade dress, but trade dress protection is akin to trademark rights and requires that the design have source significance or "secondary meaning." It is useful only to prevent source misrepresentations; trade dress protection cannot be used to prevent others from competing on the merits.

Australia

In Australia, design patent registration lasts for 5 years, with an option to be extended once for an additional 5 years. For the patent to be granted, a formalities exam is needed. If infringement action is to be taken, the design needs to become certified which involves a substantive examination.



Australian Registered Design Procedure

Chapter 11

Planned Obsolescence

Planned obsolescence or **built-in obsolescence** in industrial design is a policy of deliberately planning or designing a product with a limited useful life, so it will become obsolete or nonfunctional after a certain period. Planned obsolescence has potential benefits for a producer because to obtain continuing use of the product the consumer is under pressure to purchase again, whether from the same manufacturer (a replacement part or a newer model), or from a competitor which might also rely on planned obsolescence.

For an industry, planned obsolescence stimulates demand by encouraging purchasers to buy sooner if they still want a functioning product. Built-in obsolescence is used in many different products, from vehicles to light bulbs, from buildings to proprietary software. There is, however, the potential backlash of consumers who learn that the manufacturer invested money to make the product obsolete faster; such consumers might turn to a producer (if any exists) that offers a more durable alternative.

Planned obsolescence was first developed in the 1920s and 1930s when mass production had opened every minute aspect of the production process to exacting analysis.

Estimates of planned obsolescence can influence a company's decisions about product engineering. Therefore the company can use the least expensive components that satisfy product lifetime projections. Such decisions are part of a broader discipline known as value engineering.

Origins of the term

Origins of *planned obsolescence* go back at least as far as 1932 with Bernard London's pamphlet *Ending the Depression Through Planned Obsolescence*. However, the phrase was first popularized in 1954 by Brooks Stevens, an American industrial designer.

Stevens was due to give a talk at an advertising conference in Minneapolis in 1954. Without giving it much thought, he used the term as the title of his talk.

From that point on, "planned obsolescence" became Stevens' catchphrase. By his definition, planned obsolescence was "Instilling in the buyer the desire to own something a little newer, a little better, a little sooner than is necessary."

The term was quickly taken up by others, but Stevenson's definition was challenged. By the late 1950s, *planned obsolescence* had become a commonly-used term for products designed to break easily or to quickly go out of style. In fact, the concept was so widely recognized that in 1959 Volkswagen mocked it in a now-legendary advertising campaign. While acknowledging the widespread use of planned obsolescence among automobile manufacturers, Volkswagen pitched itself as an alternative. "We do not believe in planned obsolescence," the ads suggested. "We don't change a car for the sake of change."

In 1960, cultural critic Vance Packard published *The Waste Makers*, promoted as an exposé of "the systematic attempt of business to make us wasteful, debt-ridden, permanently discontented individuals."

Packard divided planned obsolescence into two sub categories: **obsolescence of desirability** and **obsolescence of function**. "Obsolescence of desirability", also called "psychological obsolescence", referred to marketers' attempts to wear out a product in the owner's mind. Packard quoted industrial designer George Nelson, who wrote: "Design... is an attempt to make a contribution through change. When no contribution is made or can be made, the only process available for giving the illusion of change is 'styling!'"

Rationale behind the strategy

In *Democracy in America* (1840), Alexis de Toqueville noted the rise of **planned obsolescence** in the United States:

"I accost an American sailor, and I inquire why the ships of his country are built so as to last but for a short time; he answers without hesitation that the art of navigation is every day making such rapid progress, that the finest vessel would become almost useless if it lasted beyond a certain number of years."

The rationale behind the strategy is to generate long-term sales volume by reducing the time between repeat purchases, (referred to as shortening the replacement cycle). Firms that pursue this strategy believe that the additional sales revenue it creates more than offsets the additional costs of research and development and opportunity costs of existing product line cannibalization. The rewards are by no means certain: In a competitive industry, this can be a risky strategy because consumers may decide to buy from competitors. Because of this, gaining by this strategy requires fooling the consumers on the actual cost per use of the item in comparison to the competition.

Shortening the replacement cycle has many critics as well as supporters. Critics such as Vance Packard claim the process wastes resources and exploits customers. Resources are used up making changes, often cosmetic changes, that are not of great value to the customer. Supporters claim it drives technological advances and contributes to material well-being. They claim that a market structure of planned obsolescence and rapid innovation may be preferred to long-lasting products and slow innovation. In a fast-paced competitive industry market success requires that products are made obsolete by actively developing replacements. Waiting for a competitor to make products obsolete is a sure guarantee of future demise.

The main concern of the opponents of planned obsolescence is not the existence of the process, but its possible postponement. They are concerned that technological improvements are not introduced even though they could be. They are worried that marketers will refrain from developing new products, or postpone their introduction because of product cannibalization issues. For example, if the payback period for a product is five years, a firm might refrain from introducing a new product for at least five years even though it may be possible for them to launch in three years. This postponement is only feasible in monopolistic or oligopolistic markets. In more competitive markets rival firms will take advantage of the postponement and launch their own products.

Types of obsolescence

Technical or functional obsolescence

The design of most consumer products includes an expected average lifetime permeating all stages of development. Thus, it must be decided early in the design of a complex product how long it is designed to last so that each component can be made to those specifications.

Planned obsolescence is made more likely by making the cost of repairs comparable to the replacement cost, or by refusing to provide service or parts any longer. A product might even never have been serviceable. Creating new lines of products that do not interoperate with older products can also make an older model quickly obsolete, forcing replacement. Examples include change of formats and peripheral devices in computers, change of formats in home movies and audio recordings (tapes to different types of CDs/DVDs/Blu-Ray).

Planned functional obsolescence is a type of technical obsolescence in which companies introduce new technology which replaces the old. The old products do not have the same capabilities or functionality as the new ones. For example a company that sold video tape decks while they were developing DVDs was engaging in planned obsolescence. They were actively planning to make their existing product (video tape) obsolete by developing a substitute product (DVDs) with greater functionality (better quality). Associated products that are complements to the old products also become obsolete with the

introduction of new products. For example video tape holders saw the same fate as video tapes and video tape decks.

Proprietary batteries

Many portable consumer electronics contain proprietary, often lithium-based batteries. These batteries last only about 500 cycles before losing large amounts of their capacity. Rechargeable lithium batteries always contain integrated circuits (IC); they are required because of the above average risk of fire or explosion the batteries have when improperly charged. The IC keeps track of statistics of the battery to determine the current full charge point for the battery. A manufacturer can set the algorithms of the IC to be ultra conservative or time/cycle based, rather than based around the physical properties of the battery cells; this artificially limits the life of the battery. The IC will not permit the device to charge the battery any more than the IC dictates. Production of these batteries is usually stopped at around the same time the product is discontinued, therefore rendering the product worthless once the batteries start to wear out. Some people will reset the ICs in the battery pack, and obtain almost their original runtime on the battery (minus the natural decay the battery cells), only to have to do it again in the future because the IC ran down the limit. While battery packs can be rebuilt and fitted with new cells, this is either too costly or too time consuming for most consumers.

Systemic obsolescence

Planned systemic obsolescence is the deliberate attempt to make a product obsolete by altering the system in which it is used in such a way as to make its continued use difficult. New software is frequently introduced that is not compatible with older software. This makes the older software largely obsolete. Even though an older version of a word processing program is operating correctly, it might not be able to read data saved by newer versions. The lack of interoperability forces many users to purchase new programs prematurely. The greater the network externalities in the market, the more effective this strategy is. Oftentimes, developers of hardware will try to prevent a product from being backwards compatible with older interchangeable cartridges and proprietary connector plugs.

Another way of introducing systemic obsolescence is to eliminate service and maintenance for a product. If a product fails, the user is forced to purchase a new one. This strategy seldom works because there are typically third parties that are prepared to perform the service if parts are still available. One place it does work is in proprietary software, where copyright forbids third parties from performing some kinds of service. One example of this type of obsolescence is Microsoft's termination of support for earlier versions of Windows and older service packs on more recent versions. (although Microsoft is actually supporting XP until 2014). While, Apple Inc.'s introduction of Mac OS X (post-purchase of NeXT in 1997), which is Unix-based and incompatible with previous versions of the company's operating systems (although a compatibility layer was provided for several years). This strategy can have an unintended consequence; if a

customer is not dependent on the specific proprietary system they may switch to a different system in hopes of longer support.

Style obsolescence

Marketing may be driven primarily by aesthetic design. Product categories in this case display a fashion cycle. By continually introducing new designs, and retargeting or discontinuing others, a manufacturer can "ride the fashion cycle". Such product categories include automobiles (style obsolescence), with a strict yearly schedule of new models; the almost entirely style-driven clothing industry (riding the fashion cycle); and the mobile phone industries with constant minor feature enhancements and restyling.

Planned style obsolescence occurs when marketers change the styling of products so customers will purchase products more frequently. The style changes are designed to make owners of the old model feel "out of date". It is also designed to differentiate the product from the competition, thereby reducing price competition. One example of style obsolescence is the automobile industry, in which manufacturers typically make style changes every year or two. As the former CEO of General Motors, Alfred P. Sloan stated in 1941, "Today the appearance of a motorcar is a most important factor in the selling end of the business—perhaps the most important factor— because everyone knows the car will run."

Some marketers go one step further: they attempt to initiate fashions or fads. Successfully created fashions or fads include Beanie Babies, Ninja Turtles, Cabbage Patch Kids, pet rocks, acid wash jeans, and tank tops. Obsolescence is built into these products in the sense that marketers are aware of the shortness of their product life cycles so they work within that constraint. When Beanie Babies sales revenue started to decline, company president Ty Warner decided to go for one last Christmas marketing push and then drop the product.

Another strategy is to take advantage of fashion changes, often called the fashion cycle. The fashion cycle is the repeated introduction, rise, popular culmination, and decline of a style as it progresses through various social strata. Marketers can "ride the fashion cycle" by changing the mix of products that they direct at various market segments. This is very common in the clothing industry. A certain style of dress will initially be aimed at a very high income segment, then gradually be re-targeted to lower income segments. The fashion cycle can repeat itself, in which case a stylistically obsolete product may regain popularity and cease to be obsolete.

Notification obsolescence

Some companies have developed a version of obsolescence in which the product informs the user when it is time to buy a replacement. Examples of this include water filters that display a replacement notice after a predefined time and disposable razors that have a strip that changes color. Whether the user is notified before the product has actually deteriorated or the product simply deteriorates more quickly than is necessary, planned

obsolescence is the result. In this way planned obsolescence may be introduced without the company going to the expense of developing a "more up to date" replacement model.

In some cases, notification may be combined with the deliberate disabling of a product to prevent it from working, thus requiring the buyer to purchase a replacement. Inkjet printer manufacturers who employ proprietary smart chips in their ink cartridges to prevent them from being used after a certain threshold (number of pages, time, etc.), even though the cartridge may still contain usable ink or could be refilled. Some medical equipment also exploits this technique to ensure a steady stream of revenue from sales of replacement consumables. This constitutes programmed obsolescence in that there is no random component to the decline in function.

Economics of planned obsolescence

Planned obsolescence tends to work best when a producer has at least an oligopoly. Before introducing a planned obsolescence, the producer has to know that the consumer is at least somewhat likely to buy a replacement from them. In these cases of planned obsolescence, there is an information asymmetry between the producer—who knows how long the product was designed to last—and the consumer, who does not. When a market becomes more competitive, product lifespans tend to increase. When Japanese vehicles with longer lifespans entered the American market in the 1960s and 1970s, American carmakers were forced to respond by building more durable products.

There are some industries where there is significant competition and consumers have chosen to go for products that will fail more quickly anyway. All that is needed is that the probability of repeat purchasing from the same producer exceeds that of initially choosing the producer.

Even in a situation where planned obsolescence is appealing to both producer and consumer there can also be significant harm to society in the form of negative externalities. Continuously replacing, rather than repairing, products creates more waste, pollution, uses more natural resources, and results in more consumer spending. One workaround for these setbacks can involve a consumer getting more tech-savvy about them so they can jury-rig them to work with newer equipment similar to a MacGyverism; and upcycling the resources can offset the budget for home projects, whereas downcycling allows for more generalized purposes to live on. And those consumer strategies can counter the setbacks.

Others have defended planned obsolescence as a necessary driving force behind innovation and economic growth. Many products, such as DVDs, become both cheaper and more useful the more people have them. Planned obsolescence will also tend to benefit those companies with the most modern and up-to-date products, thus encouraging extra investment in research and development that often has large positive externalities.

Obsolescence and durability

If marketers expect a product to become obsolete, they can design it to last for a specific lifetime. If a product will be technically or stylistically obsolete in five years, many marketers will design the product so it will only last for that time. This is done through a technical process called value engineering. An example is home entertainment electronics which tend to be designed and built with moving components like motors and gears that last until technical or stylistic innovations make them obsolete.

These products could be built with higher-grade components, but they are not because it is stated that this imposes an unnecessary cost on the purchaser. Value engineering will reduce the cost of making the product and lower the price to consumers. A company will typically use the least expensive components that satisfy product's lifetime projections.

The use of value engineering techniques have led to planned obsolescence being associated with product deterioration and inferior quality. Vance Packard claimed that this could give engineering a bad name, because it directed creative engineering energies toward short-term market ends rather than more lofty and ambitious engineering goals.

Planned obsolescence in software

Software companies are sometimes thought to deliberately drop support for older technologies as a calculated attempt to force users to purchase new products to replace those made obsolete. Most proprietary software will ultimately reach an end-of-life point, at which the manufacturer will cease updates and support. As free software can always be updated and maintained by the end user, the user is not at the sole mercy of a proprietary vendor.

Fair trade

In the United Kingdom, planned obsolescence engineered into products is considered a breach of customer rights. The Office of Fair Trading and Trading Standards Institute investigate claims of products constantly failing just outside the warranty period. A famous case of this was the 'Click Wheel' Apple iPod, which many consumers found to fail within 18 months of purchase.

Chapter 12

Automotive Design



Designers at work in 1961. Standing by the scale model's left front fender is Richard Teague, a famous automobile designer at American Motors Corporation (AMC)

Automotive design is the profession involved in the development of the appearance, and to some extent the ergonomics, of motor vehicles or more specifically road vehicles. This most commonly refers to automobiles but also refers to motorcycles, trucks, buses,

coaches, and vans. The functional design and development of a modern motor vehicle is typically done by a large team from many different disciplines included in automotive engineers. Automotive design in this context is primarily concerned with developing the visual appearance or aesthetics of the vehicle, though it is also involved in the creation of the product concept. Automotive design is practiced by designers who usually have an art background and a degree in industrial design or transportation design.

Design elements



A Bertone Birusa concept car on display at an International Car Show. In the Background are some concept sketches



Draft of OScar design proposal

The task of the design team is usually split into three main aspects: exterior design, interior design, and color and trim design. Graphic design is also an aspect of automotive design; this is generally shared amongst the design team as the lead designer sees fit. Design focuses not only on the isolated outer shape of automobile parts, but concentrates on the combination of form and function, starting from the vehicle package.

The aesthetic value will need to correspond to ergonomic functionality and utility features as well. In particular, vehicular electronic components and parts will give more challenges to automotive designers who are required to update on the latest information and knowledge associated with emerging vehicular gadgetry, particularly dashtop mobile devices, like GPS navigation, satellite radio, HD radio, mobile TV, MP3 players, video playback and smartphone interfaces. Though not all the new vehicular gadgets are to be designated as factory standard items, but some of them may be integral to determining the future course of any specific vehicular models.

Exterior design

The stylist responsible for the design of the exterior of the vehicle develops the proportions, shape, and surfaces of the vehicle. Exterior design is first done by a series of digital or manual drawings. Progressively more detailed drawings are executed and approved. Clay (industrial plasticine) and or digital models are developed from, and along with the drawings. The data from these models are then used to create a full sized mock-up of the final design (body in white). With 3 and 5 axis CNC Milling Machines, the clay model is first designed in a computer program and then "carved" using the machine and large amounts of clay. Even in times of high-class 3d software and virtual

models on powerwalls the clay model is still the most important tool to evaluate the design of a car and therefore used throughout the industry.

Interior design

The stylist responsible for the design of the vehicle interior develops the proportions, shape, placement, and surfaces for the instrument panel, seats, door trim panels, headliner, pillar trims, etc. Here the emphasis is on ergonomics and the comfort of the passengers. The procedure here is the same as with exterior design (sketch, digital model and clay model).

Color and trim design

The color and trim (or color and materials) designer is responsible for the research, design, and development of all interior and exterior colors and materials used on a vehicle. These include paints, plastics, fabric designs, leather, grains, carpet, headliner, wood trim, and so on. Color, contrast, texture, and pattern must be carefully combined to give the vehicle a unique interior environment experience. Designers work closely with the exterior and interior designers.

Designers draw inspiration from other design disciplines such as: industrial design, fashion, home furnishing, architecture and sometimes Product Design . Specific research is done into global trends to design for projects two to three model years in the future. Trend boards are created from this research in order to keep track of design influences as they relate to the automotive industry. The designer then uses this information to develop themes and concepts which are then further refined and tested on the vehicle models.

Graphic design

The design team also develop graphics for items such as: badges, decals, dials, switches, kick or tread strips, liveries.

Development process

Includes the following steps:

- Concept sketching
- Clay modeling
- Class A surfaces
- Scale model creation
- Prototype development
- Computer-aided design
- Computer modeling
- Powertrain engineering
- Manufacturing process design

History of automobile design in the U.S.

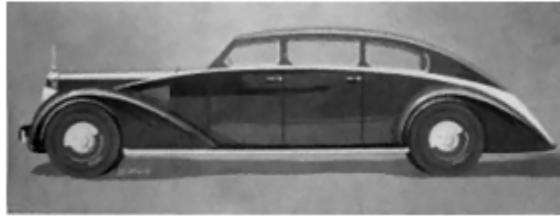
In the United States, automotive design reached a turning point in 1924 when the American national automobile market began reaching saturation. To maintain unit sales, General Motors head Alfred P. Sloan Jr. suggested annual model-year design changes to convince car owners that they needed to buy a new replacement each year, an idea borrowed from the bicycle industry (though Sloan usually gets the credit, or blame). Critics called his strategy planned obsolescence. Sloan preferred the term "dynamic obsolescence". This strategy had far-reaching effects on the auto business, the field of product design, and eventually the American economy. The smaller players could not maintain the pace and expense of yearly re-styling. Henry Ford did not like the model-year change because he clung to an engineer's notions of simplicity, economics of scale, and design integrity. GM surpassed Ford's sales in 1931 and became the dominant company in the industry thereafter. The frequent design changes also made it necessary to use a body-on-frame rather than the lighter, but less flexible, monocoque design used by most European automakers.

In the 1930s Chrysler's innovation with aerodynamics made them launch Chrysler Airflow in 1934, which was quite revolutionary and radical. But lower acceptance of the car forced Chrysler to re-design its later models of 'Airflow' made the industry take note of risks involved in taking major design advancements in short cycles.

One very well-known American auto stylist is Harley Earl, who brought the tailfin and other aeronautical design references to auto design in the 1950s. He is joined among legendary designers by Gordon Buehrig, responsible for the Auburn 851 and iconic Cord 810 and 812 (hence also the Hupmobile Skylark and the Graham Hollywood). Another notable designer who had a markedly different style was Chrysler group's designer Virgil Exner, an early pioneer of cab forward (a.k.a. Forward look) design in mid-1950s later adapted by rest of the industry. He is also credited with introducing the pointed tail fins in the 1956 Plymouth Belvedere later adapted by all other Detroit studios. Personal injury litigation had a dramatic effect on the design and appearance of the car in the 20th century. Raymond Loewy was responsible for a number of Studebaker vehicles, including the Starlight (including the iconic bulletnose). Richard A. Teague, who spent most of his career with the American Motor Company, originated the concept of using interchangeable body panels so as to create a wide array of different vehicles using the same stampings starting with the AMC Cavalier. He was responsible for such unique automotive designs as the Pacer, Gremlin, Matador coupe, Jeep Cherokee, and the complete interior of the Eagle Premier.

In the 1960s Ford's first generation Ford Mustang and Thunderbird marked another era leading into new market segments from Detroit. The Ford Mustang achieved record sales in its first year of production and established the pony car segment.

History of automobile design in Europe



6 CYL. C 26 VOISIN

An early radical French Voisin C27

Europe is the continent where the first Automobile was invented, eventually replacing the Horse Drawn Coaches. Till World War I most of the manufacturers were concerned with mechanical reliability rather than its external appearance. Later, luxury and aesthetics became a demand and also an effective marketing tool. Designs from each nation with its own strong cultural identity, reflected in their exterior and interior designs. World War II slowed the progress, but after early-1950s, Italian designers set the trend and remained the driving force until the early part of the 1980s.

France



Citroën DS

In France notable designs came from Bugatti and Avions Voisin. Of the mass selling cars Citroën, launched their vehicles with innovative designs and engineering and mostly aided by the Styling of Flaminio Bertoni as evident from Citroën DS. After World War II with the disappearance of the French coach building industry, with the exception of Citroën, others stuck to following British and other popular trends till they gained financial stability. From the 1980s, manufactures like Renault cultivated their own strong design identities with designers like Patrick Le Quement demanding more freedom from engineering departments. Peugeot, which was dependent on Pininfarina since early post-war period, later established its own brand identity from 1980s onwards. Its other company Citroën still retains its distinctive French innovations in its designs. Today French designs are known for their innovativeness and forward looking.

Great Britain



1981 Ford Sierra with "jelly-mould" or "aero look" (low CD) styling was advanced for its time

Great Britain was Europe's leading manufacturer of automobiles until the late-1960s. During that era there were more British-based automakers than in the rest of Europe combined. The British automobile industry catered to all segments ranging from compact, budget, sports, utility, and luxury-type cars. Car design in Britain was markedly different from other European designs largely because British designers were not influenced by other European art or design movements, as well as the British clay modelers used a different sweep set.

British cars until World War II were sold in most of the British colonies. Innovations in vehicle packaging and chassis engineering combined with global familiarity with British designs meant vehicles were acceptable to public tastes at that time. British skilled resources like panel beaters, die machinists, and clay modelers were also available also partly due their involvement with motorsport industry.

Still during the 1960s British manufacturers sought professional help from the Italians, Giovanni Michelotti, Ercole Spada and Pininfarina. Notable British contributions to automobile designs were Morris Mini by Alec Issigonis, Several Jaguar Cars by Sir William Lyons, Aston Martin DB Series, and several cars from Triumph and MG. Ford Europe based in Great Britain is notable for Ford Sierra, a creation of Uwe Bahnsen, Robert Lutz, and Patrick le Quément. Other well known British designers were William Towns for Aston Martin designs and David Bache, for his Land Rover and Range Rover vehicles.

Germany



The 1972 BMW 2002 by Giovanni Michelotti

Germany is often considered the birthplace of industrial design with Bauhaus School of Design. However, the Nazi regime closed down the design school. Ferdinand Porsche and his family played a significant role in German design. Mercedes Benz passenger cars were also in luxury segment and played more importance to aesthetics. After the 1980s German design evolved into a distinctive Teutonic style often to compliment their high engineered cars suited to Autobahns. But the early German design clues of present day owes some part to Italian designers like Giovanni Michelotti, Ercole Spada, Bruno Sacco and Giorgetto Giugiaro. During Mid and late 20th century one of the most influential coach builder/designer in Germany was Karmann.

German designs started gaining popularity after the 1980s, notable after the formation of Audi. Volkswagen, which was dependent on Marcello Gandini and Giorgetto Giugiaro and Karmann, later formed the contemporary design language along with Audi. BMW's foray into sports sedan marked a new trend in automobile design as it called for a sporty-looking everyday sedan with Giovanni Michelotti, later enhanced by Ercole Spada right into the 1980s, and Klaus Luthe till mid-1990s. The American born designer Chris Bangle hired by BMW in late-1990s to re-define the brand and he used new single press technology for compound curves adding controversial styling elements in his designs.

The Porsche family contribution were instrumental in the evolution of Porsche cars, while the Italian designer Bruno Sacco helped create various Mercedes Models from the 1960s till the 1990s.

Italy



Ferrari Testarossa from Pininfarina Studios by Leonardo Fioravanti

In Italy, where art is often considered a serious profession since Renaissance period, companies like Fiat and Alfa Romeo played a major role in car design. Many coach builders were dependent on these two major manufacturers. Italian manufacturers had a large presence in Motorsports leading to several sport car manufacturers like Ferrari, Lancia, Lamborghini, Maserati, etc. During late-1950s the elegant Italian designs gained global popularity coinciding with the modern fashion and architecture at that time around the world. Various design and technical schools in Turin turned out designers in large scale. By the late-1960s almost all Italian coach builders transformed into design studios catering to automakers around the world. The trend continued in the 1990s when the Japanese and Korean manufacturers sourced designs from these styling studios. One example is Pininfarina.

The most famous Italian designers whose designs services were sought globally are Giovanni Michelotti, Ercole Spada, Bruno Sacco, Marcello Gandini and Giorgetto Giugiaro. All the following designers helped create the design foundations for most of the European brands in the post-world war II period, whose influence is still seen in present times.

Sweden (Scandinavian)



Ursaab, an early Saab concept illustrating an advanced headlamp treatment

Sweden has Volvo and Saab and the Scandinavian landscape required that cars had to be sturdy and withstand Nordic climate conditions. The Scandinavian design elements are known for their minimalism and simplicity. One of the early original Scandinavian designs was the Saab 92001 by Sikstena Sasona and Gunnar Ljungström.

Czechoslovakia



The 1934 Czechoslovakian Tatra T77 is the first serial-produced aerodynamically designed automobile designed by Hans Ledwinka and Paul Jaray

Prior to World War and until early 1990s, Czechoslovakia had strong presence in the automotive industry with manufacturers like Skoda, Jawa, Tatra, CZ, and Zetor. Czech automobiles were generally known for their originality in mechanical simplicity and designs were remarkably Bohemian as evident from Tatra cars and Jawa motorcycles. During the Communist regime, design started falling back and ultimately the domestic automakers ended up as subsidiaries of EU-based companies.

Chapter 13

Interaction Design and Product Design

Interaction design



Kortunefookie at *Art Under The Bridge* in DUMBO, Brooklyn, September 2008

Interaction design (abbreviated as **IxD**) defines the structure and behavior of interactive systems. Interaction Designers strive to create meaningful relationships between people and the products and services that they use, from computers to mobile devices to appliances and beyond. The practice typically centers on "embedding information technology into the ambient social complexities of the physical world."

Interactivity, however, is not limited to technological systems. It can also apply to other types of non-electronic products and services, and even organizations. Also, people have been interacting with each other as long as humans have been a species. Therefore, interaction design can be applied to the development of all solutions (or offerings), such as services and events. Those who design these offerings have, typically, performed interaction design inherently without naming it as such.

Related disciplines

Industrial Design

The core principles of Industrial Design overlap with those of interaction design, and vice versa. These include Physical form of an object, Aesthetics, Human perception & desire, and usability.

Human factors & Ergonomics

Certain basic principles of Ergonomics provide grounding for interaction design. These include anthropometry, biomechanics, kinesiology, physiology and psychology as they relate to human behavior in the built environment.

Cognitive psychology

Certain basic principles of cognitive psychology provide grounding for interaction design. These include mental models, mapping, interface metaphors, and affordances. Many of these are laid out in Donald Norman's influential book *The Design of Everyday Things*.

Human computer interaction

Academic research in human-computer interaction (HCI) includes methods for describing and testing the usability of interacting with an interface, such as cognitive dimensions and the cognitive walkthrough.

Design research

Interaction designers are typically informed through iterative cycles of user research. User research is used to identify the needs, motivations and behaviour of end users. They design with an emphasis on user goals and experience, and evaluate designs in terms of usability and affective influence.

Architecture

As interaction designers increasingly deal with ubiquitous computing and urban computing, the architects' ability to make, place, and create context becomes a point of contact between the disciplines.

User interface design

Like User Interface design and Experience design, Interaction Design is often associated with the design of system interfaces in a variety of media but concentrates on the aspects of the interface that define and present its behavior over time, with a focus on developing the system to respond to the user's experience and not the other way around.

Methodologies

Interaction designers often follow similar processes to create a solution (not *the* solution) to a known interface design problem. Designers build rapid prototypes and test them with the users to validate or rebut the idea.

There are six major steps in interaction design. Based on user feedback, several iteration cycles of any set of steps may occur.

1. Design research

Using design research techniques (observations, interviews, questionnaires, and related activities), designers investigate users and their environment in order to learn more about them and thus be better able to design for them.

2. Research analysis and concept generation

Drawing on a combination of user research, technological possibilities, and business opportunities, designers create concepts for new software, products, services, or systems. This process may involve multiple rounds of brainstorming, discussion, and refinement.

To help designers realize user requirements, they may use tools such as personas or user profiles that are reflective of their targeted user group. From these personae, and the patterns of behavior observed in the research, designers create scenarios (or user stories) or storyboards, which imagine a future work flow the users will go through using the product or service.

After thorough analysis using various tools and models, designers create a high level summary spanning across all levels of user requirements. This includes a vision statement regarding the current and future goals of a project.

3. Alternative design and evaluation

Once a clear view of the problem domain exists, designers develop alternative solutions with crude prototypes to help convey concepts and ideas. Proposed solutions are evaluated and, perhaps, merged. The end result should be a design that solves as many of the user requirements as possible.

Among the tools that may be used for this process are wireframing and flow diagrams. The features and functionality of a product or service are often outlined in a document known as a wireframe ("schematics" is an alternate term). Wireframes are a page-by-page or screen-by-screen detail of the system, which include notes ("annotations") describing how the system will operate. Flow Diagrams outline the logic and steps of the system or an individual feature.

The cognitive dimensions framework provides a specialized vocabulary to evaluate particular design solutions, and aid in the creation of new designs from existing ones through *design manoeuvres*.

4. Prototyping and usability testing

Interaction designers use a variety of prototyping techniques to test aspects of design ideas. These can be roughly divided into three classes: those that test the **role** of an artifact, those that test its **look and feel** and those that test its **implementation**. Sometimes, these are called **experience prototypes** to emphasize their interactive nature. Prototypes can be physical or digital, high- or low-fidelity.

5. Implementation

Interaction designers need to be involved during the development of the product or service to ensure that what was designed is implemented correctly. Often, changes need to be made during the building process, and interaction designers should be involved with any of the on-the-fly modifications to the design.

6. System testing

Once the system is built, often another round of testing, for both usability and errors ("bug catching") is performed. Ideally, the designer will be involved here as well, to make any modifications to the system that are required.

Aspects of interaction design

Social interaction design

Social interaction design (SxD) is emerging because many of our computing devices have become networked and have begun to integrate communication capabilities. Phones, digital assistants and the myriad connected devices from computers to games facilitate

talk and social interaction. Social interaction design accounts for interactions among users as well as between users and their devices. The dynamics of interpersonal communication, speech and writing, the pragmatics of talk and interaction—these now become critical factors in the use of social technologies. And they are factors described less by an approach steeped in the rational choice approach taken by cognitive science than that by sociology, psychology, and anthropology.

Affective interaction design

Throughout the process of interaction design, designers must be aware of key aspects in their designs that influence emotional responses in target users. The need for products to convey positive emotions and avoid negative ones is critical to product success. These aspects include positive, negative, motivational, learning, creative, social and persuasive influences to name a few. One method that can help convey such aspects is the use of expressive interfaces. In software, for example, the use of dynamic icons, animations and sound can help communicate a state of operation, creating a sense of interactivity and feedback. Interface aspects such as fonts, color pallet, and graphical layouts can also influence an interface's perceived effectiveness. Studies have shown that affective aspects can affect a user's perception of usability.

Emotional and pleasure theories exist to explain peoples responses to the use of interactive products. These include Don Norman's emotional design model, Patrick Jordan's pleasure model, and McCarthy and Wright's Technology as Experience framework.

Interaction design domains

Interaction designers work in many areas, including software interfaces, (business) information systems, internet, physical products, environments, services, and systems which may combine many of these. Each area requires its own skills and approaches, but there are aspects of interaction design common to all.

Interaction designers often work in interdisciplinary teams as their work requires expertise in many different domains, including graphic design, programming, psychology, user testing, product design, etc. Thus, they need to understand enough of these fields to work effectively with specialists.

History

The term *interaction design* was first proposed by Bill Moggridge and Bill Verplank in the late 1980s. To Verplank, it was an adaptation of the computer science term *user interface design* to the industrial design profession. To Moggridge, it was an improvement over *soft-face*, which he had coined in 1984 to refer to the application of industrial design to products containing software (Moggridge 2006).

In 1990, Gillian Crampton-Smith established an interaction design MA at the Royal College of Art (RCA) in London (originally entitled "computer-related design" and now known as Design Interactions). In 2001, she helped found the Interaction Design Institute Ivrea, a small institute in Northern Italy dedicated solely to interaction design; the institute moved to Milan in October 2005 and merged courses with Domus Academy. In 2007, some of the people originally involved with IDII have now set up the Copenhagen Institute of Interaction Design (CIID).

Today, interaction design is taught in many schools worldwide.

Relationship with instructional design

Instructional design is a goal-oriented, user-centric approach to creating training and education software or written materials. Interaction design and instructional design both rely on cognitive psychology theories to focus on how users will interact with software. They both take an in-depth approach to analyzing the user's needs and goals. A needs analysis is often performed in both disciplines. Both approach the design from the user's perspective. Both involve gathering feedback from users and making revisions until the product or service has been found to be effective. (Summative / formative evaluations) In many ways, instructional design can be considered a precursor to interaction design.

Product design



Example of designed product - Roomba robotic vacuum cleaner.

Product design is concerned with the efficient and effective generation and development of ideas through a process that leads to new products.

Product Designers conceptualize and evaluate ideas, making them tangible through products in a more systematic approach. Their role is to combine art, science and technology to create tangible three-dimensional goods. This evolving role has been facilitated by digital tools that allow designers to communicate, visualize and analyze ideas in a way that would have taken greater manpower in the past.

Product design is sometimes confused with industrial design, industrial design is concerned with the aspect of that process that brings that sort of artistic form and usability usually associated with craft design to that of mass produced goods.

Process Product designers follow various methodology that requires a specific skill set (usually in engineering) to complete.

Initial Stage

- **Idea Generation** can be from imagination, observation, or research.

- **Need Based Generation** can be from the need to solve a problem, the need to follow the popular trends, or the need for a product to do a specific task.

Mid Stage

- **Design Solutions** arise from meeting user needs, concept development, form exploration, ergonomics, prototyping, materials, and technology.
- **Production** involves fabrication and manufacturing the design.

Final Stage

- **Marketing** involves selling the product. It can either be client based which mean the a client buys the design and manufactures it and then sells it to customers. Or it can be user based where the product is sold directly to the user by the designer.

Application

Product design ranges from furniture, electronics, lighting, tools, toys, and general everyday objects.

Chapter 14

New Product Development

In business and engineering, **new product development (NPD)** is the term used to describe the complete process of bringing a new product or service to market. There are two parallel paths involved in the NPD process: one involves the idea generation, product design and detail engineering; the other involves market research and marketing analysis. Companies typically see new product development as the first stage in generating and commercializing new products within the overall strategic process of product life cycle management used to maintain or grow their market share.

The process

1. **Idea Generation** is often called the "fuzzy front end" of the NPD process
 - Ideas for new products can be obtained from basic research using a SWOT analysis (Strengths, Weaknesses, Opportunities & Threats), Market and consumer trends, company's R&D department, competitors, focus groups, employees, salespeople, corporate spies, trade shows, or Ethnographic discovery methods (searching for user patterns and habits) may also be used to get an insight into new product lines or product features.
 - Lots of ideas are being generated about the new product. Out of these ideas many ideas are being implemented. The ideas use to generate in many forms and their generating places are also various. Many reasons are responsible for generation of an idea.
 - Idea Generation or Brainstorming of new product, service, or store concepts - idea generation techniques can begin when you have done your OPPORTUNITY ANALYSIS to support your ideas in the **Idea Screening Phase** (shown in the next development step).
2. **Idea Screening**
 - The object is to eliminate unsound concepts prior to devoting resources to them.
 - The screeners should ask several questions:

- Will the customer in the target market benefit from the product?
 - What is the size and growth forecasts of the market segment/target market?
 - What is the current or expected competitive pressure for the product idea?
 - What are the industry sales and market trends the product idea is based on?
 - Is it technically feasible to manufacture the product?
 - Will the product be profitable when manufactured and delivered to the customer at the target price?
3. **Concept Development and Testing**
- Develop the marketing and engineering details
 - Investigate intellectual property issues and search patent data bases
 - Who is the target market and who is the decision maker in the purchasing process?
 - What product features must the product incorporate?
 - What benefits will the product provide?
 - How will consumers react to the product?
 - How will the product be produced most cost effectively?
 - Prove feasibility through virtual computer aided rendering, and rapid prototyping
 - What will it cost to produce it?
 - Testing the Concept by asking a sample of prospective customers what they think of the idea. Usually via Choice Modelling.
4. **Business Analysis**
- Estimate likely selling price based upon competition and customer feedback
 - Estimate sales volume based upon size of market and such tools as the Fourt-Woodlock equation
 - Estimate profitability and break-even point
5. **Beta Testing and Market Testing**
- Produce a physical prototype or mock-up
 - Test the product (and its packaging) in typical usage situations
 - Conduct focus group customer interviews or introduce at trade show
 - Make adjustments where necessary
 - Produce an initial run of the product and sell it in a test market area to determine customer acceptance
6. **Technical Implementation**
- New program initiation
 - Finalize Quality management system
 - Resource estimation
 - Requirement publication
 - Publish technical communications such as data sheets
 - Engineering operations planning
 - Department scheduling
 - Supplier collaboration

- Logistics plan
 - Resource plan publication
 - Program review and monitoring
 - Contingencies - what-if planning
7. **Commercialization** (often considered post-NPD)
- Launch the product
 - Produce and place advertisements and other promotions
 - Fill the distribution pipeline with product
 - Critical path analysis is most useful at this stage
8. **New Product Pricing**
- Impact of new product on the entire product portfolio
 - Value Analysis (internal & external)
 - Competition and alternative competitive technologies
 - Differing value segments (price, value, and need)
 - Product Costs (fixed & variable)
 - Forecast of unit volumes, revenue, and profit

These steps may be iterated as needed. Some steps may be eliminated. To reduce the time that the NPD process takes, many companies are completing several steps at the same time (referred to as **concurrent engineering** or **time to market**). Most industry leaders see new product development as a *proactive* process where resources are allocated to identify market changes and seize upon new product opportunities before they occur (in contrast to a *reactive strategy* in which nothing is done until problems occur or the competitor introduces an innovation). Many industry leaders see new product development as an ongoing process (referred to as *continuous development*) in which the entire organization is always looking for opportunities.

For the more innovative products indicated on the diagram above, great amounts of uncertainty and change may exist, which makes it difficult or impossible to plan the complete project before starting it. In this case, a more flexible approach may be advisable.

Because the NPD process typically requires both engineering and marketing expertise, cross-functional teams are a common way of organizing projects. The team is responsible for all aspects of the project, from initial idea generation to final commercialization, and they usually report to senior management (often to a vice president or Program Manager). In those industries where products are technically complex, development research is typically expensive, and product life cycles are relatively short, strategic alliances among several organizations helps to spread the costs, provide access to a wider skill set, and speeds the overall process.

Also, notice that because engineering and marketing expertise are usually both critical to the process, choosing an appropriate blend of the two is important.

People respond to new products in different ways. The adoption of a new technology can be analyzed using a variety of diffusion theories such as the Diffusion of innovations theory.

A new product pricing process is important to reduce risk and increase confidence in the pricing and marketing decisions to be made. Bernstein and Macias describe an integrated process that breaks down the complex task of new product pricing into manageable elements.

Fuzzy Front End

The Fuzzy Front End is the messy "getting started" period of new product development processes. It is in the front end where the organization formulates a concept of the product to be developed and decides whether or not to invest resources in the further development of an idea. It is the phase between first consideration of an opportunity and when it is judged ready to enter the structured development process (Kim and Wilemon, 2002; Koen et al., 2001). It includes all activities from the search for new opportunities through the formation of a germ of an idea to the development of a precise concept. The Fuzzy Front End ends when an organization approves and begins formal development of the concept.

Although the Fuzzy Front End may not be an expensive part of product development, it can consume 50% of development time, and it is where major commitments are typically made involving time, money, and the product's nature, thus setting the course for the entire project and final end product. Consequently, this phase should be considered as an essential part of development rather than something that happens "before development," and its cycle time should be included in the total development cycle time.

Koen et al. (2001, pp. 47–51) distinguish five different front-end elements (not necessarily in a particular order):

1. Opportunity Identification
2. Opportunity Analysis
3. Idea Genesis
4. Idea Selection
5. Concept and Technology Development

The first element is the opportunity identification. In this element, large or incremental business and technological chances are identified in a more or less structured way. Using the guidelines established here, resources will eventually be allocated to new projects.... which then lead to a structured NPPD (New Product & Process Development) strategy. The second element is the opportunity analysis. It is done to translate the identified opportunities into implications for the business and technology specific context of the company. Here extensive efforts may be made to align ideas to target customer groups and do market studies and/or technical trials and research. The third element is the idea genesis, which is described as evolutionary and iterative process progressing from birth

to maturation of the opportunity into a tangible idea. The process of the idea genesis can be made internally or come from outside inputs, e.g. a supplier offering a new material/technology, or from a customer with an unusual request. The fourth element is the idea selection. Its purpose is to choose whether to pursue an idea by analyzing its potential business value. The fifth element is the concept and technology development. During this part of the front-end, the business case is developed based on estimates of the total available market, customer needs, investment requirements, competition analysis and project uncertainty. Some organizations consider this to be the first stage of the NPPD process (i.e., Stage 0).

The Fuzzy Front End is also described in literature as "Front End of Innovation", "Phase 0", "Stage 0" or "Pre-Project-Activities".

A universally acceptable definition for Fuzzy Front End or a dominant framework has not been developed so far. In a glossary of PDMA, it is mentioned that the Fuzzy Front End generally consists of three tasks: strategic planning, concept generation, and, especially, pre-technical evaluation. These activities are often chaotic, unpredictable, and unstructured. In comparison, the subsequent new product development process is typically structured, predictable, and formal. The term *Fuzzy Front End* was first popularized by Smith and Reinertsen (1991). R.G.Cooper (1988) describes the early stages of NPPD as a four step process in which ideas are generated (I), subjected to a preliminary technical and market assessment(II) and merged to coherent product concepts(III) which are finally judged for their fit with existing product strategies and portfolios (IV). In a more recent paper, Cooper and Edgett (2008) affirm that vital predevelopment activities include:

1. Preliminary market assessment.
2. Technical assessment.
3. Source-of-supply-assessment:suppliers and partners or alliances.
4. Market research : market size and segmentation analysis,VoC (voice of the customer) research.
5. Product concept testing
6. Value-to-the customer assessment
7. Product definition
8. Business and financial analysis.

These activities yield vital information to make a Go/No-Go to Development decision.

In the in-depth study by Khurana and Rosenthal front-end activities include:

- product strategy formulation and communication,
- opportunity identification and assessment,
- idea generation,
- product definition,
- project planning, and
- executive reviews.

Economical analysis, benchmarking of competitive products, and modeling and prototyping are also important activities during the front-end activities.

The outcomes of FFE are the

- mission statement
- customer needs
- details of the selected concept
- product definition and specifications
- economic analysis of the product
- the development schedule
- project staffing and the budget, and a
- business plan aligned with corporate strategy.

In a paper by Husig, Kohn and Huskela (2005) was proposed a conceptual model of Front-End Process which includes early Phases of Innovation Process. This model is structured in three phases and three gates:

- Phase 1: Environmental screening or opportunity identification stage in which external changes will be analysed and translated into potential business opportunities.
- Phase 2: Preliminary definition of an idea or concept.
- Phase 3: Detailed product, project or concept definition, and Business planning.

The gates are:

- Opportunity screening;
- Idea evaluation;
- Go/No-Go for development.

The final gate leads to a dedicated new product development project . Many professionals and academics consider that the general features of Fuzzy Front End (fuzziness, ambiguity, and uncertainty) make difficult to see the FFE as a structured process, but rather as a set of interdependent activities (e.g. Kim and Wilemon ,2002). However, Husig et al.,2005 argue that front-end not need to be fuzzy, but can be handled in a structured manner. Peter Koen argue that in the FFE for incremental, platform and radical projects, three separate strategies and processes are typically involved. The traditional Stage Gate (TM) process was designed for incremental product development, namely for a single product. The FFE for developing a new platform must start out with a strategic vision of where the company wants to develop products and this will lead to a family of products. Projects for breakthrough products start out with a similar strategic vision, but are associated with technologies which require new discoveries. It is worth mentioning what are incremental, platform and breakthrough products. *Incremental products* are considered to be cost reductions, improvements to existing product lines, additions to existing platforms and repositioning of existing products introduced in markets. *Breakthrough products* are new to the company or new

to the world and offer a 5-10 times or greater improvement in performance combined with a 30-50% or greater reduction in costs. *Platform products* establish a basic architecture for a next generation product or process and are substantially larger in scope and resources than incremental projects.

NPD organizations

- Product Development and Management Association (PDMA)
- Association of International Product Marketing & Management

NPD strategies

- Design for six sigma
- Stage-Gate model
- Quality function deployment
- Flexible product development