DESIGN THINKING

SUBJECT CODE : MC140

YEAR II SEM

(COMMON TO CIVIL, ECE, EEE)

UNIT IV
REVERSE ENGINEERING IN PRODUCT DEVELOPMENT

Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering. Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. In some situations, there may be a physical part/ product without any technical details, such as drawings, bills-of-material, or without engineering data. The process of duplicating an existing part, sub assembly, or product, without drawings, documentation, or a computer model is known as reverse engineering. Reverse engineering is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/ digitizing existing parts/products. The process of digitally capturing the physical entities of a component, referred to as reverse engineering (RE), is often defined by researchers with respect to their specific task (Motavalli & Shamsaasef 1996).

Abella et al. (1994) described RE as, "the basic concept of producing a part based on an original or physical model without the use of an engineering drawing". Yau et al.(1993) define RE, as the "process of retrieving new geometry from a manufactured part by digitizing and modifying an existing CAD model".

Reverse engineering is now widely used in numerous applications, such as manufacturing, industrial design, and jewelry design and reproduction. For example, when a new car is launched on the market, competing manufacturers may buy one and disassemble it to learn how it was built and how it works. In software engineering, good source code is often a variation of other good source code. In some situations, such as automotive styling, designers give shape to their ideas by using clay, plaster, wood, or foam rubber, but a CAD model is needed to manufacture the part. As products become more organic in shape, designing in CAD becomes more challenging and there is no guarantee that the CAD representation will replicate the sculpted model exactly.

Why Use Reverse Engineering?

Following are some of the reasons for using reverse engineering:

• The original manufacturer no longer exists, but a customer needs the product, e.g., aircraft spares required typically after an aircraft has been in service for several years.

• The original manufacturer of a product no longer produces the product, e.g., the original product has become obsolete.

• The original product design documentation has been lost or never existed.

• Creating data to refurbish or manufacture a part for which there are no CAD data, or for which the data have become obsolete or lost.

• Inspection and/or Quality Control–Comparing a fabricated part to its CAD description or to a standard item.

• Some bad features of a product need to be eliminated e.g., excessive wear might indicate where a product should be improved.

• Strengthening the good features of a product based on long-term usage.

• Analyzing the good and bad features of competitors' products.

• Exploring new avenues to improve product performance and features.

• Creating 3-D data from a model or sculpture for animation in games and movies.

• Creating 3-D data from an individual, model or sculpture to create, scale, or reproduce artwork.

• Architectural and construction documentation and measurement.

• Fitting clothing or footwear to individuals and determining the anthropometry of a population.

• Generating data to create dental or surgical prosthetics, tissue engineered body parts, or for surgical planning.

• Documentation and reproduction of crime scenes.

Reverse Engineering–The Generic Process

The generic process of reverse engineering is a three-phase process as depicted in the below diagram. The three phases are scanning, point processing, and application specific geometric model development. Reverse engineering strategy must consider the following:

• Reason for reverse engineering a part

• Number of parts to be scanned–single or multiple

• Part size–large or small

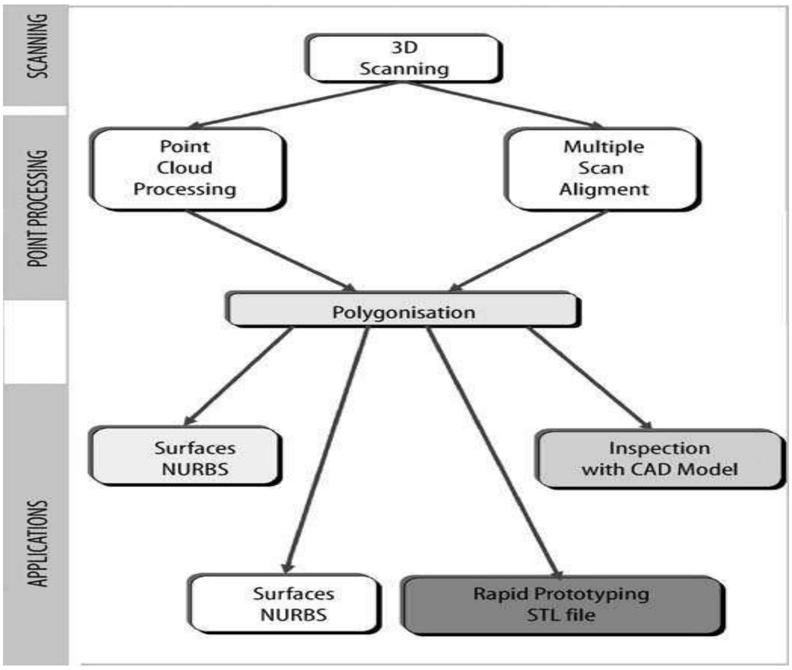
• Part complexity–simple or complex

• Part material–hard or soft

• Part finish–shiny or dull

• Part geometry–organic or prismatic and internal or external

• Accuracy required–linear or volumetric



What Is Not Reverse Engineering?

Each discipline of engineering has a different definition for RE. Computer engineers and computer scientists, for example, refer to RE when they speak of determining the algorithmic functionality of a software package when they have no prior knowledge of the original software design. Engineers and programmers attempt to develop functional block diagrams of the software through interaction with the interface and to develop high-level code descriptions from raw machine code. This software definition is not the scope of our RE discussion.

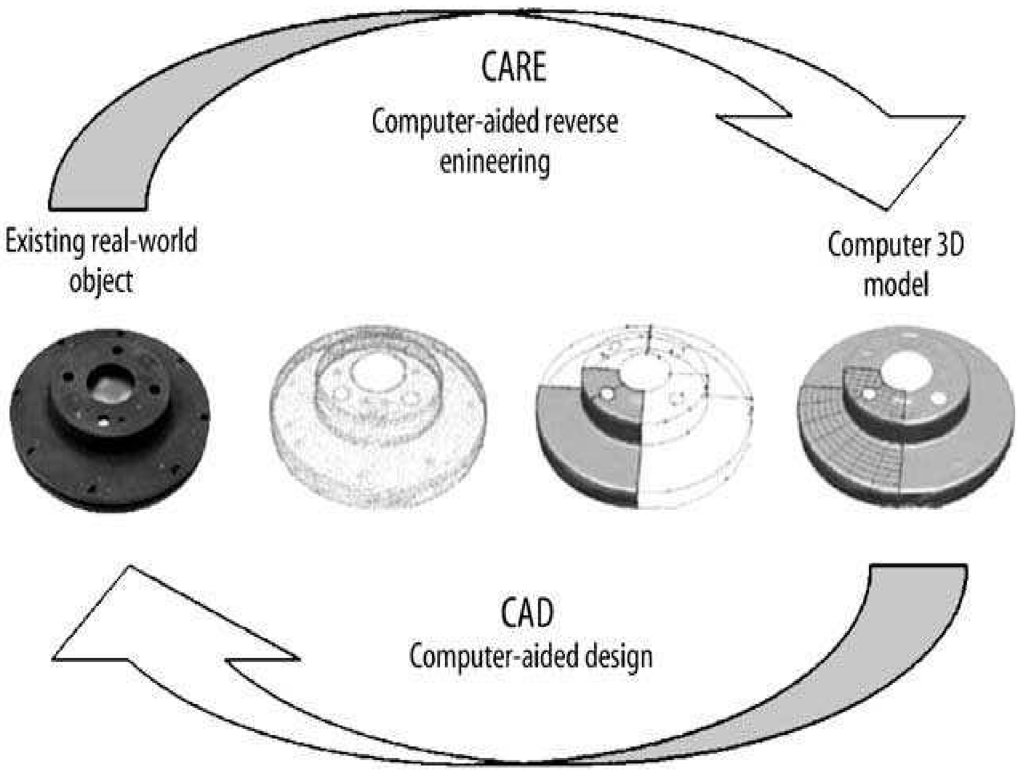
Another example of RE that might be familiar–but also outside the scope of this chapter–concerns revealing the inner workings of a machine to figure out what makes it tick. This form of RE is also a systems level approach where an engineer disassembles the item of interest to develop an understanding of the functional relationship of components or to gain insight into the types of materials used to fabricate the components. As with software RE, the goal is to develop a high level description of a system without a priori knowledge. These two examples are common applications that use the term RE, but we wish to emphasize that our definition of RE is not related to these examples, but is instead related to the area of computer-aided engineering (CAE).

Computer-aided (Forward) Engineering (CAE)

In the late 1970s and into the 1980s, computer-aided design (CAD)–a component of CAE–began to revolutionize engineering disciplines. The peak of this revolution occurred in 1990 with the design of the Boeing 777; the entire aircraft was designed and pre-assembled through a virtual CAD) simulation. According to Boeing, the first 777 to roll out of the production hangar in 1994 was just hundredths of an inch–about the thickness of a playing card–within alignment. This precision contrasts with the half-inch alignments common with most aircraft parts before that time–an improvement of several orders of magnitude. This revolution in technology has continued into the 1990s and today with the emergence and growth of computer-aided manufacturing (CAM). CAM is the automation of the manufacturing process itself–beyond just the design process– where machines such as computerized numerically controlled (CNC) mills allow precise fabrication of objects directly from CAD descriptions. With CAM, a designer can rapidly move from a conceptual CAD description to a real-world 2.1 Computer-aided Reverse Engineering 13 tangible object. We might use the term forward engineering—in a tongue-in cheek manner—to describe this type of design, and the term CAE to describe the automation of forward engineering through CAD and CAM technologies.

What Is Computer-aided Reverse Engineering (CARE)

CAE through CAD and CAM technologies is the automation of engineering and fabrication, where a design formalizes ideas through computer modeling and then fabricates those models into real-world objects. CARE flows in the opposite direction. CARE creates a computer model of an object through measurements of the object, as it exists in the real world. In this context, we define CARE as the reversal of CAE or the ability to generate a CAD model from a real-world tangible object. We illustrate this flow in Figure 2.1. The disc brake appears on the left side of this figure and its CAD model appears on the right. We acquired this particular brake from a local junkyard and cleaned the surfaces of rust and dirt. Then, we used a laser-based range scanner to create the CAD model. This model is metrically accurate to within a few millimeters of the original junkyard brake. By analogy, one might think of this capability as a 3-D fax. Just as a facsimile (fax) machine converts a hand-written document into digital form, we have converted a tangible object (the disc brake) into a computer model. This figure illustrates our definition of CARE.



To understand the CARE steps, consider the stages shown in Figure from left to right. The first step in the CARE process is to make measurements at points along the surface of the brake. Each point has an x, y, and z coordinate locating the point in 3-D space. For a given object, a CARE system will measure hundreds or even thousands of such points depending on the nature of the object and the type of CARE system. The collection of these points is known as a point cloud; an example appears in the second picture from the left in Figure shown above. In most applications, the point cloud is a sufficient description of the object. However, higher levels are possible as the remaining two pictures on the right show. The third picture from the left is a feature description of the object, in which the CARE system has detected surface edges and creases from the point cloud data. The final picture on the right is a full and complete CAD description of the object. For this description, the CARE system uses the point cloud and the detected features to fit surfaces for modeling the entire geometry of the object.

For both industrial and military applications, CARE offers many advantages to the engineering design, manufacturing fabrication, and field support of a part or component. For example, CARE allows rapid inspection and validation in real time at the production line based on the original CAD designs.

As another example, because CARE creates digital models, the technology is ideal for electronic dissemination of information. A manufacturing center in Asia can transmit as-built models of components to a design center in North America or vice versa. Although many thousands of miles separate these two centers, CARE enables more efficient collaboration. The North American team can transmit their CAD design to Asia via electronic mail, and the Asian team can return a CARE model of a fabricated prototype. Previously, such electronic sharing was a one-way endeavour where the physical prototype would require expensive courier-based delivery back to North America.

Engineers often encounter situations where nontechnical personnel develop novel and important modifications of their designs but only after they are deployed. Such field-operations personnel are inadequately equipped to communicate their modifications to the engineers. These modifications are typically ad hoc with little or no documentation, such as CAD drawings. Thus, engineers have little hope if they wish to capture these modifications and incorporate them into future designs. This ability is the promise of CARE to allow both technical and nontechnical individuals to generate engineering quality CAD models of existing objects quickly and automatically.

Reverse Engineering Methods

I. Contact Methods

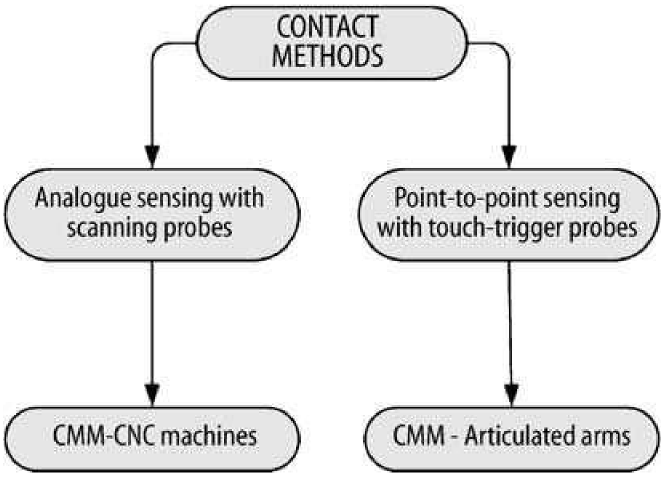
Contact methods use sensing devices with mechanical arms, coordinate measurement machines (CMM), and computer numerical control (CNC) machines, to digitize a surface. There are two types of data collection techniques employed in contact methods:

(i) point-to-point sensing with touch-trigger probes and

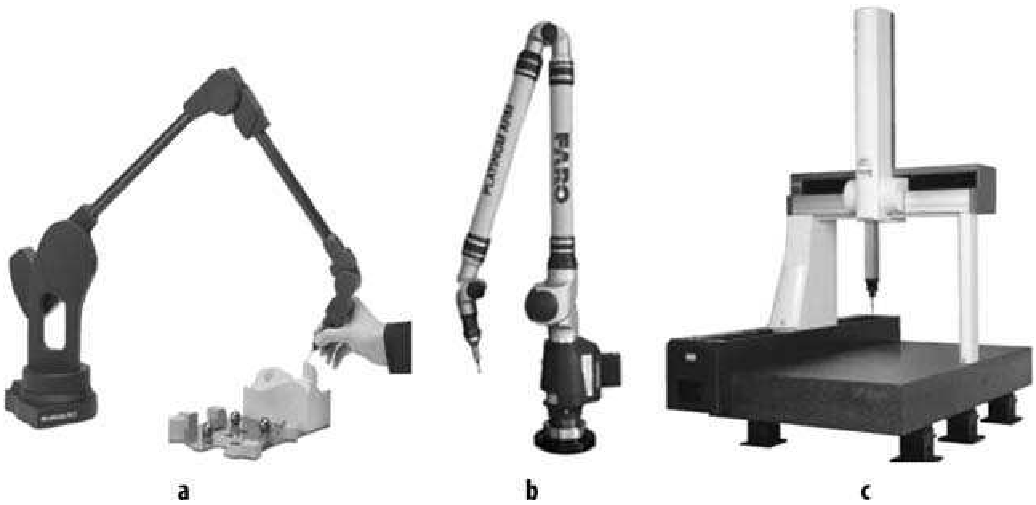
(ii) analogue sensing with scanning probes.

In the point-to-point sensing technique, a touch-trigger probe is used that is installed on a CMM or on an articulated mechanical arm to gather the coordinate points of a surface. A manually operated, articulated mechanical arm with a touch-trigger probe allows multiple degrees of freedom (DOF) of movement to collect the measurement points. A CMM with a touch-trigger probe can be programmed to follow planned paths along a surface. A CMM provides more accurate measurement data compared to the articulated arm. However, the limitation of using CMM is the lack of number of DOF so that a CMM cannot be used to digitize complex surfaces in the same way as an articulated arm.

In analogue sensing, a scanning probe is used that is installed on a CMM or CNC machine. The scanning probe provides a continuous deflection output that can be combined with the machine position to derive the location of the surface. When scanning, the probe stylus tip contacts the feature and then moves continuously along the surface, gathering data as it moves. Therefore, throughout the measurement, it is necessary to keep the deflection of the probe stylus within the measurement range of the probe. The scanning speed in analogue sensing is up to three times faster than in point-to-point sensing.



Contact Method



(a) MicroScribe MX Articulated Arm from Immersion Corporation (Immersion, 2005). (b) Faro Arm–Platinum articulated arm from FARO Technologies (FARO, 2005). (c) Mitutoyo CMM machine–CRA Apex C model (Mitutoya, 2005).

a b

(a) SP25M scanning probes from Renishaw Inc (2005). (b) Roland DGA Corp. MDX-15/20 scanning and milling machine, using the Roland Active Piezo Sensor for 3-D scanning (Roland, 2005).

Advantages:

(i) high accuracy,

(ii) low costs,

(iii) ability to measure deep slots and pockets, and

(iv) insensitivity to color or transparency

Disadvantages:

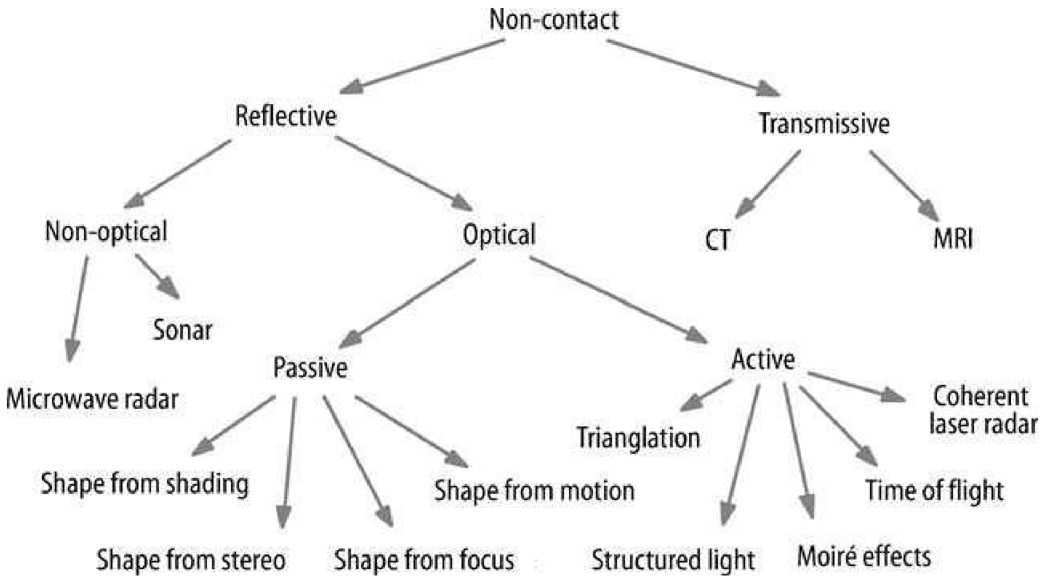
(i) slow data collection and

(ii) distortion of soft objects by the probe.

II. Noncontact Methods

In noncontact methods, 2-D cross-sectional images and point clouds that represent the geometry of an object are captured by projecting energy sources (light, sound, or magnetic fields) onto an object; then either the transmitted or the reflected energy is observed. The geometric data for an object are finally calculated by using triangulation, time-of-flight, wave-interference information, and image processing algorithms. There is no contact between the RE hardware and an object during data acquisition.

There are different ways to classify RE hardware that uses noncontact RE methods for data acquisition. These classifications are based on the sensor technologies or data acquisition techniques employed. Figure shown below presents a classification of noncontact RE hardware based on data acquisition techniques.



Classification–noncontact methods

The advantages and disadvantages of noncontact methods compared to contact methods are as follows.

Advantages:

(i) no physical contact;

(ii) fast digitizing of substantial volumes;

(iii) good accuracy and resolution for common applications

(iv) ability to detect colors; and

(v) ability to scan highly detailed objects, where mechanical touch probes may be too large to accomplish the task.

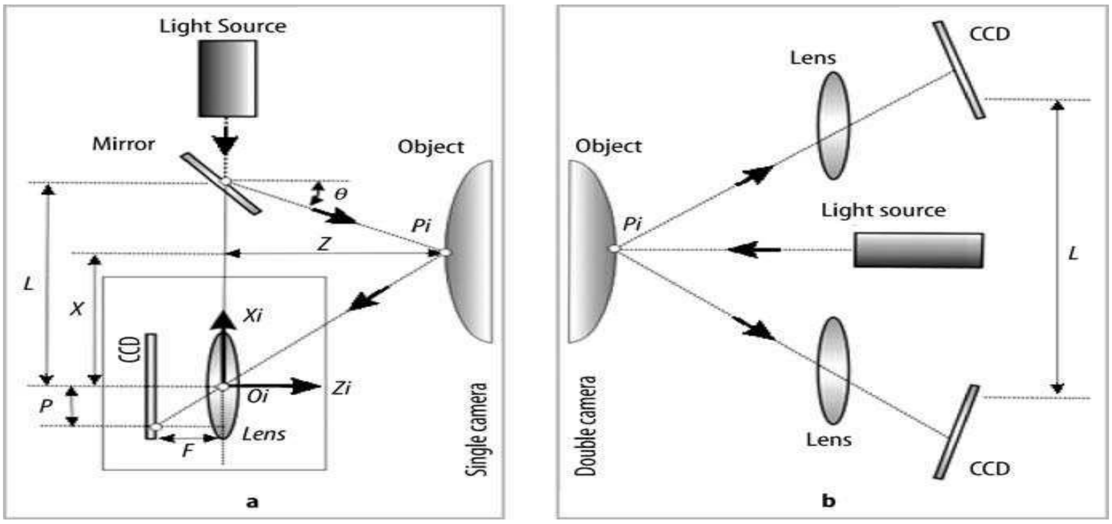
Disadvantages:

(i) possible limitations for colored, transparent, or reflective surfaces and

(ii) lower accuracy.

Optical Techniques

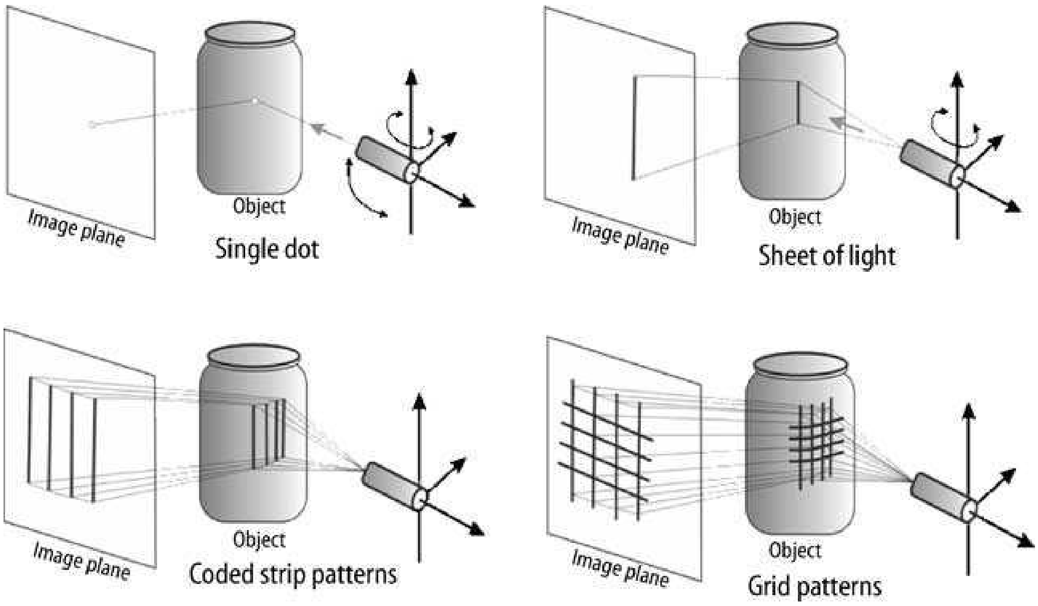
Triangulation: Most laser scanners use straightforward geometric triangulation to determine the surface coordinates of an object. Triangulation is a method that employs locations and angles between light sources and photosensitive devices (CCD–charge-coupled device camera) to calculate coordinates.



*Triangulation methods: (**a**) single and (**b**) double camera arrangement*

<u>Structured Light:</u> In structured-light techniques a light pattern is projected at a known angle onto the surface of interest and an image of the resulting pattern, reflected by the surface, is captured. The image is then analyzed to calculate the coordinates of the data point on the surface.

A light pattern can be (i) a single point; (ii) a sheet of light (line); and (iii) a strip, grid, or more complex coded light.



Different light patterns used in structured-light techniques

Structured-light systems have the following strong advantages compared to laser systems, and these features have resulted in favoring structured-light systems for digitizing images of human beings:

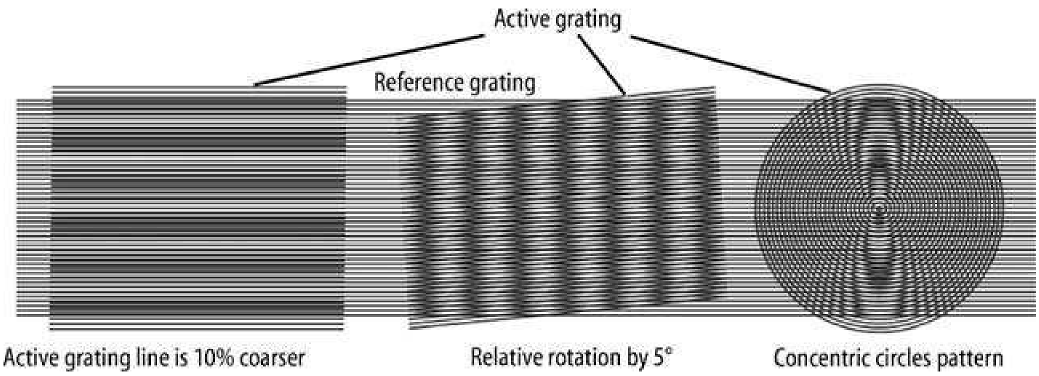
(i) the data acquisition is very fast (up to millions of points per second)

(ii) color texture information is available

(iii) structured-light systems do not use a laser.

<u>Interferometry (Moiré Effects):</u> The interferometry technique is well known in dimensional inspection as well as in flatness and deformation measurements, in which structured-light patterns are projected onto a surface to produce shadow moiré effects. The light contours produced by moiré effects are captured in an image and analyzed to determine distances between the lines. This distance is proportional to the height of the surface at the point of interest, and so the surface coordinates can be calculated.

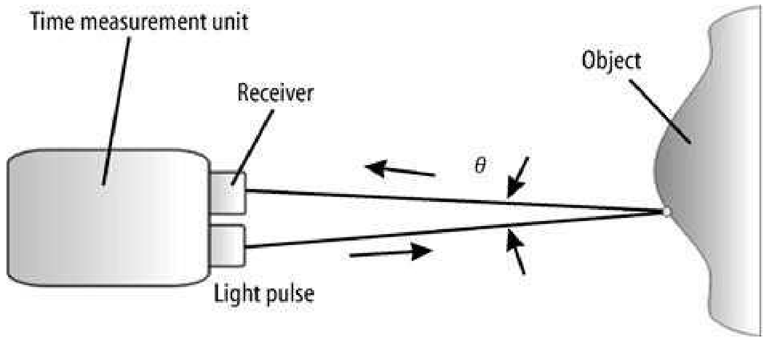
The moiré technique gives accurate results for 3-D reconstruction and measurement of small objects and surfaces. However, it has limitations for larger objects because precision is sacrificed for range.



Formation of moiré fringes

<u>Time of Flight:</u> The principle behind all time-of-flight (TOF) implementations is to measure the amount of time (t) that a light pulse (i.e., laser electromagnetic radiation) takes to travel to the object and return. Because the speed of light (C) is known, it is possible to determine the distance traveled. The distance (D) of the object from the laser would then be equal to approximately one half of the distance the laser pulse traveled: $D=C\times t/2$.

The main disadvantage is that TOF scanners are large and do not capture an object's texture, only its geometry. They are not practical for fast digitization of small and medium-sized objects. Moreover, it takes time to complete the digitization process because the object (or environment) has to be swept during scanning.



Principle of TOF scanners

Passive Methods: Passive methods reconstruct a 3-D model of an object by analyzing the images to determine coordinate data. It is similar to (active) structured-light methods in its use of imaging frames for 3-D reconstruction; however, in passive methods, there is no projection of light sources onto the object for data acquisition. There are many different passive methods, including shape from shading, shape from stereo, shape from motion, shape from focus/defocus, shape from silhouette, and volumetric reconstruction. The typical passive methods are shape from shading and shape from stereo. Shapes from shading (SFS) methods are used to reconstruct a 3-D representation of an object from a single image (2-D input) based on shading information. The first SFS technique was developed by Horn in the early 1970s. These are the main disadvantages of this method:

(i) the shadow areas of an object cannot be recovered reliably because they do not provide enough intensity information;

(ii) the method cannot be applied to general objects because it assumes that the entire surface of an object has the same reflectance;

(iii) the method is very sensitive to noise because the computation of surface gradients is involved.

Shape from stereo or stereovision refers to the extension of SFS to a class of methods that use two or more images from different viewpoints for shading based 3-D shape recovery. Normally, two cameras are coordinated to generate 3-D information about an object by automatically finding corresponding features in each of the two images; then triangulation is used to measure the distance to objects containing these features by intersecting the lines of sight from each camera to the object. Compared to SFS methods, there is improved accuracy. However, finding correspondence between images is extremely difficult and can produce erroneous results from mismatches.

Nonoptical Techniques

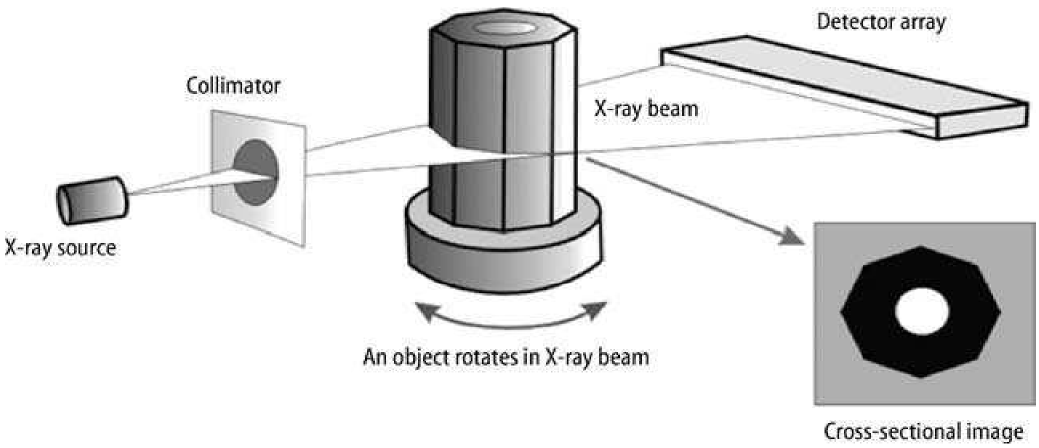
Nonoptical approaches include acoustic (active sonar) and microwave radar (radio detecting and ranging). The principle of these techniques for 3-D reconstruction is measuring distances from the sensing device to objects by measuring the time delay between the transmitted and returned signals.

Sonar techniques are normally used in 3-D underwater mapping; they provide mariners with a major advancement in obstacle avoidance and navigation. Sonar range sensors are inexpensive, but their accuracy is not high and they do not have high acquisition speeds. Acoustic interference or noise is often a problem, as is determining the focused point location. Radar is typically intended for use with long-range remote sensing, especially in airline applications. Commercial airliners are equipped with radar devices that warn of obstacles in or approaching their path and give accurate altitude readings. In 3-D reconstruction applications, radar is used to measure distances and map geographic areas and to navigate and fix positions at sea.

Transitive Techniques

Computerized tomography (CT) is a powerful transmissive approach for 3-D reconstruction. CT has revolutionized the medical diagnostic field since the 1970s. It has also been called computerized axial tomography (CAT), computerized transaxial tomography (CTAT), and digital axial tomography (DAT).

CT is a nondestructive method that allows three-dimensional visualization of the internals of an object. It provides a large series of 2-D X-ray cross-sectional images taken around a single rotational axis.



Working principle of the CT scanner

Figure presents the CT working principle of generating 2-D cross-sectional images. By projecting a thin X-ray or Y-ray beam through one plane of an object from many different angles and measuring the amount of radiation that passes through the object along various lines of sight, a map of attenuation coefficients (a density map or cross-sectional image) for the scanned surface is reconstructed.

CT is widely used for medical applications; however, it has been extended and adapted to a wide variety of industrial and 3-D modeling tasks. Today, industrial CT and related technologies (digital computed laminography) are commercially available and specialized for industrial applications. High-resolution X-ray CT and micro CT scanners can resolve details as small as a few tens of microns, even when imaging objects are made of high-density materials. It is applicable to a wide range of materials, including rock, bone, ceramic, metal, and soft tissue. Magnetic resonance imaging (MRI) is a state-of-the-art imaging technology that uses magnetic fields and radio waves to create high-quality, cross-sectional images of the body without using radiation. When hydrogen protons in the human body are placed in a strong magnetic field, by sending in (and stopping) electromagnetic radio-frequency pulses, these protons emit signals. These signals are collected and processed to construct cross-sectional images. Compared to CT, MRI gives superior quality images of soft tissues such as organs, muscle, cartilage, ligaments, and tendons in many parts of the body.

CT and MRI are powerful techniques for medical imaging and reverse engineering applications; however, they are the most expensive in terms of both hardware and software for data processing.

THE TEARDOWN PROCESS

Next to building things (shelters, tools, weapons, etc.), the most natural thing for human beings to do would seem to be taking things apart. If something falls apart or begins to fail during the process of its creation, production, or construction, engineers (as those responsible for such things) seek to determine why, in order to correct the problem. If, on the other hand, something survives creation, production, or construction (as is usually the case), engineers, not uncommonly, take it apart (at some point) in a systematic process of teardown.

Product teardown is the intentional dissection and analysis of a product (in the broadest sense, to include parts, components, objects, devices, structures, substances, materials, assemblies, and systems) in order to gain experience and knowledge to add to a database and/or for benchmarking. When used for products that have failed either prematurely or catastrophically, product teardown is a key part of failure analysis(or, for the purpose of forensic engineering, to solve crimes or support cases of litigation). When used for products that work or didn't necessarily fail, it is part of the higher-level technique of reverse engineering.

They do so for either of two primary purposes:

1.To learn from something that works or worked well what makes or made it successful (or)

2.To discover why something no longer works as it was intended to work

To make it easier we will focus discussion of the teardown process on teardown of a "product" in the broadest sense, by which could be meant part (e.g., automobile sparkplug or shock absorber or tire), component (e.g., machine cam or spring or bolt), structural element (e.g., beam or truss or arch), object (e.g., soccer ball or golf club or lightbulb), device (e.g., p-n junction diode or rectifier or computer microprocessor unit), product (e.g., vacuum cleaner or iPod or smartphone), substance (e.g., Coca-Cola or proprietary adhesive or coating on a consumable arc welding electrode), material (e.g., metallic alloy or engineered polymer or synthetic composite), structure (e.g., pyramid or bridge or dam), assembly (e.g., self-winding Swiss watch or aircraft landing gear or populated printed circuit board), or system (e.g., automobile or laser-guided missile or LCD TV). Based on this, product teardown is the process of taking apart a product to understand it.

Product teardown serves three central (or key) purposes, as follows:

1.Dissection and technical (as well as cost) analysis

2.Experience and knowledge for one's own personal (or for an organization's) database

3.Benchmarking

KEY ASPECTS OF TEARDOWN

Observation

An American poet, Wallace Stevens (1879–1955) to say it best: "The accuracy of observation is the equivalent of accuracy of thinking."

Reverse engineering, perhaps more than anywhere else in engineering, demands meticulous observation.

In tearing down a product (again, in the broadest sense of that word given earlier), it is critical that everything there is to be seen is seen—and is thoroughly documented.

At the highest level, it is very important—and may prove to be very informative—to look at the overall workmanship of the product. Workmanship reflects more than simply the care taken by the worker(s), although it surely does that. It reflects the value the creator of the product placed on creating it. Care in workmanship generally reflects care in every other aspect of the product's creation, from design to marketing to customer support and service. Design has a particularly significant impact, however, on the ability to create a physical entity from what began as an abstract concept. It has been said that decisions made during the design stages of a product have the most profound and lasting impact on the product's life-cycle cost—from "womb to tomb," as it were. It may be unfair and/or untrue to say a product that looks good (in terms of its workmanship) is good, but it is more true than not that a product that looks bad will probably be bad. What caring designers—or engineering design organization—would tolerate poor workmanship in making their design a reality? Surely, a bad design cannot be saved by the best workmanship, but a great design can be ruined by poor workmanship!

Measurement

H. James Harrington (1929–) is an American author (of more than 35 books), engineer, entrepreneur, and consultant in performance improvement wrote: "Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it."

Measurement is extremely important—following initial observation—during product teardown.

Two broad categories of measurements become apparent:

(1) measurement of geometry and

(2) measurement of function (when possible).

Measurement of geometry (i.e., geometric measurement) is straightforward. Every aspect of the geometry of a product (in the broadest sense) needs to be measured or quantified on some appropriate dimensional scale. This includes dimensional measurements that would allow reproduction of the overall product, as well as each and every detail part or component in the product. Measurement of length, width, thickness, hole diameter, hole depth, hole location, radii of curvature are all obvious, but, for 3D objects or features with compound curvature (i.e., curvature in two directions) or with nonuniform curvature, the task is somewhat more involved. Modern computer-based coordinate measuring systems make this task much simpler than it once was, however. By digitizing points on a surface, that surface can be reproduced with whatever accuracy, in terms of resolution, is desired or required. The points, after all, define the surface.

When, during product teardown to reverse engineer a product, it is also desired to capture information to characterize the known—or deduce the uncertain—function of a product (i.e., its use) and performance (i.e., its level of function), one needs to make appropriate measurements where possible. The general procedure for functional measurement involves decomposing the product into a set of "elements" that represent all of the key functions, for which a set of measurements can then be defined from each function to allow the overall product's function to be quantified (i.e., measured). To do this, one must first list the known or presumed (or deduced) functions of the product from what is known as a function structure or functional structure. In some cases, this list can change from predicted functions before product decomposition to actual(or deduced) functions after product decomposition.

With a list of functions in hand, appropriate measurements can be taken wherever possible, or, where not possible, some enumeration of function by estimation must be attempted (see Chapter 7). One of the methods for accomplishing product teardown actually involves taking apart a functioning product to observe how—and from where—function arises.

Since a proper functional analysis of a product provides a complete representation of the product, a more accurate set of measurements can be developed by examining each function, one by one. In this context, function includes customer needs, operating ranges, and flows of energy, material, and information (or signal).

Experimentation

"Observation is a passive science, experimentation an active science."

After observation, as the first key step in product teardown and reverse engineering, and measurement, as the second key step, it is sometimes possible and appropriate to conduct experimentation. If a product to be subjected to teardown is currently operational, particularly (but not only) if the purpose and function of the product is known, experimentation with the product can provide valuable information, knowledge, and understanding. Examples where experimentation with a product can prove useful include:

- Benchmarking of one's product against a competitor's (or competitors') product (or products)
- Benchmarking one's new product concept (e.g., as a prototype) against one's earlier product
- Troubleshooting one's product that falls short of expectations or is experiencing problems in the marketplace
- Reverse engineering a weapon system (as part of military espionage) or a product in the marketplace for which your organization has no counterpart (as part of industrial espionage)
- Learning about an unknown object (e.g., the Rosetta stone), device (e.g., the Antikythera mechanism), structure (e.g., Stonehenge), or product

Other Specific Forms of Teardown

There are actually several specific forms or types of teardown besides product teardown, which has been discussed at length herein, including:

- Dynamic teardown
- Cost teardown
- Material teardown
- Matrix teardown

Dynamic teardown applies the principle of comparative analysis to the assembly process. The focus is the examination of all the design features that specifically (directly or indirectly) contribute to the time and cost of assembling the product during production.

Cost teardown has the specific objective of assessing the total cost to bring a product to market, excluding general overhead. In this method of teardown, product comparisons and differences are specifically identified and measured with cost estimates.

Material teardown focuses on saving on direct material costs and labor costs brought about by the particular material. The goal is to identify which materials could be changed to reduce such costs, as well as to have less adverse impact on the environment.

Finally, matrix teardown deals with the comparison of a company's own products with an eye toward standardizing and communizing wherever possible. A specific goal is to reduce part count and prevent the intrusion of new part numbers that are not absolutely necessary. Process teardown is similar to matrix teardown, except that it is focused on standardizing a simplifying internal fabrication and assembly processes.

IDENTIFYING THE CHARACTERISTICS OF BAD PRODUCT DESIGN

Product design, like anything, can be done well and it can be done poorly. If done well, a product has the potential to be used daily and loved by many consumers. Ideally, every product in the world would be a "perfect" design; however, nothing is perfect, and no product is without flaw. Below are 5 characteristics that (in my opinion) define a "bad" product design.

<u>1. The design is not self-explanatory</u>

Of all things a design could do wrong, this is possibly the worst. Customers should be able to, fairly quickly, determine what the product is and does and how to use it. Long instruction manuals are necessary from a technical standpoint, but a product should strive to be as intuitive as possible. Some products are designed with too many unnecessary features which detract from the product's primary use and user friendliness. If a product is not self-explanatory enough, it will do more harm than good in the consumer's eye.

2. The design is distracting

A captivating design is always a good thing, however, there is a difference between captivating and distracting. A distracting design tries too hard to capture the user's eye. Instead of seamlessly integrating itself into the user's life, it is constantly calling out for attention through obnoxious aesthetics or arbitrary functionality. The designs which pleasantly impact consumers subconsciously are generally better than those which impact consciously.

3. The design is difficult to use.

This characteristic differentiates from #1 in that it may be an intuitive product, but the actual act of using it is difficult. The coffee mug in the accompanying photo has a small "handle" that not only looks nearly impossible to grip comfortably, but also has a groove which allows hot coffee to flow freely towards your fingers. Ergonomics are a key factor in well designed products. If a user cannot physically connect with a product in a satisfying manner, that product is a bad design.

4. The design is forgettable.

How often do you use badly designed products? Probably not very often, because that product has been sitting in the back of your closet since you got it. Whether it be poor aesthetics or mediocre performance, thousands of products fall into the same forgettable trap. Instead of being a product that is useful or enjoyable to use, these products are so bland or useless that they leave no psychological impression on the user. Product design heavily relies on psychology, and the connection humans have with objects. To leave no psychological impression at all, is to almost not even exist.

5. The design is short lived.

A design's quality is measured not only by aesthetics and usefulness, but more obviously, by it's lifespan. A bad design will have faults which render it useless quicker than a consumer would like. Many companies will purposely design products this way through planned obsolescence, however I believe this is the wrong way to approach product design. My favorite products to use are ones which I have inherited from family or have been in my possession for years and still perform as well as when they were first bought. I believe the best products are those which can be used for a lifetime.

No design is perfect, however, even if just one of these 5 characteristics is tended to, a product could easily be raised above it's competition. Product design is generally an involved process that takes time to get right. Market research, ergonomics, form studies, user testing, prototyping; these are all things that should be pursued if a design is to truly be "good." To create a product which is loved by consumers, a designer must take time to consider all details of the design whether they be physical or psychological.

Shrinkflation

In economics, shrinkflation is the practice of reducing the size or quantity of a product while the price of the product remains the same or slightly increases. In some cases, the term may indicate lowering the quality of a product or its ingredients while the price remains the same.

British economist Pippa Malmgren is generally credited for inventing the term in 2009. The phenomenon has become quite common in the food and beverage industry.

Breaking Down Shrinkflation

Essentially, shrinkflation is a form of hidden inflation. Instead of increasing the price of a product, something that would be immediately evident to consumers, producers reduce the size of the product while maintaining the same price. The absolute price of the product doesn't go up, but the price per unit of weight or volume has increased. The small reduction in quantity is usually unnoticed by consumers (at least that's what the manufacturer hopes).

Shrinkflation is widely used by producers in the food and beverage industry. It has become a common tactic to help producers deal with their own inflation problems from suppliers. Many companies determined that their customers would balk and perhaps begin to look for substitute products if confronted with yet another price increase. The solution? – Shrinkflation.

Note that shrinkflation cannot be viewed as a fraud or misrepresentation of products. Producers always indicate the weight, volume, or quantity of their products on packaging labels. It's not illegal – it's just sneaky.

What Causes Shrinkflation?

1. Higher production costs

Rising production costs are generally the primary cause of shrinkflation. Increases in the cost of ingredients or raw materials, energy commodities, and labor increase production costs and subsequently diminish producers' profit margins.

Reducing the products' weight, volume, or quantity while keeping the same retail price tag can improve the producer's profit margin. At the same time, the average consumer will not notice a small reduction in quantity. Thus, sales volume will not be affected.

2. Intense market competition

Fierce competition in the marketplace may also cause shrinkflation. The food and beverage industry is generally an extremely competitive one, as consumers are able to access a variety of available substitutes. Therefore, producers look for options that will enable them to keep the favor of their customers and maintain their profit margins at the same time.

Examples of Shrinkflation

Even some of the most famous companies and brands have adopted using shrinkflation with their products, including:

Coca-Cola: in 2014, Coca-Cola reduced the size of its large bottle from 2 liters to 1.75 liters.

Toblerone: in 2010, Kraft slashed the weight of Toblerone bars from 200 grams to 170 grams.

Tetley: in 2010, Tetley reduced the number of teabags sold in one box from 100 to 88.

Nowadays, shrinkflation is a common practice among producers. The number of products that undergo downsizing increases every year. Large producers in the European and North American markets rely on this strategy to maintain the competitive prices of their products without significantly reducing their profits.

At the same time, shrinkflation can frequently lead to customer frustration and deteriorating consumer sentiment regarding the producer's brand. Eventually, consumers do "wise up" to what's going on. Cereal boxes that are the same size as before, but seem only about half full, have almost become a sort of shared joke between companies and consumers.

3D Printing

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the object is created. Each of these layers can be seen as a thinly sliced cross-section of the object.

3D printing is the opposite of subtractive manufacturing which is cutting out / hollowing out a piece of metal or plastic with for instance a milling machine.

3D printing enables you to produce complex shapes using less material than traditional manufacturing methods.

3D Printing Industry

Adoption of 3D printing has reached critical mass as those who have yet to integrate additive manufacturing somewhere in their supply chain are now part of an ever-shrinking minority. Where 3D printing was only suitable for prototyping and one-off manufacturing in the early stages, it is now rapidly transforming into a production technology.

Most of the current demand for 3D printing is industrial in nature. Acumen Research and Consulting forecasts the global 3D printing market to reach $41 billion by 2026.

As it evolves, 3D printing technology is destined to transform almost every major industry and change the way we live, work, and play in the future.

Examples of 3D Printing

3D printing encompasses many forms of technologies and materials as 3D printing is being used in almost all industries you could think of. It’s important to see it as a cluster of diverse industries with a myriad of different applications. A few examples:

- – consumer products (eyewear, footwear, design, furniture)
- – industrial products (manufacturing tools, prototypes, functional end-use parts)

- – dental products
- – prosthetics
- – architectural scale models
- – reconstructing fossils
- – replicating ancient artifacts
- – reconstructing evidence in forensic pathology
- – movie props

Rapid Prototyping & Rapid Manufacturing

Companies have used 3D printers in their design process to create prototypes since the late seventies. Using 3D printers for these purposes is called **rapid prototyping**.

Why use 3D Printers for Rapid Prototyping?

In short: it's fast and relatively cheap. From idea, to 3D model to holding a prototype in your hands is a matter of days instead of weeks. Iterations are easier and cheaper to make and you don't need expensive molds or tools.

Besides rapid prototyping, 3D printing is also used for **rapid manufacturing**. Rapid manufacturing is a new method of manufacturing where businesses use 3D printers for short run / small batch custom manufacturing.

DIGITALIZATION

Why Digital Transformation is More Important Today Than Ever Before

Technological advancements have disrupted the traditional methods of business operations. Now, artificial intelligence, IoT, robotics are being used to create advanced and more sophisticated machines that are safer and have higher production capacity. Similarly, the digitalization of various business aspects has started happening to reap the maximum benefits of digital technology. One of these aspects is product digitization.

Product Digitization

Product digitization means adding the digital capabilities to physical products so that product buyers can interact with the product and get information in digital format. It is achieved by putting scannable codes on the product or product packaging. Buyers can scan the code using their smartphones and access the product information on their phone screen. Product digitization converts physical products into digital gateways to convey the right marketing message at the right moment.

Benefits of product Digitization

Digitizing any aspect of business helps you to collect more and more of business data. Similarly, product digitization helps you to collect the data of all the stakeholders involved in the product's journey. And data has become the foundation in taking any business to the path of success.

The increasing number of smartphone users and the capability of scanning the QR codes through the native camera in iOS and many Android phones, has made QR codes very popular.

From making payments to checking into events, QR codes are being used everywhere, and millennials prefer to scan these codes to do things faster and error-free. This popularity of QR codes makes placing QR codes on product items, a very efficient and economical way of product digitization.

Following are the key benefits of product digitization:

<u>Generate Trust in Consumer's mind with Product Journey and Story</u> –Brands can show product journey and story on the scan of product code; this helps in increasing customer's trust in the brand.

<u>Convey dynamic information to your users</u> – Product digitization presents an opportunity to show dynamic content to the users without the need for change in the product codes. For example, Brands can display information in regional languages based on the scan location. Brands can also showcase new/related products on the product information page.

Collect and access product interaction information in realtime – With the help of product digitization, brands can collect user data in realtime, and this data can contribute to making crucial business decisions. Product digitization also enables products to participate in marketing automation.

Protect your brand against counterfeiting – Product digitization can protect your products fro counterfeiting if the product codes are clone-proof.

Enhance your supply chain visibility and prevent diversion – The same product codes can also help in supply chain management and preventing the diversion by flagging any anomalies in product code scan geo-location if the backend software platform is equipped with such capabilities.

Customer engagement – Product digitization opens new channels to engage users. Product codes can be used to run loyalty programs and re-engage the users for repeat sales.

Good for the environment – Another very important benefit is that product digitization helps brands to go greener by helping them to save paper on printed media.

The importance of ERGONOMICS

Ergonomics is about ensuring a good fit between people and the things they interact with. This could include the objects they use or the environments they live in. You should consider ergonomics in the design of every product, system or environment.

You should focus on ergonomics early in the design process. Ignoring ergonomics can lead to designs that are likely to fail commercially - as they don't fit the needs of the user.

Ergonomics is an important part of research in the product development process. Its purpose is to increase the safety, comfort and performance of a product or an environment, such as an office.

Ergonomics uses measurement data to determine the optimum size, shape and form of a product, and make it easier for people to use.

Ergonomists can help you to identify which user characteristics you should take into account during your design process. This is important when you consider how much individuals vary in terms of:

- body size

- body shape
- strength
- mobility
- sensory sensitivity
- mental ability
- experience
- training
- culture
- emotions

When you apply ergonomic methods early in the design process, they can often identify opportunities for innovation.

Categories of Ergonomics

There are three broad areas of ergonomics:

Physical ergonomics looks at how human anatomical, anthropometric, physiological and biomechanical characteristics relate to physical activity. This includes:

- working postures
- manual handling
- repetitive movements
- musculoskeletal disorders
- workplace layout and environment

Psychological ergonomics studies mental processes (eg perception, cognition, memory, reasoning and emotion) and how people interact with products, systems and environments. This includes:

- mental workload
- decision-making
- human-computer interaction
- human reliability

- attitudes
- stress
- motivation
- pleasure
- cultural differences

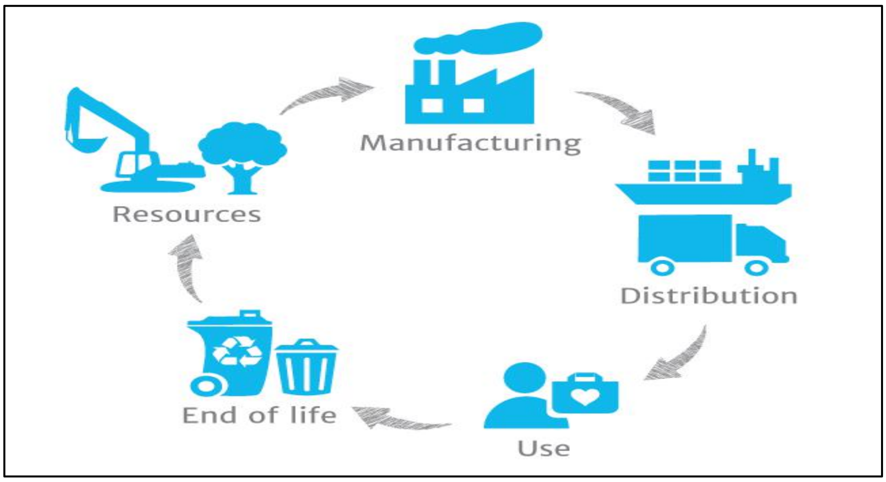
Organisational ergonomics is about optimising the organisational structures, policies and processes of socio-technical systems. This includes:

- communication
- work design
- staff resource management
- working time patterns
- co-operative work
- quality management
- organisational culture

To ensure that you keep your end users' needs in focus at all times, you should make ergonomists an integral part of your design development team.

Designing the products to meet environmental challenges is possible and needed

Eco-design is an approach that aims to reduce a product's environmental impact throughout its life-cycle. It thus assesses every stage of its development, from the initial idea to the end of its life, including its production, logistics, distribution and use. It also factors in its consumption of raw materials and possible negative impact on the environment (atmospheric pollution, discharges into natural environments, harmful effects on biodiversity, etc.). The approach also applies to product packaging. The aim is to achieve « optimum packaging »: neither too much nor too little, so that it can play its role in storage, hygiene and protection against contamination (with food products) while minimizing the resources used and the waste generated.



The eco-design takes into consideration the entire product life cycle

Eco-design benefits

Eco-design minimizes a product's negative impact by factoring environmental concerns into its specifications, such as the preservation of precious or non-renewable resources, the prevention of pollution and the absence of danger for animal and plant species. And it does not involve merely marginal improvements: the European Commission says that "nearly 80% of a product's environmental impact can be improved through eco-design."

Safety in Design:

Safety in Design is defined as:

"The integration of hazard identification and risk assessment methods early in the design process to eliminate or minimize the risks of injury throughout the life of the product being designed. It encompasses all design including facilities, hardware, systems, equipment, products, tooling, materials, energy controls, layout, and configuration (AS&CC 2006)"

Safe design is the method of ensuring the health and safety of individuals who will interact with a product during its entire lifetime. It encompasses not just those people who will operate the product, but also those who will assemble, clean, maintain, repair, and dispose of it. A designer must consider the potential risks and work to reduce them during the entire design phase through careful choices about materials, manufacturing processes, method of use, intended disposal practices, and additional safety features - whether required by law or otherwise.

Successful safe design relies on finding a balance between function, aesthetics, manufacturing costs and other such design aspects without risking the safety of all who will come into contact with the product.

Who is Responsible for Safe Design?

Safe design is influenced at every stage of the process. Those responsible include:

Design: architectural designers, industrial designers, and design engineers;

Supply: importers, plant equipment suppliers, and manufacturers;

Labour: constructors, installers, tradesmen, contractors, and maintenance;

Other parties: clients, developers, land owners, management, health & safety and ergonomic assessment practitioners;

Government: regulation bodies and inspectorate agencies;

How Successful Safety in Design is Achieved

Every decision a designer makes affects the safety and health of all those who will, or may, be affected by the product during the entire course of its lifespan. Even the earliest design choices need to include safety considerations, else considerable work may need to be done later on to retroactively implement health & safety design changes. It is also critical that this approach to safe design is continued throughout the process and addressed in each stage of the asset's lifecycle.

Why Safe Design Matters

Just a few critical benefits of a safe design are:

- Improving the designer's understanding of design needs and limits;
- Preventing injury, disease, and in many cases: death;
- Happier work environments that are free from risk; Improving the use of structures and products;
- Improving productivity; Reducing costs;
- Improving the prediction and control of production, including operational costs
- Easier compliance with safety legislation & New avenues of thought and design innovation