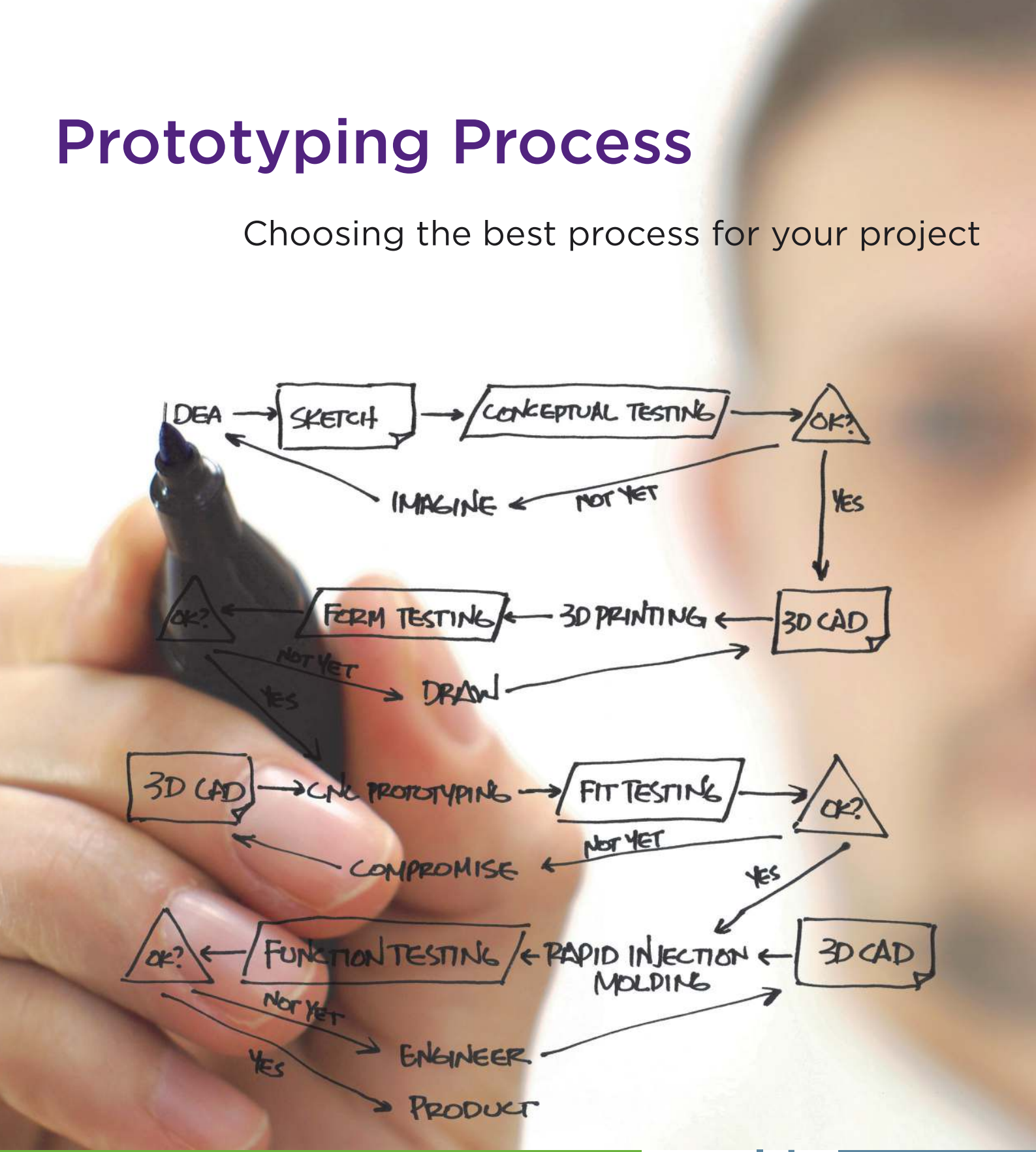
Prototyping Process

Choosing the best process for your project



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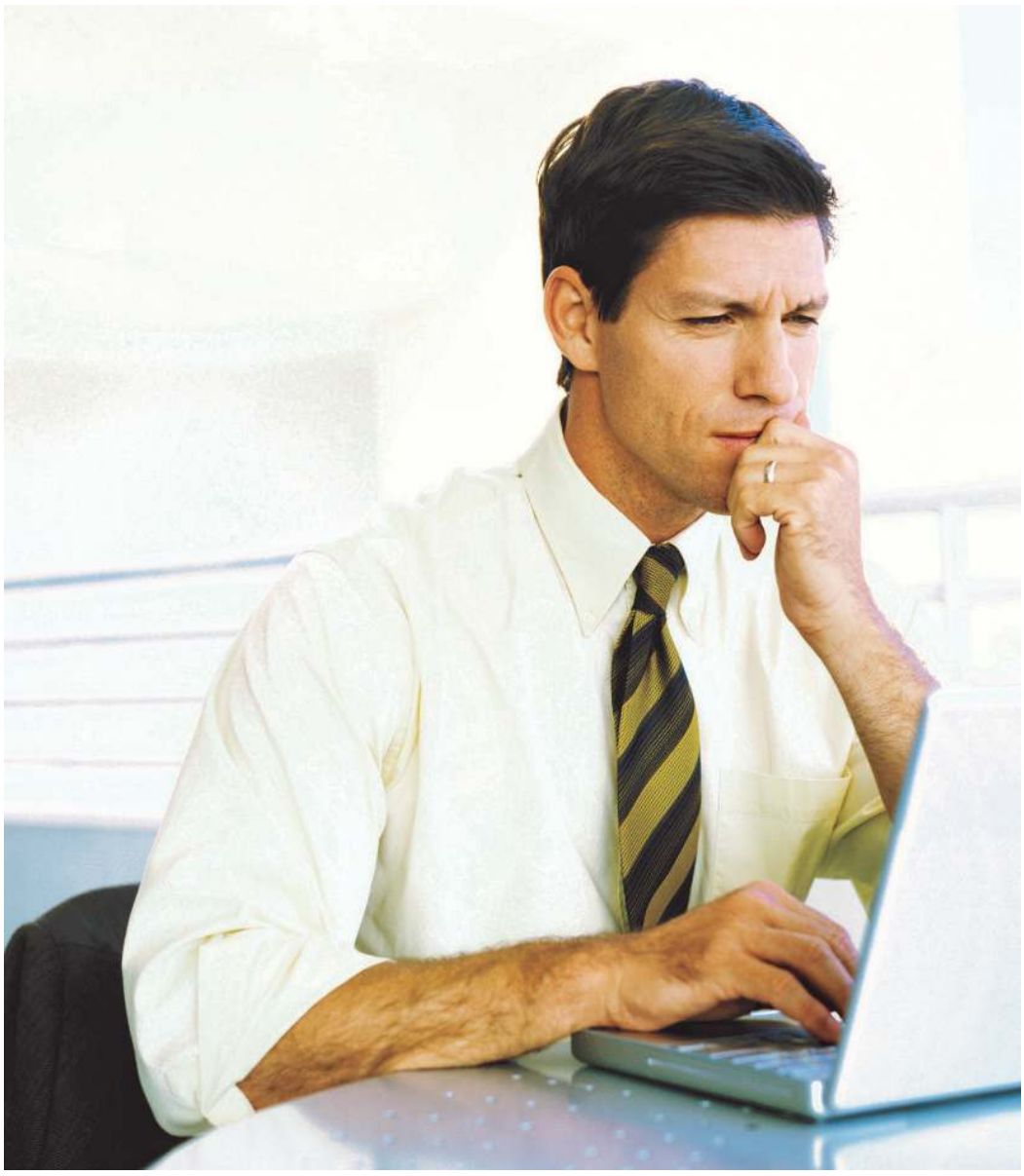
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Introduction to the Prototyping Process

Being able to obtain prototype parts quickly to test for component fit and function can help get your product to market faster than your competition. Adjustments in design, materials, size, shape, assembly, colour, manufacturability and strength can be made following the results of your testing and analysis.

Many prototyping processes are available to today's product design teams. Some prototyping processes utilise traditional manufacturing methods to produce prototypes. Other technologies have emerged and have been improved upon over a relatively short period of time. There are dozens of ways prototypes can be made. As prototyping processes continue to evolve, the product designer is constantly trying to determine what process or technology is best for their unique application.

The purpose of this white paper is to explore the advantages and shortcomings of the major prototyping processes available to today's designer. This paper will provide detailed process descriptions and discuss material properties of parts produced by each specific prototyping process. In addition, a helpful decision tree will highlight key questions designers must consider when choosing a prototyping process. Ultimately, the goal of this paper is to help you select the best prototyping process for your product development process.

Quick Reference Prototyping Process Comparison

PROCESS		DESCRIPTION	STRENGTH	FINISH	EXAMPLE MATERIALS
SLA	Stereolithography	Laser cured photopolymer	2,500-10,000 (psi) 17.2-68.9 (mpa)	Additive layers 0.051-0.152mm typical	"Thermoplastic-like" photopolymers
SLS	Selective Laser Sintering	Laser sintered powder	5,300-11,300 (psi) 36.5-77.9 (mpa)	Additive layers 0.102mm typical	Nylons, Metals
FDM	Fused Deposition Modelling	Fused extrusions	5,200-9,800 (psi) 35.9-67.6 (mpa)	Additive layers 0.127-0.330mm typical	ABS, PC, PC/ABS, PPSU
3DP	Three Dimensional Printing	Liquid binder inkjet printed onto powder	Low	Additive layers 0.089-0.203mm typical	Plaster-based powder/Liquid binder
Pjet	Poly-Jet	UV-cured jetted polymer	7,200-8,750 (psi) 49.6-60.3 (mpa)	Additive layers 0.015-0.30mm typical	Acrylic Based photopolymers Elastomeric photopolymers
CNC	Computer Numerically Controlled (Machining)	Machined using CNC mills	3,000-20,000 (psi) 20.7-137.9 (mpa)	Subtractive machined (smooth)	Most commodity and engineering grade thermoplastics/aluminium
RIM	Rapid Injection Moulding	Injection moulded using aluminium tooling	3,100-20,000 (psi) 21.4-137.9 (mpa)	Moulded smooth (or with selected texture)	Most commodity and engineering grade thermoplastics

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Process Comparisons for Prototyping Options

SLA

Stereolithography

SLA is an additive fabrication process that builds parts in a pool of UV-curable photopolymer resin using a computer controlled laser. The laser is used to trace out and cure a cross-section of the part design on the surface of the liquid resin and the process is repeated. Each newly cured layer adheres to the layer below it. This process continues until the part is completed. SLA was the first 'rapid prototyping' technology.



For: For concept models or patterns to be used as masters for other prototyping methods, SLA can produce parts with complex geometries and excellent surface finishes as compared to other additive processes. The cost is very competitive and the technology is available from several sources.

Against: Prototype parts are much weaker than those made from engineering grade resins, so the parts made using SLA are typically unsuitable for functional testing. Also, since the resin is UV-curable, exposure to sunlight continues to cure the resin and parts can become brittle over time. While SLA can make parts with complex geometries, it gives no insight into the eventual manufacturability of the design. The liquid polymers can be very toxic.

SLS

Selective Laser Sintering

The SLS process uses a laser to build parts by sintering (fusing) powdered material layer by layer from the bottom up. SLS parts can be accurate and more durable than SLA parts, but the finish is relatively poor with a grainy or sandy feel. There is reduced strength between the fused particles, so the parts will tend to be weaker than machined or moulded parts made from the same resin. In addition, there are very few resins available in the powdered form that is required for SLS.



For: SLS Parts tend to be more accurate and durable than SLA parts. The process can make parts with complex geometries.

Against: The parts have a grainy or sandy texture and are typically not suitable for functional testing due to their reduced mechanical properties. While SLS can make parts with complex geometries, it gives no insight into the eventual manufacturability of the design.

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FDM

Fused Deposition Modelling

The FDM process builds parts from the bottom up through the use of a computer controlled print head. The feedstock for the process is a filament of extruded resin, which the machine selectively re-melts and deposits on the prior layer for each cross section of the desired part. The FDM process produces parts in ABS or PC, so they tend to be stronger than parts from other additive processes. However, the parts are sometimes porous and have a pronounced stair-stepping or rippling texture on the outside finish, especially at layer junctions. It may also be difficult to achieve tight tolerances with the process.

For: FDM parts are relatively strong and can be good for some functional testing. The process can make parts with complex geometries.



Against: The parts have a poor surface finish, with a pronounced rippled effect. It is also a slower additive process than SLA or SLS from the standpoint of build time. While FDM can make parts with complex geometries, it gives no insight into the eventual manufacturability of the design.

3DP

Three Dimensional Printing

3DP uses an inkjet head and a water fusible material similar to “Plaster of Paris”. The machine lays down a thin layer of plaster powder; the inkjet head passes over and sprays tiny drops of water wherever solidification is desired. While the parts are weak and rough, it is easy to incorporate colours into the finished object. This method is not recommended for functional testing because of the inherent weakness.

For: 3DP offers the fastest build time of any additive process, and is also among the least expensive options for prototype quantities. Coloured models can communicate more information and have aesthetic appeal. This plaster material is non-toxic, inexpensive and readily available. The process can make parts with complex geometries.



Against: Parts are rough and weak, and there are very few material options. While 3DP can make parts with complex geometries, it gives no insight into the eventual manufacturability of the design.

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Pjet

Poly-Jet

PJET uses inkjet heads to jet a UV-curable material in very thin layers at high resolution. The materials are jetted in ultra-thin layers onto a build tray, layer by layer, until the part is completed. Each photopolymer layer is cured by UV light immediately after it is jetted. The gel-like support material, which is specially designed to support complicated geometries, is easily removed by hand and water jetting. This method has the same shortcomings as SLA, but it can yield an even better surface finish.



For: This process yields a good surface finish; the best of the additive processes. It is the best additive choice for complex parts with undercuts. The process can make parts with complex geometries.

Against: PJET parts have poor strength (comparable to SLA). While PJET can make parts with complex geometries, it gives no insight into the eventual manufacturability of the design.

CNC

Computer Numerically Controlled (Machining)

A solid block of plastic is clamped into a CNC mill and cut into a finished part. This method produces superior strength and surface finish to any additive process. It also has the complete, homogenous properties of the plastic because it is made from solid blocks of extruded or compression moulded thermoplastic resin, as opposed to the additive processes which use “plastic like” materials and are built in layers. The wide range of material choices allows parts to be made with the desired material properties, such as: tensile strength, impact resistance, heat deflection temperatures, chemical resistance and biocompatibility.

Good tolerances yield parts suitable for fit and functional testing. Prototypes can be delivered in days like additive processes. Because the process is removing material instead of adding it, milling undercuts can sometimes be difficult. Machining also tends to be somewhat more expensive than the additive processes.



For: Machined parts have a good surface finish and they are very strong because they use real plastic resins or metals.

Against: There are some geometry limitations associated with CNC machining, and it is much more expensive to do this in-house than the additive processes due to the cost of the programmers and machinists needed to create CNC toolpaths and fixturing for the parts.

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RIM

Rapid Injection Moulding

Rapid Injection Moulding is done by injecting thermoplastic resins into a mould, just as is done in production injection moulding. What makes the process “rapid” is the technology used to produce the mould, which is often made from aluminum instead of the traditional steel used in production moulds. Moulded parts are strong and can have excellent finishes. It is also the industry standard production process for plastic parts, so there are inherent advantages to prototyping in the same process if the situation allows. Almost any engineering grade resin can be used, so the designer is not constrained by the material limitations of the prototyping process.

There is an initial tooling cost associated with RIM that does not occur with any of the additive processes or with CNC machining. So in most cases it makes sense to do one or two rounds of rapid prototypes (subtractive or additive) to check fit and function before moving to injection moulding.



For: Moulded parts are made from a wide array of engineering grade resins, have excellent surface finish and are an excellent predictor of manufacturability during the production phase.

Against: Front-end costs can be higher due to tooling costs.

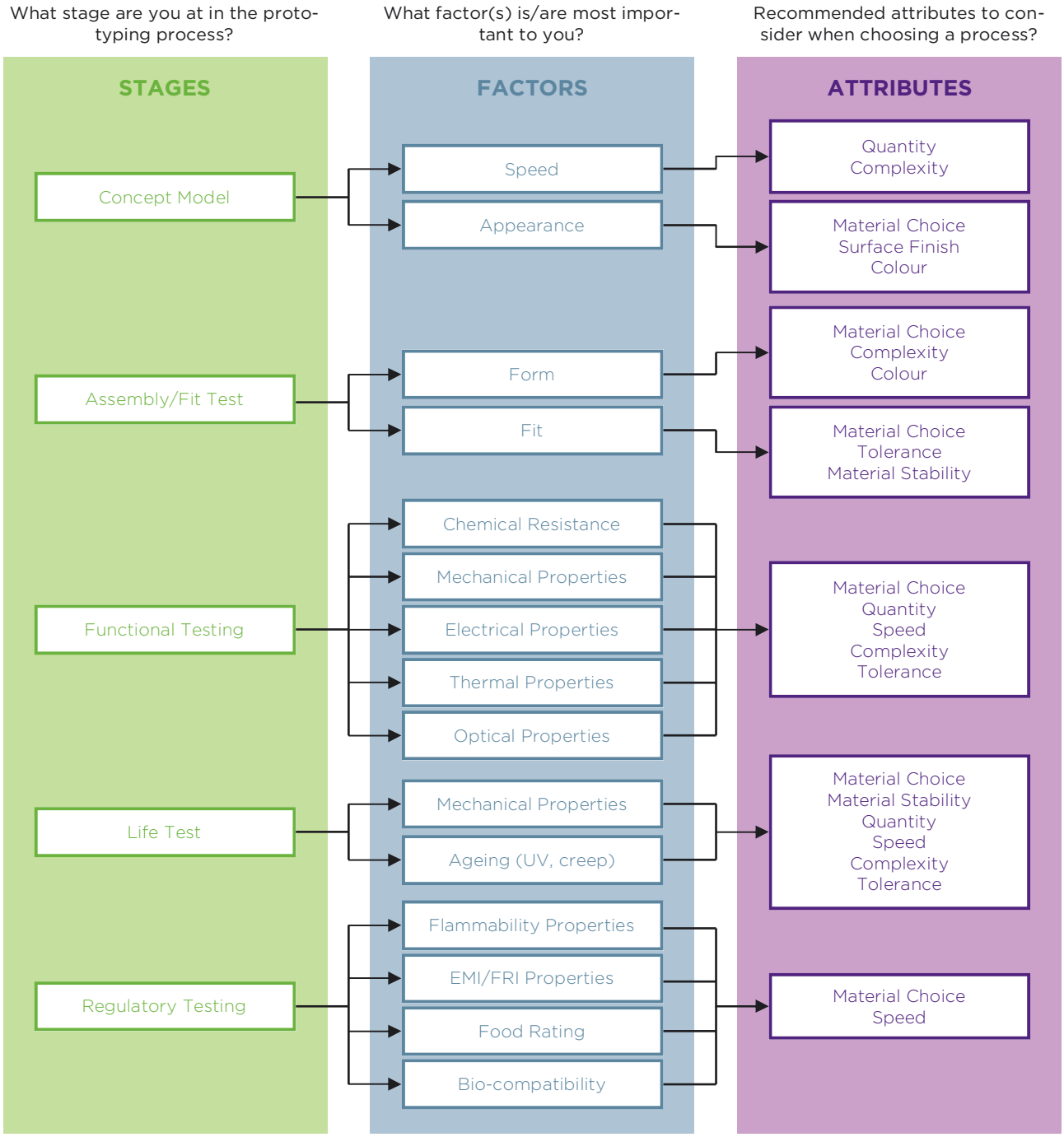
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Choosing a Process

Determine the process that is the best fit for your project by using the tools shown here.

Step 1: Begin by using the decision tree below to narrow down which factors are of the highest importance to you based on the stage you are at in the prototyping process, referring to the definitions on page 8 as needed.

Step 2: Based on the recommended attributes for your most important factor(s) from Step 1, compare the processes using the matrix on page 8 to determine which process will be the best fit for your project.



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Comparison of Prototype Attributes

ATTRIBUTE	SLA	SLS	FDM	3DP	Pjet	CNC	RIM
Quantity	⊖	⊖	⊖	⊖	⊖	○	⊕
Complexity	⊕	⊕	⊕	⊕	⊕	○	⊕
Surface Finish	○	○	⊖	⊖	○	⊕	⊕
Material Choice	○	⊖	⊖	⊖	⊖	○	⊕
Material Stability	⊖	○	⊕	⊖	⊖	⊕	⊕
Colour	⊖	⊖	○	⊕	⊖	⊖	⊕
Tolerance	⊖	⊖	⊖	⊖	⊖	⊕	⊕
Speed	⊕	⊕	⊕	⊕	⊕	⊕	○
Price - Low volume	⊕	⊕	⊕	⊕	⊕	○	⊖
Price - High volume	⊖	⊖	⊖	⊖	⊖	⊖	⊕

⊖ Poor ○ Fair ⊕ Good

Definitions

Definitions vary and may differ at different organisations but the definitions below may be used as a starting point.

Concept Model
A crude physical model made to demonstrate an idea. Concept models allow people from different functional areas to see the idea, stimulate thought and discussion, and drive acceptance or rejection.
Important prototyping attributes:
Speed – turnaround time to convert a computer file into a physical Prototype.
Appearance – any visual attribute – colour, texture, size, shape, etc.

Assembly/Fit Test
Making some or all of the parts of an assembly, putting them together, and seeing if they fit properly. At the gross level, this checks for design errors, such as placing two tabs at 2" spacing and the mating slots at 1" spacing. At the fine level, this is a matter of minor dimensional differences and tolerances. Obviously any test involving tolerances needs to use the actual manufacturing process or one which has similar tolerances.
Important prototyping attributes:
Form – the shape of the part – features and size.
Fit – how the part mates with other parts.

Functional Testing
Seeing how a part or assembly will function when subjected to stresses representing what it will see in its actual application.
Important prototyping attributes:
Chemical Resistance – resistance to chemicals including acids, bases, hydrocarbons, fuels, etc.
Mechanical Properties – strength of the part measured by tensile strength, compressive strength, flexural strength, impact strength, tear resistance, etc.
Electrical Properties – interaction of electrical fields and the part. This may include dielectric constant, dielectric strength, dissipation factor, surface and volume resistivity, static decay, etc.
Thermal Properties – Changes in mechanical properties that occur with changes in temperature. These may include thermal expansion coefficient, heat deflection temperature, vicat softening point, etc.
Optical – ability to transmit light. May include refractive index, transmittance and haze.

Life Test
Testing properties that may change with time and that are important for a product to remain functional throughout its expected life. Life testing often involves subjecting the product to extreme conditions (e.g. temperature, humidity, voltage, UV, etc) to estimate in a shorter period of time, how the product will react over its expected life.
Important prototyping attributes:
Mechanical Properties – fatigue strength – ability to withstand large numbers of load cycles at various stress levels.
Aging Properties (UV, creep) – ability to withstand exposure to ultraviolet light with an acceptable amount of degradation; ability to withstand extended applications of forces to the part with acceptable levels of permanent deflection.

Regulatory Testing
Testing specified by a regulatory or standards organization or agency to assure parts are suitable for a particular use such as medical, food service or consumer application. Examples include Underwriters Laboratory (UL), the Canadian Standards Association (CSA) the US Food and Drug Agency (FDA), the US Federal Communications Commission (FCC), the International Standard Organisation (ISO) and the European Commission (EC).
Important prototyping attributes:
Flammability Properties – the resistance of a resin or part to ignition in the presence of a flame.
EMI/RFI Properties – the ability of a resin, part or assembly to shield or block Electromagnetic Interference or Radio Frequency Interference.
Food Rating – approval of a resin or part to be used in applications where it will come in contact with food while it is being prepared, served or consumed.
Bio-compatibility – the ability of the resin or part to be in contact with human or animal bodies, outside or inside the body, without causing undue adverse effects (e.g. irritations, blood interactions, toxicity, etc). Bio-compatibility is important for surgical instruments and many medical devices.

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Summary

Prototype models help design teams make better informed decisions by obtaining invaluable data from the performance of, and the reaction to, the prototypes. The more data that is gathered at this stage of the product development cycle the better the chances of preventing potential product or manufacturing issues down the road. If a well thought out prototyping strategy is followed, there is a far greater chance that the product will be introduced to the market on time, be accepted, perform reliably and be profitable.

What is the best way to get a prototype made? As we hope you have learned from this white paper, the answer depends on where you are at in your process and what you are trying to accomplish. Early in the design process, when the ideas are flowing freely, concept models are very helpful. As the design progresses, a prototype that has the size, finish, colour, shape, strength, durability and material characteristics of the intended final product becomes increasingly important. Therefore, using the right prototyping process is critical. In order to most effectively validate your design, pay close attention to these three key elements of your design: functionality, manufacturability and viability.

If your prototype can faithfully represent the attributes of the end-product, it is by definition **functional.** These requirements often include such things as material properties (e.g. flame resistance), dimensional accuracy for fit-up with mating parts and cosmetic surface finishes for appearance.

If your prototype design can be repeatedly and economically produced in a manner that supports the requirements of the end-product, it is by definition **manufacturable.** These requirements include the ability to maintain the functionality of the design as described above, keep the piece -part cost below the required level, and support the production schedule. No matter how great a design is, it will go nowhere if it can't be manufactured. Make sure your prototyping process takes this into consideration.

Finally, even if your prototype design is functional and manufacturable, it doesn't mean anyone will want to use it. Prototypes are the only true way to verify the **viability** of the design in this sense. If your design can also pass the challenges associated with market trials (e.g. trade show displays, usability testing) and regulatory testing (e.g. EU testing of medical devices), you're well on your way to a successful product launch.

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Notes

About Proto Labs

Proto Labs utilises proprietary computing technologies and automated manufacturing systems to provide prototype parts and short-run production services. Our interactive, web-based Protomold® service provides real injection-moulded parts from a 3D CAD file in as little as one business day. Real CNC machined parts are available in a choice of over 30 different engineering resins and aluminium or brass in as little as one business day via our Firstcut® service. Learn more at www.protomold.co.uk and www.firstcut.eu.gb

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