Reverse Engineering:

What You Need to Know



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Introduction

If you're planning on reverse engineering a part or device or any other physical object, but don't know where to start or what aspects to consider, then please read on. This paper will address the key elements of the process, providing you with ideas and competent advice to help you decide which solutions are right for your needs.

In order to reverse engineer something, you first need to precisely measure it. That might be an easy task if we're talking about simple geometrical shapes and shoebox-sized objects.

HIGHLIGHT:

In order to reverse engineer an object, you need to precisely measure it, bring those measurements over into a CAD system, and create a CAD model of the object to work from.

Yet in the real world, you may need to reverse engineer something as tiny as a matchhead, or an object as massive as a skyscraper, with levels of complexity ranging from utterly basic to mind-bogglingly intricate. But rest assured, there's a technology out there for measuring it, regardless of its dimensions or how detailed it is.

Once you've measured your object, whether by ruler and caliper, 3D scanner, CMM machine, or another technology, you'll need to do something with that measurement data, otherwise it's just that: data. By bringing the data over into a CAD system and using it to create an accurate CAD model of your object, you'll be on your way to whatever plans you have in mind for your new design.

Now let's take a closer look at some facets of reverse engineering, as well as a few of the most frequently asked concerns about getting started and making your workflow as productive and successful as possible.



Popular uses of reverse engineering



HIGHLIGHT:

Some of the common applications of reverse engineering include recreating legacy parts, inspecting a malfunctioning component or assembly, and improving the performance of machinery that has been in use for years.

Let's say that the manufacturer of a part or machine that you need no longer offers that unit or series of parts, or they've simply gone out of business. Or even if they do still make what you need, it's extremely difficult to get a hold of, with extended delivery times at best.

Maybe you're focused on a piece of equipment your company owns, and there's a component or process that's failing somewhere along the line, but you haven't yet pinpointed it. You need to understand what's happening and why, so you can come up with a solution that doesn't in turn create another problem or failure.

Or maybe your company has an existing design that isn't exactly running at peak performance. Certain parts could be experiencing more wear and failure than acceptable, resulting in product returns, bad reviews, and potentially even lawsuits.

Reverse engineering can help solve all of the above headaches. Not only can you replicate legacy or difficult-to-source parts, especially with additive manufacturing and modern machining, but you can often do so at a considerable cost savings.

Once you've reverse-engineered a specific part or unit, you can go about enhancing its performance and durability by analyzing the CAD model in an FEA (finite element analysis) system, pinpointing any weak spots, and modifying the structure and/or materials used to deliver the desired outcome.

These are just a handful of the many possible uses for reverse engineering. That said, anyone planning on venturing down this pathway needs to keep in mind a few potentially-problematic limitations.

Limitations to bear in mind

Aside from the legal limitations faced by reverse engineering, specifically, that you shouldn't be copying patented or otherwise protected designs, there are also several other limitations to be aware of.

Size: Even though almost any machine or part can in theory be reverse engineered, if you're focusing on a part the size of a gaming miniature, this will demand a different workflow and technology set than will an object the size of a house, if not larger.



HIGHLIGHT:

Depending on the size, material, shape, and other physical properties of the object to be measured, you may want to take care of not only choosing the most suitable tool to capture it in 3D but also preparing the object itself to ultimately increase the accuracy of measurements.

Both are entirely within reason, and by planning ahead of time and gathering the appropriate tools and expertise, your timelines won't experience any slowdowns, especially during critical phases.

Complexity: Does the object you're reverse engineering feature smooth surfaces with little in the way of variations or details? Or are there lots of thin edges, curved geometries, gaps or recessed surfaces?

What about objects with internal structures that aren't visible from the outside yet are crucial to their performance? Understanding the complexity of the objects you'll be working with will help you choose the right technology for properly capturing it for your workflow.

Surface quality: Will you be working primarily with objects that have non-reflective, matte finishes? Or will there be at least some sections with black and/or shiny surfaces? How about glass or other transparent materials?

And if you'll be dealing with glass or another kind of reflective surface, will it be possible for you to apply scanning spray or some type of matting powder? As per other surface treatments, if the need arises, can you place targets or stickers? In the case of rare historical and high-value items, there can be significant restrictions.

Movement: When it comes time to scan and measure your part or other object, you'll need to keep it as still as possible throughout the process. This means that flexible or soft parts need to be secured and made stationary prior to scanning.

Otherwise, the errant data that you capture simply won't line up, and then when it's time to transform your scans into a CAD model, the measurements will be inexact at best. Sometimes even hours of frustrating editing work won't save such scans. In brief, it's wise to keep this in mind as early as possible.

As you can see, although there are some limitations to factor into your reverse engineering workflow, they're certainly manageable, particularly when given enough time and attention beforehand.

Choosing the right tools

You can begin reverse engineering with any number of technologies, including manual measurement methods, photogrammetry, 3D scanners, and other digital capture solutions. Yet each choice carries with it distinct strengths and weaknesses. These should be taken into consideration in relation to your specific company requirements and constraints, including budget, available expertise, project time, etc.

Ultimately, whatever measurement option you choose, the captured dimensions of your object will be used to create a CAD model of it. And while accuracy is definitely essential, the features of your component that call for supreme accuracy are those that will interface with other parts.



Manual measurement: While it is possible to obtain accurate measurements for reverse engineering with calipers and rulers, it certainly takes some experience, time, and finesse. If high accuracy is a must for your resulting CAD model, then digital calipers are the way to go, as opposed to dial calipers, which can be off by as much as 25%.

The good news is that these tools are quite affordable and relatively easy to learn, although the technology remains mostly at a standstill, due to its low-tech nature.

Metrology-grade photogrammetry: To guarantee extremely high (submillimeter) degrees of accuracy even on large objects (several meters long), you'll probably want to use a metrology-grade photogrammetry kit, which includes adhesive/magnetic targets, scale bars, reference crosses, and a camera designed to spec.

If you need to measure distances between selected points on your object's surface, then place the targets, bars, and crosses on/around your object and photograph it from multiple angles, making sure that each target attached to the surface is visible in at least six photographs.

Once you're done, the photogrammetry software calculates the precise locations and distances between the targets, while the scale bar and reference cross enable the system to gauge the real-world size of the object as well as the absolute coordinates of the targets, respectively. What you get as an end result on your computer screen is a sparse cloud of precisely positioned 3D points, each representing a corresponding target.

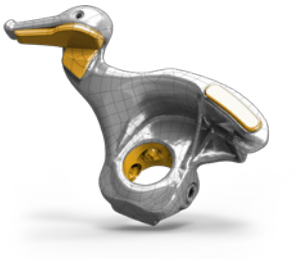
If you aim to create a very accurate, full 3D model of a large object, consider adding a 3D scanner to your workflow. Using a 3D scanner, you'll be able to capture the entire surface of your object in 3D. If needed, the scan mesh can be aligned to the 3D points generated via a metrology-grade photogrammetry solution for even greater accuracy.

The combined workflow will bring you a final 3D model that's ready for a broad spectrum of possibilities, from inspection to reverse engineering and beyond.

Desktop and handheld 3D scanners: By far the most popular choice for reverse engineering in recent years, due to the wide range of solutions available for every object size, budget, and level of detail required. Handheld and desktop 3D scanners can deliver scan data that contains the precise measurements of the surfaces of your object, often in the form of a point cloud or polygonal mesh.

But this data doesn't have geometric properties, which are a must for reverse engineering. Yet there are multiple scan-to-CAD software packages that bridge this gap for you, making it easier and quicker than ever to create highly-accurate CAD models.

Long-range laser scanners: These tripod-mounted Lidar scanners use a laser beam to capture data from an object or scene. As the laser beam strikes an object, the reflected light bounces back to the scanner's sensor, which uses this data to create a highly-accurate point cloud of what's being scanned. To achieve full coverage of your object or environment, you simply reposition the scanner as needed.



The final point cloud can then be processed into a mesh and finally a precise CAD model. Such laser scanners can be costly and aren't nearly as portable as handheld 3D scanners, but when it comes to capturing large and even massive objects for CAD, they're exceptionally useful.

CT scanners: Industrial Computed Tomography scanners can accurately and non-destructively capture the internal geometries of parts or objects from the outside. Ideal for complex components and objects that can't be disassembled, CT scanning lets you capture all the surface data needed, with submillimeter accuracy, making it an ideal technology for medical and electronics applications.

CT scanners deliver results that are sufficient not only for reverse engineering but also high-precision inspection. That said, these scanners can be extremely costly to purchase, and scanning times can be excessively long, which can be a substantial factor in many workflows.

CMM machines: For decades coordinate measuring machines have been a mainstay for dependable solution for high-accuracy measurements of solid objects of many sizes. With four main types of CMMs available, including gantry, horizontal-arm, cantilever, and bridge, this technology uses a touch probe to measure the precise coordinates of a series of points across the surface of an object, which can then be turned into a solid model of the object in CAD.

HIGHLIGHT:

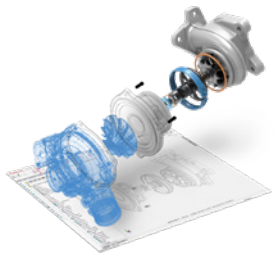
3D measurement tools vary in price, accuracy, ease of use, ability to capture hard-to-reach surfaces, and compatibility with reverse engineering software.

Although CMM solutions are high-priced yet exceptionally accurate, speed isn't one of their strong points, and neither is comprehensiveness. For example, in a typical CMM measurement job, if 250 reference points across the surface of an object are measured, this can easily take 3-3.5 hours, with there being large gaps between the points that get measured. In contrast, a 3D scanner can measure the same object in 20-25 minutes, yet will capture 2 million or more data points in the process.

As a crucial footnote, it must be said that a growing number of legacy CMM users are upgrading to handheld 3D scanners. The numerous drawbacks of CMM machines listed above, expressly, the long-drawn-out time needed for measuring objects of even average complexity, are no longer seen as being acceptable.

In contrast, today's 3D scanners are able to achieve the same and even greater levels of accuracy across an object's entire landscape, not merely discrete points, while being portable, much faster, and easy to operate.

A question of detail



HIGHLIGHT:

If you need to measure a complex part or assembly that has narrow, recessed or overlapping elements, splines, threads, curvatures, bends, or concavities, consider investing in a high-quality 3D data capture solution.

The question may seem foolish to many, but if you ask a metrology engineer how much detail they need in their measurements of a part or device in order to achieve their reverse engineering goals, most likely you'll hear in reply, "It all depends." In this case, more is not always better. Since your intent is to create a CAD model that faithfully mirrors the original object in terms of its surface dimensions, the complexity of that object, as well as your final use of the finished part, will dictate how much detail you need.

As an example, let's say you're reverse engineering the exhaust pipe on a classic car, where the object is smooth and almost entirely cylindrical, perhaps with a few bends occasionally.

Contrast that with aerospace gears and assemblies, where each part has dozens of fine edges and precisely-machined surfaces, many of which will need to interface with other parts at high speeds, with extreme loads and levels of torque.

Understanding which levels of detail you'll need to measure will be a key consideration in helping you choose the right solution. While many low-cost 3D scanners can capture simple objects with few details present, it's also true that extra time and effort will be needed to turn these scans into viable CAD models.

But if the objects you're working with are more challenging, then you'll want to make sure your solution is fit for the job.

If your application demands as much, by investing upfront in a technology that will precisely measure every thin edge, recessed surface, and curve, you're bound to initially spend more money.

But at the same time you'll be saving countless hours of frustration, repeated measurements, and CAD drawing and redrawing, not to mention avoiding product defects, customer returns, and perhaps even highly-damaging lawsuits.

Reverse engineering software – an overview

Even if you're new to reverse engineering, it won't take long for you to see how much of a difference having the right software can bring to the speed and precision of your workflow. For that reason, it's a wise decision to not make price alone the pivotal factor in your choice of reverse engineering software.

As a rule, what you should consider is how rich of a feature set you'll need, how often you'll be making use of it, as well as how quickly and easily it paves the way for a seamless, at-least-relatively-hiccup-free workflow. Why shouldn't the price tag be at the forefront? Simply because what may seem very expensive as an upfront cost may actually be the most affordable choice in the long run.

Only by seeing the software firsthand, and ideally trying it out yourself, will you be able to discover how long it takes to achieve your reverse engineering goals. Easy learning curve? Multiple reiterations needed? Cumbersome toolsets? All of these issues must be taken into account before you can understand the true cost of a reverse engineering software solution.

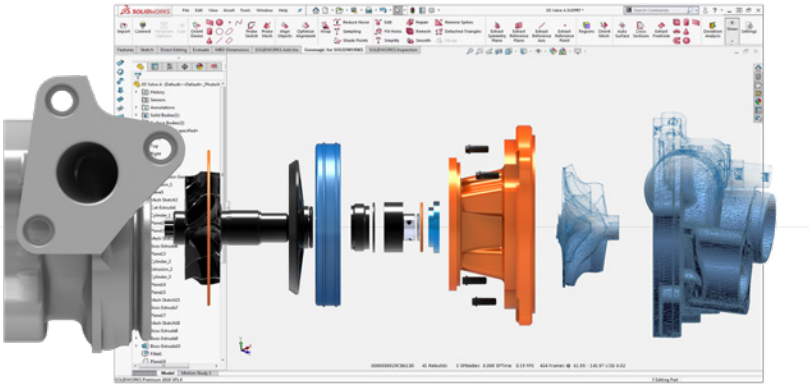
With this in mind, let's take a quick look at three popular reverse engineering software packages:

Geomagic Design X – For years now, Design X has been the unquestionable gold standard among engineering professionals for creating history-based parametric CAD models from 3D scan data. With an extremely-well-thought-out toolset, you can easily import 3D meshes of the objects you've scanned and use these as starting points for your designs, whether geometric, organic-shaped, or anything in between.

HIGHLIGHT:

The extent and complexity of modifications you intend to make via reverse engineering defines what toolset you'll need for your project.

Design X's powerful toolsets give you everything you need to confidently create and work with solids, meshes, and surfaces of all kinds, e.g. artistic sculptures, intricate aerospace parts, etc. And even if you've scanned a mammoth object and are working with large scan data sets, unlike with most other CAD systems on the market, Design X users never have to deal with lagging processes and frozen screens.



Is it expensive? Certainly, but on the other hand, users enthusiastically report that the software has a massive ROI, paying for itself quickly, not merely by handing you the power to complete your projects in record time, but also by expanding your design repertoire like no other reverse engineering package. With Design X, you'll take on considerably more projects, even the complex ones, with results nothing short of exceptional.

Mesh2Surface – If you're looking for an economical scan-to-CAD solution that comes standard with numerous options for transforming your scans into solids, then Mesh2Surface could be the package for you. As a plugin for Rhino 3D software, Mesh2Surface is designed for direct modeling organic shapes from scan data.

This makes it an effective tool for architects, sculptors, automobile designers, and many others. To highlight one popular feature, the Autosurface tool gives you click-and-go functionality for transforming scan data to free-form surfaces.

SUMMARY:

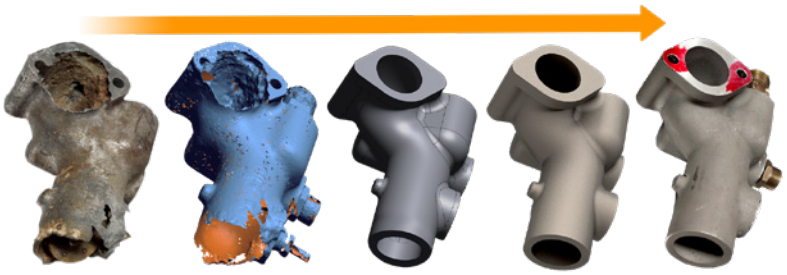
The three packages described above are just several of the best reverse engineering software solutions on the market today. As mentioned previously, you're highly encouraged to try out one or more of these packages yourself, so as to understand whether or not it's the right option for your needs. Videos and feature lists will only ever tell you so much.

SpaceClaim – Even if you have no previous CAD experience, you can be creating and editing solid CAD models in SpaceClaim in just a few hours. This standalone package's intuitive design makes it easy for users to learn and use the software's four central modeling tools: pull, move, fill, and combine.

Designed primarily for mechanical engineers, SpaceClaim's direct modeling paradigm gives you the flexibility to easily go back in and modify your designs without too much effort. Among many features for working with STL files, the software's Skin Surface Tool lets you create surface contours and organic shapes by extracting surface or solid geometries from an STL file.

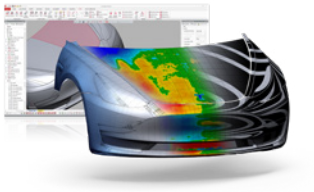
The reverse engineering process

Once you've decided to reverse engineer a specific part or object, there's a general workflow that you'll need to follow from beginning to end. Timelines and exact sequences may vary, depending upon availability of equipment, and if appropriate personnel are on hand to assist, not to mention time to manufacture, delivery, etc.



Choose your tools – Once you've decided upon the right technology for measuring your part or object, you'll need to make preparations for the actual process. In the case of a 3D scanner, that can mean finding a suitable location for scanning, such as a turntable for small objects.

If the part you're capturing features any extremely shiny or glassy surfaces, then you'll need to consider applying a temporary scanning spray or matte powder, depending on the individual capabilities of your scanner.



Measure your object – Whether you're scanning your component inside an industrial CT scanner, using a CMM machine to measure hundreds of discrete points across the surfaces of your object, or a desktop or handheld 3D scanner, or a long-range laser scanner, to capture millions of data points from a similar-sized object in minutes, this is where you'll be gathering your measurement data.

Process your data – Unless you've chosen to measure your object manually, most likely your measurement data file will be in the form of either a point cloud or a mesh. This is your starting point for what comes next. Ideally what you have now are the same dimensions as the original object, or at least within acceptable tolerances.

Create a CAD model – This is the step where you'll import your measurement data, which should consist of precise measurements of all your object's surfaces. By choosing the right CAD tools for each phase, you'll use this data as a reference for sketching your CAD model to life, feature by feature.

HIGHLIGHT:

The success of each stage of your reverse engineering project depends on your choice of the right tools. Request a demo from the developer, manufacturer, or dealer of any software/hardware solution to properly evaluate the product before deciding on a purchase.

Modify the model – After your CAD model has been built, you're free to rework it as needed. Such changes may include structural variations, including new features, thinner or thicker walls, as well as dimensional adjustments, for example, downscaling a large sculpture into a fist-sized paperweight.

Analyze your design – Under the umbrella of CAE (computer-aided engineering), as mentioned previously, you can analyze and optimize your CAD model in a variety of ways. CAE is currently in wide use throughout such industries as aerospace, automotive, motor sports, and shipbuilding.

Based upon the results achieved, if any changes from the existing model are needed, you can return to the previous stage (modification) to implement them.

3D print or manufacture your design – Especially if you want to keep open the possibility of 3D printing the part or object you've just reverse engineered, having a dependable CAD file of it is a must. Without it, a 3D printer won't have the instructions it needs, to understand how much material is required for printing, not to mention precisely where the material should be laid down.

Your CAD model will also be crucial for traditional manufacturing, including CNC machining and milling, as both these processes make use of CAD file formats such as STEP and IGES.

Conclusion

Even though the list of factors and options to consider may at first glance seem daunting, the reverse engineering process itself has become markedly easier in recent years, especially with the arrival of powerful, easy-to-use 3D scanning technology and reverse engineering software. What used to take many days or weeks when done manually can now be accomplished in as little as a few hours.

That said, by thoughtfully considering the aspects of the process as detailed above, and basing your choice of solutions and workflow on them, you'll be that much closer to a solid and stable reverse engineering process, one that will support your work for years to come.