# e-Manufacturing – Making Mass Customization real by Laser-Sintering

C. M. Stotko; H. Dirrigl

EOS GmbH – Electro Optical Systems

E-mail : christof.stotko@eos.info Tel : +49 89 89336-0

www.eos.info

**Abstract**

e-Manufacturing™ means the fast, flexible and cost effective production directly from 3D CAD data files. Laser-sintering is a very efficient way of making e-Manufacturing reality, because the 3D CAD can directly be feed into a laser-sintering machine. This makes laser-sintering an extremely attractive mode of production for companies that highly customize their products. While the customer can design the desired product in an internet-based tool-kit or configurator, the company can take the electronic data directly to the laser-sintering system where the individual product is build in a cost effective manner. This makes laser-sintering the ideal mode of production in a mass customization business environment.

Keywords: e-Manufacturing, Laser-Sintering, Mass Customization, Personalization, one-off production

## 1 INTRODUCTION

The requirements that result from a paradigm shift from mass production to one-off production are twofold:

1. First, you need to better know than your competitor what customers want and to what extent they are willing to pay for.
2. You need to transfer this knowledge into physical products and services to offer.

This results in the ability to offer individualized products and services in the sense of mass customization. [1, 2] This both requires restructuring efforts in sales and manufacturing.[3] While the efforts in sales focus around minimizing the customer perceived uncertainty and risk when acquiring customized products, research in manufacturing revolves around the issue of producing customized products at costs comparable to series production. In this paper we will investigate what contribution e-Manufacturing by laser-sintering can make to the aspects of producing customized products. [4]

As a rule of thumb we can claim that e-Manufacturing has a good chance of unleashing its potential if ...

- the customer demands a high number of varieties which culminates in the extreme in the demand for one-off products.
- demanded products are of high complexity.
- customer demand is subject to sudden and unpredictable change.
- product life-cycles ever shorten.
- the sheer number of identical products sold is low.

This always is the case in a mass customization environment. The result of e-Manufacturing activities can either be direct customized parts or tools and casts that support conventional manufacturing processes.

In the following we will give a short overview of what laser-sintering is. Then we will give several examples of successful laser-sintering implementations in a small series environment. All these case-studies have been implemented on EOSINT equipment. The initiators of theses case-studies were either EOS, independent service bureaus, the end customers or a consortium consisting of these parties. Finally we will summarize the reasons why laser-sintering is the method of choice for manufacturing in a mass customization environment.

## 2 LASER-SINTERING BASICS

### 2.1 Laser-sintering working principle

Shortly after its introduction in the early 90s laser-sintering had proven to be a successful tool in product development. [5] As a technical solution to the Rapid Prototyping concept it helps to significantly reduce the time to market by supplying fully functional prototypes, molds or forms within days based on a 3D CAD description. Improvements of the technology and the increasing knowledge about it have enlarged the application fields in many ways. Today laser-sintering is the key technology for e-Manufacturing, the fast, flexible and cost effective production directly from 3D CAD data files.

Laser-sintering is a layer manufacturing technology. Prerequisite for its use is the availability of 3 D data of the object one intends to build. When mass customizing, this data is easily available at the outset of a tool-kit. The three dimensional description is then converted into a set of slices that each describes a cross section of the part in a defined height. In state-of-the art EOSINT P systems this height typically is 0,1 mm. The laser-sintering machine now builds up theses slices layer by layer to create the desired object. In each layer the powder is fused using laser energy. With the help of a scanner the laser energy is "printed" onto the powder layer and by this creates a solidified layer that later will be part of the finished product. The next layer is then produced on top of the first and so on until the build is complete. Figure 1 illustrates the repeating process of building a layer.

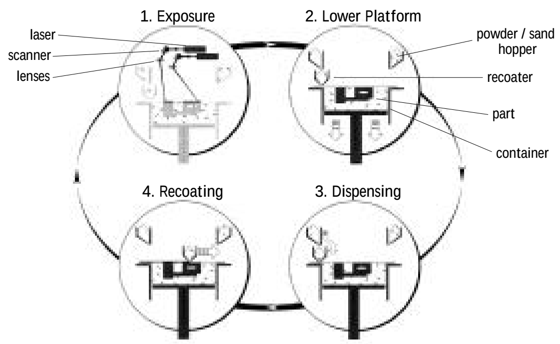



Figure 1: Working Principle of Laser-Sintering

The process takes around one hour to build between 15 and 25 mm of in height. Although this seems rather slow at first sight, it has to be taken into account that with laser-sintering you are not building one single product at a time but filling the entire building space with products to build. EOS provides adequate software with its systems that assist the customer optimizing the fill rate of their building envelopes. Later in this paper you will find examples of how a building envelope can be packed to the brim in order to maximize efficiency in a laser-sintering system. Taking the phone cradles in figure 6 as an example, you can calculate that while the entire build process takes about 30 hours, the individual product only takes around 15 minutes to produce (of course this holds only true in calculation, since you can not interrupt the process for taking out single products before the entire job is finished).

In the end, you have the solidified products embedded in the powder that was not solidified. This powder partly can be reused in the next run. In a sieving station you separate the solidified products from the unsolidified powder remnants. In a glove-box the parts are cleaned from adhesive powder remnants by compressed air carrying small glass peens. Then the products are already in a state ready to sell. If a special treatment to the surface was necessary, several post processes are available polishing the surface to almost any quality necessary in order to satisfy customer needs.

Limitations in using laser-sintering are caused by lack of imagination. In order to exploit the technology it has to be identified as a potential solution. This is the case in mass customization that can be made real by laser-sintering.

From a quantity point of view typical break even points between the laser-sintering process and traditional tool based processes are between 10 and 50 liters build volume of identical parts for plastic. If parts are small like plugs or fixtures this can mean up to 10,000 parts, if parts are bigger, like the later mentioned sunglass, this can mean 300 – 400 parts. For metal this number is somewhat lower. In any case it is important to remember that the prerequisite of reaping upon economies-of-scale by maximizing the output of identical parts is not necessary. Laser-sintering has the same economic properties dependent on the filling rate of the building envelope but independent on the shape and size of the products built. This is ideal for mass customization because heavy up-front investment in tooling is not necessary and variable costs only depend on the solidified volume a product consumes in the building envelope of an EOSINT system.

### 2.2 Laser-sintering Materials

An important success factor for producing end-use parts with laser-sintering are the material properties. Over the years both the plastic and metal materials have been significantly improved so that, for example, parts built in today's PA 2200 polyamide material have mechanical properties comparable to and in some cases better than injection molded PA12 or ABS. Glass- and aluminum-filled versions are available which offer significantly higher stiffness and better thermal properties, and further fillers are being investigated to further extend the range of properties. Some applications require very specific properties or certification, for example many medical and aerospace applications. Some laser-sintering plastics have already been certified as biocompatible for long-term skin contact, and also a flame-retardant polyamide is available at EOS.

Using the polyamide (nylon) material in the plastic laser-sintering process the typical tensile strength ranges from 40 MPa to 50 MPa with Young's modulus between 1,700 MPa and 3,500 MPa with the help of fillers. Direct metal laser-sintered parts can achieve tensile strength above 1.000 MPa. Metal parts in the latest tool steel material, called DirectSteel H20, can have a tensile strength of up to 1,100 MPa and a hardness of more than 40 Rockwell C. At the same time the accuracy and surface finish of the parts has been greatly improved. For example, the introduction in 1999 of fine metal powders for building Direct Metal Laser-Sintering (DMLS®) parts in 20 micron layer thickness represented a real breakthrough for this application. Additional metal materials are being developed at EOS particularly with a view to direct manufacture of end-use parts, including stainless steel, cobalt chrome alloys and titanium alloys.

### 2.3 Laser Sintering for Mass Customization

Unique with laser sintering is the fact that one can directly use a material that offers the mechanical properties that are finally needed. The powder materials available today offer the possibility to manufacture parts that behave like "normal parts" manufactured with technology used so far like milling or injection molding.

The fact that parts are built up in layers offers additional possibilities - a new freedom of design. "Impossible parts" can be manufactured because undercuts or internal structures can be produced without difficulties. If one builds a part in layers you have always access to every area within a layer. The undercut develops during the build and therefore is not a problem but an opportunity.

Important for mass customization is the fact that all information necessary to build a part is the 3 dimensional data of the part. The control information for the machine is automatically derived from the 3D data. Laser-sintering is fully "IT" compatible and therefore can directly be linked into the mass customization process chain as what has been described as an appropriate set of manufacturing technologies. [6] This is true in its use for the production of end use parts as well as for the manufacture of tools, molds or dies facilitating the manufacturing process.

## 3 CUSTOMIZED PLASTIC PARTS

### 3.1 e-Manufacturing of direct plastic parts

*Sunglasses*

Sunglasses are a prime example for a product that can be offered as a mass customized product. The demand for sunglasses is very much subject to current trends and fashion styles. This makes it very hard for sunglass manufacturers to predict a plausible forecast for next years sales. If the manufacturer overestimates demand this might result in excessive stocking costs and heavy discounts to make the overstocked products sell. However, the other extreme, the underestimation of future demand, isn't any better. The inability to offer customers what they want results in lost sales. This dilemma calls for a production method that easily can adapt to both a change in fashion trends and in demanded quantity. Laser-sintering can be such a method as shown in this case study.

Figure 2: Laser-sintered sunglasses (Tecnologia & Design, Crabbi Sunliving, EOS)

Implementing e-Manufacturing also can open new ways in sales. In this case it very much could be possible that the customer enters a kind of "mini-factory" where the customer could design individual sunglasses at a suitable "tool-kit" providing support in doing so. Once the design efforts result in sunglasses the customer will be happy to buy, the created 3D data is directly transferred to a EOSINT system where the sunglasses are built. In order to transfer the crude sintered part to a posh fashion product it still has to undergo a AutoFinish process that results in sunglasses as shown in Figure 2.

*Hearing aids*

Another industry that highly customizes its products are hearing aids. Since the success of hearing aids very much depends on its ability to adapt to the anatomy of the auditory canal. Figure 2 illustrates a hearing-aid with a laser-sintered shell.

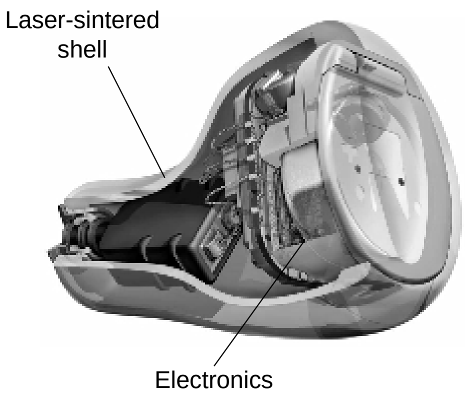



Figure 2: Laser-sintered Hearing aid (Phonak)

The process of e-Manufacturing a hearing aid is as following:

1. Take a copy of the auditory canal anatomy by creating a wax cast.
2. Scan the wax cast with a to create 3D data.
3. Integrate an identification number in the 3D data that helps identify the product after the laser-sintering process.
4. Laser-sinter the shell.
5. Combine the laser-sintered shell with the electronics components.

It is important to note that each of the laser-sintered shell is a one-off not only carrying the customer specific geometry but also the serial number used in the follow-up process matching each shell with the right customer.

In the building envelope of a "small" P 385 you can build between 60 and 120 of these shells. Since the height of these shells is comparable low (ca. 30 mm) you can empty the building envelope after building one layer of shells. This calculates to approx. 30 to 60 shells per hour. This easily adds up to 60,000 shells you can produce per year on an EOSINT systems.

*Skiboot Buckles*

Figure 3 illustrates the result of a laser-sintered and auto finished skiboot buckle that was painted in the last process steps (the iron rod was not laser-sintered).

Figure 3: Laser-sintered skiboot buckles (Tecnologia & Design)

Whether skiboot buckles, inline skaters, ice-hockey boots or any other trendy sports shoe, the buckle can become a vital part in determining both individual fit and aesthetic preferences. The major benefit of e-Manufacturing buckles like these with laser-sintering equipment is in a significantly reduced time-to-market. Because of omitting tooling that is necessary in traditional manufacturing (e. g. blowmolding) the entire manufacturing process is sped up. Figure 4 illustrates the time saving effects of up to 58 % in this example.

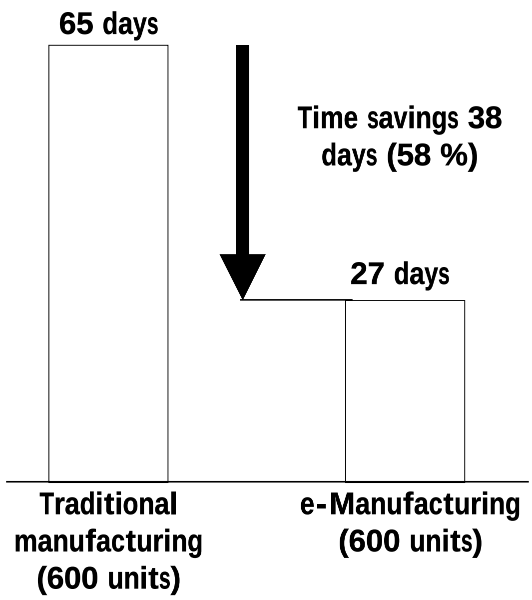
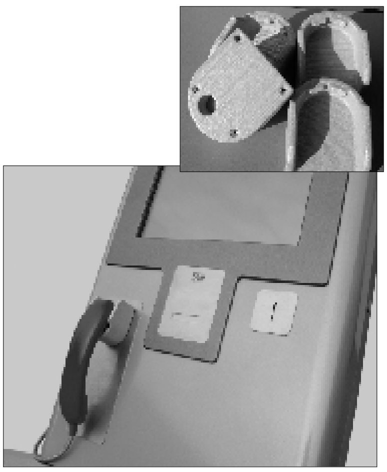



Figure 4: Comparing time-to-market of a laser-sintered skiboot buckle with traditional manufacturing methods

A T&D research program in 2004 on this particular product indicates that laser-sintering leads blowmolding from an economic point of view up to 630 units. [7] Many consumer goods will not exceed this number of units, making e-Manufacturing with laser-sintering the manufacturing method of choice when it comes to small series. This especially holds true if you consider that each part produced by laser-sintering can be a one-off at no extra costs.

*Public phone cradle*

Leaving consumer goods, e-Manufacturing can be even more valuable for certain B2B applications. A very good example is the e-Manufacturing case of Model Shop Vienna, using laser-sintering technology to laser-sinter a cradle for a public phone receiver in Austria. The following figure illustrates this application.



MODEL SHOP VIENNA TELE KOM AUS TRIA

Figure 5: Laser-sintered public phone cradle

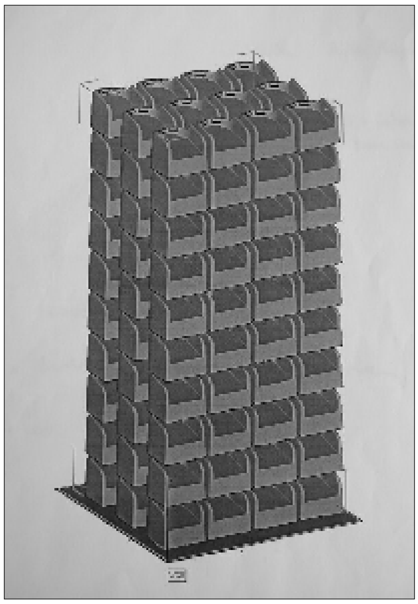


Figure 6: Fitting 120 cradles into an EOSINT P 380 building envelope (Model Shop Vienna)

The issue for Model Shop Vienna was to produce a lot size of 250 of the described cradles. Since this lot size is quite limited conventional manufacturing methods were not suitable, if not prohibitive. Heavy investments in tooling would have increased cost per unit dramatically. On top, once tooling was fixed design changes would be impossible. Since Model Shop Vienna could not say for sure how many units of this cradle they would have to build, they decided to go for laser-sintering with Alumide$^{TM}$. On the one hand this material combines all the properties the customer Telekom Austria demanded (metallic appearance, high stiffness etc.). On the other hand laser-sintering made Model Shop Vienna flexible to unpredictable design changes the customer might want to add in a second order. Since laser-sintering results in a linear cost curve Model Shop Vienna did not have to calculate the break-even-point where the heavy investments in tooling would pay off. Model Shop Vienna estimates that laser-sintering leads the costs compared to conventional manufacturing up to 500 identical pieces. If it was necessary to customize each and every one of the cradles (e. g. adding position information of the phone cell to the cradle for customer orientation) there is no alternative to laser-sintering.

### 3.2 e-Manufacturing of tools for plastic parts

*Hammtronic Joystick "HI-Drive"*

The way e-Manufacturing by laser-sintering helped implement this product was not by laser-sintering the joystick itself, but laser-sintering the tools required for injection molding the required parts. With a lot size of ca. 5,000 the advantages of e-Manufacturing were not in laser-sintering the components itself but in laser-sintering the metal tools for injection molding these components. Figure 7 illustrates some of these inserts.

Figure 7: Some of the insert geometries laser-sintered on EOSINT M (Fruth Innovative Technologien – FIT)

The major value add in e-Manufacturing these inserts with laser-sintering was in a dramatically reduced time to market.

*Rubber boots*

A very interesting example showing the potential of direct tooling in plastics laser-sintering is the injection molding of a rubber boot sole as illustrated in figure 8. [8]

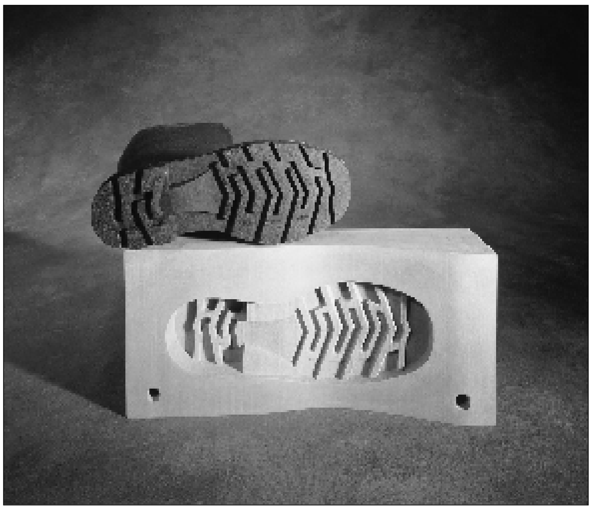


Figure 8: DirectTool injection mold and resulting rubber boot sole (Tecnologia & Design)

The advantages of employing laser-sintering in this case mainly is the reduced time-to-market. Following the mantra of e-Manufacturing this means the direct way from 3D CAD data to a tool featuring the sole of the rubber boot or any other trendy shoe. Using EOS Alumide further has the advantage that it can be used as a proper tool that can be fixed to the injection molding machine as it is. This is mainly because of the material properties resembling that of metal. This also results in a tool endurance that is sufficient for producing several hundred shots of shoe soles. This number is very well sufficient in trendy markets like fashion shoes where design aspects are integrated into a trendy sole design. Laser-sintering the tooling for this kind of shoes can help this industry adapt sole design to sudden changes in customer preferences. Of course such a tool also would be suitable for integrating customer specific items such as the name of the shoe's owner.

## 4 CUSTOMIZED METAL PARTS

### 4.1 e-Manufacturing of direct metal parts

*Dental camera*

A good example for a metal part directly laser-sintered from 3D CAD data is the Planmeca dental camera as illustrated in figure 9.

Figure 9: Dental camera (Planmeca)

The market for dental cameras is on the one hand relatively small and on the other can offer substantial value add by customizing to the anatomy of a dentist's hands. This makes the customized manufacturing of dental cameras as one-offs feasible from an economic point of view. By doing so, manufacturers of such equipment can both address new markets by offering customization and gain an image boost by leveraging innovative technology.

*Computer locks*

The requirement in this case study was the production of 300 sets of computer locking parts, each comprising the assembly of 3 components as illustrated in figure 10:

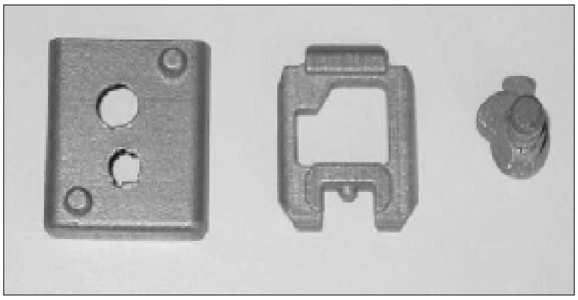


Figure 10: Computer lock: the three laser-sintered assembly components (Rapid Product innovations)

The solution in this case was a DirectPart solution on an EOSINT M system as direct metal laser-sintering (DMLS). The required 300 sets were built in 5 jobs, 60 sets per job. The built time per job was 32 hours. This means that the required 300 sets were built in approximately 7 days. Although the time requirement of 7 days seems long on first sight it has to be considered that the first 60 sets were built immediately after the 3D CAD design phase was over. With a conventional method of manufacturing the design phase of required tools would easily have consumed these 7 days. On top with laser-sintering each component can be a one-off customized to specific customer needs at no extra costs.

### 4.2 e-Manufacturing of patterns/casts for metal parts

*Hydraulic valve for rail vehicle*

When designing a new hydraulic valve for a rail vehicle EOSINT customer ACTech was approached. The initial goal was to manufacture two prototypes to see whether the valve-design was sufficient. The product is illustrated in the following figure.

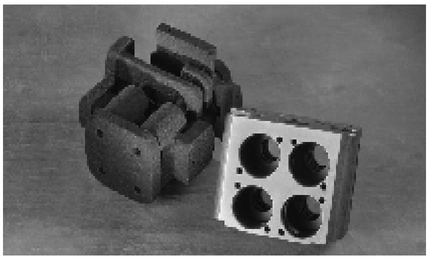


Figure 11: Laser-sintered sand core and end-product (ACTech)

To produce these prototypes ACTech laser-sintered the cores on a EOSINT S system. These cores were used in a follow-on casting process. The unconventional way of producing cores however, had the positive side effect that the mold draft was not necessary anymore. This had the effect that the switching properties of the prototype valve exceeded expectations that far, that the rail car company insisted to produce the entire batch size of 200 with laser-sintered sand cores. Rail-car industry also is an industry that very much relies on its ability to adapt to specific customer demands. This makes it an ideal environment employing laser-sintering.

*Racing gearbox*

Many interesting examples for e-Manufacturing stem from the racing industry, helmed by formula one racing teams. This not only is because of an abundance of money but also because of an inherent drive for innovation that can give the lead of the tenth of a second missing to win the race.

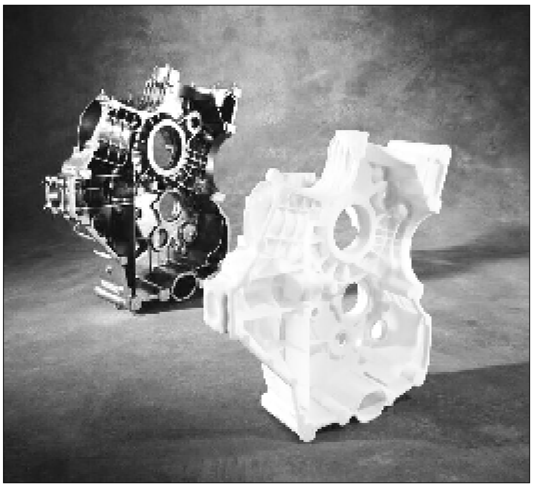


Figure 12: Laser-sintered PrimeCast sacrificed model and final gear box (Poggipolini)

The example presented here for a DirectPattern® application was the need to produce a newly designed motor cycle gear box in titanium. Figure 12 shows both the sacrificed model laser-sintered as a DirectPattern on an EOSINT P system using EOS PrimeCast® 100 and the final titanium cast product.

In this application the DirectPattern was used as a sacrificed model in investment casting. The entire process was that fast that the originator Poggipolini Titanium coined the term “Racing parts in racing speed”. DirectPatterns applications can also be very suitable for making mass customization reality. Just think of integrating the name of a motor-cycle owner into the engine.

## 5 E-MANUFACTURING IN A BRIEF

This paper showed that e-Manufacturing with laser-sintering can be a viable solution in a plethora of industries. It is important to stress that this not only holds true in a rapid prototyping environment but especially in a series production environment of complex products that are offered in a high number of varieties. This holds especially true for mass customization. e-Manufacturing gains the most impact in those cases were end-products can be manufactured with laser-sintering technologies either in plastics or in metal. By eliminating time and cost consuming detours through tooling processes laser-sintering end-products can very much help certain industries gaining a competitive edge over competitors.

Still the other major application of laser-sintering as a DirectTool®, DirectPattern® or DirectCast® application is a very interesting solution in such cases where conventional methods such as injection molding are the preferred way to produce (e. g. because of the end product material). As the case studies above showed, laser-sintering can help boosting the economic aspects by providing fast access to adequate tools. This aspect even gains momentum if the required tools are of great complexity thus leveraging the effect of laser-sintering and e-Manufacturing. As the example of the Hammtronic joystick proved, producing tools by laser-sintering helps save precious time in the development process.

To sum up we can conclude that laser-sintering not only is a viable tool for rapid prototyping but increasingly becomes the manufacturing method of choice in industries that face a high number of varieties of complex products. This is especially true for industries that mass customize their products. That is why laser-sintering eventually makes mass customization reality.

[1] Piller, F. T., Stotko, C. M., 2002, Mass Customization: Four Approaches to Deliver Customisation Products and Services with Mass Production Efficiency, IEEE International Engineering Management Conference. Managing Technology for the New Economy, August 18-20, 2002 St. John's College, Cambridge, UK, Vol. II, pp. 773-778.

[2] Piller, F. T., Möslein, K.; Stotko, C. M., 2004, Does mass customization pay? An economical framework to evaluate customer integration, Production Planning & Control. The Management of Operations, Vol. 15, issue. 4, 2004, pp. 435-444.

[3] Stotko, C. M., 2005, Vertriebseffizienz durch Kundenintegration. Empirische Untersuchung am Beispiel deutscher Hersteller von Werkzeugmaschinen, Wiesbaden.

[4] EOS, EOSINT, DirectPart, DirectTool, DirectPattern, DirectCast, DirectSteel, DirectMetal, DMLS, PrimeCast, PrimePart, Alumide, Autofinish, and e-Manufacturing are registered trademarks of EOS – Electro Optical Systems GmbH, Krailling, Germany (also see www.e-manufacturing.biz).

[5] Junior, V. ; Shellabear, M., 2003, Enabling Mass Customisation Through Laser Sintering. From R&D to Manufacturing, World Congress on Mass Customization and Personalization, München.

[6] Bullinger, H.-J et al., 2003, Towards the Extended User Oriented Shoe Enterprise, Tseng, M. M., Piller, F. T. (eds.), The Customer Centric Enterprise: Advances in Mass Customization and Personalization, New York, Berlin, p. 451-464.

[7] Tecnologia & Design; Veneto Innovazione: Progetto di ricerca.Rapid Manufacturing per la produzione di nuovi prodotti, p. 50 (http://www.tecnologiadesign.it).

[8] Tecnologia & Design 2004: Time compression per la calzatura sportiva con technice di reverse engineering e rapid tooling.