Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

3D Printing at the Highest Quality in a Home Environment

Gábor Krupa
Gábor Dénes College, Budapest, Hungary
krups.hun@gmail.com

Abstract – Owing to a quick development in 3D printing technologies nowadays we are able to produce fully functioning and flexible items in our home, meeting the highest expectations of all kind, which can be used in any domain and field of industry. With minimal geometrical restrictions, being 25 µm at most, we can print functioning component parts, flexible and lasting models, even dental elements which meet the highest medical and hygienic requirements. The term 3D printing used to be an equivalent for prototype production and making unique elements, but in the near past we could witness the start of a progress in which the shift of focus from prototypes to mass production could be detected.

This writing is going to focus on 3D printing at home utilizing stereolithography method, then going to shed light on the ongoing technological developments and those of the near past, in addition to that, newly opened possibilities lacking the need to have an industrial background: materials available and possible products of using a 3D printer at home.

In order to have a deeper insight of this matter I am going to present this topic through my personal projects, utilizing SLA printing method, highlighting the particularity, advantages and home printing possibilities of the method.

At last, I am going to reflect on the developmental directions of SLA printing, highlighting the determining possibilities of the future of 3D printing in automation processes.

Keywords: 3D printing, 3D printing at home, stereolithography, high quality

I. Introduction

Four years ago, marking the beginning of my fascination with additive industrial technologies, I was truly satisfied with my achievements in 3D printing of a component part designed and produced at home by myself. Reaching for the perfect surface quality of the piece was not a top requirement at the time, since the joy of producing my very own designs was bliss itself. The quality and design of the producible model was strongly defined by the narrow field of base materials and –the only available material for me at the time – the geometrical restrictions of the FDM technology. However, innovation in the field of 3D printing was in a swift advance.

Owing to the technological advancement, there has been an ongoing progress as a result of which we are able to 3D print elements and components in our studies or workshops that meet the highest expectations and can be used in any part of the industrial domain. With minimal geometrical restrictions, being 25 µm at most, we can print functioning component parts, flexible and lasting models, even dental elements which meet the highest medical and hygienic requirements. The term 3D printing used to be an equivalent for prototype production and making unique elements, but in the near past we could witness the start of a progress in which the shift of focus from prototypes to mass production could be detected.

In my presentation I am going to highlight the possibilities of 3D printing along with the base materials in reach and the results of home manufacturing in the past few years and their constant change. Following that I am going to present the most modern 3D printer which utilizes SLA methods and its probable usage, highlighting liquid base elements that are the easiest to use all along with the quality, features and characteristics of models made out of these materials. Later on I present further usage of the process, respectively in regard of engineering, dental and jeweller field, with additional and supplementary equipment and follow-up treatment.

I am going to reflect on the characteristics of SLA with the help of printing projects, highlighting the possible disadvantages, software preparations, orientation of the model, producing proper underpins and choosing the appropriate resolution apart from the many advantages of the method. By this we can have a deeper insight of the process itself.

At last I hope to shed light on the developmental directions of SLA system, pointing out the automation which determines the future of 3D printing.

II. First Phase of 3D Printing at Home

Although the beginning of 3D printing is marked by the invention of stereolithography in 1986 [1], FDM[1] printers were the pioneers of 3D printing, concerning home environment. The reasons for this were firstly the simplicity of the working method and mechanism – on figure 1 – secondly the expiry date of the patents.

The spread of 3D printing was based and initialized by the RepRap[2] movement, in which engineers from the

[1] FDM: Fused Deposition Modelling.

[2] RepRap: Replication Rapid Prototyper, a printer being able to replicate its own component parts.

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

University of Bath in England endeavoured to design a low-budget 3D printer which is able reproduce its own main parts if needed. [2] This technology was open for anybody, concerning the software and blueprints of it, which eventually lead to the wide scale spread of 3D printing.

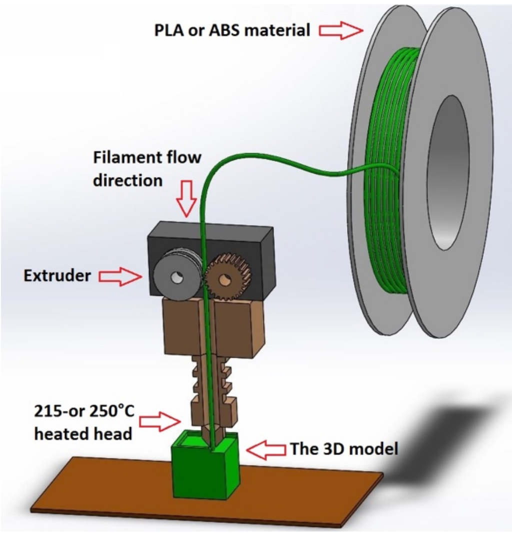

Figure 1: Working mechanism of an FDM 3D printer

RepRap systems made it available for everybody to use highly developed FDM systems at home, with which we can produce the needed parts of required quality without any technical knowledge, thus the emphasis has been shifted from making the mechanism and DIY work to real production.

By 2018 FDM printer manufacturers reaching for the small industrial sector has overcome the difficulties of their own printers, making it possible for everybody and anybody to buy device -without investing millions into the project-, that can fulfil any kind of expectations and needs. Hungary is a pioneer of this branch: a Hungarian 3D printer developer and manufacturer, called CraftUnique, designed a new device, named CraftBot 3, with two separate heads with a big printing bed. This device is easy to use through a touch screen and software, with which we can connect to computers. Moreover, any kind of 3D printing material can be used in the printing process, meaning that owners of such devices are relieved from using the company's own printing filaments[3] in the process.

The sophisticated appearance of CraftBot 3 is shown in figure 2. The ability to work on 300C° widens the range of possible printing materials; the two separate heads make it possible to use solvent support elements/materials, thus producing items of better quality or two separate items at the same time. All-inclusive warranty and service lifts weight of handling possible malfunction off the shoulders of users and a built-in system checks and monitors the base material in avoidance of producing less waste products [3][4].

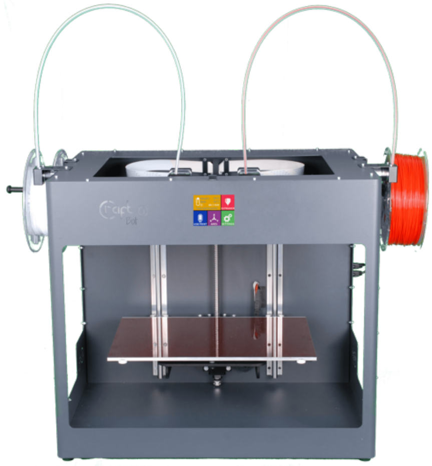

Figure 2: CraftUnique CraftBot 3 3D printer

FDM systems have reached a level of development which was considered utopian a couple of years ago. Well detailed models, the ability to produce the main components parts, more and more sophisticated technical solutions and built-in systems, tasked with monitoring and controlling productions show the level of development of this technology.

Despite these achievements models and basically the whole industry built upon FDM method are restricted by some barriers, which cannot be overcome with nowadays technical development. Geometrical restrictions originating from layers built upon each other determine the range of printable models; terraced surfaces appear even in the case of finest resolution; the differing minimal height of layers is restricted and can only be used with certain forms; the range of usable base materials is set. Overcoming these obstacles was a must due to a change in production processes and users' needs, besides there was a need for designing a system, which can produce parts using the widest range of base materials and at the same time able to print µm precise elements with the smallest geometrical restrictions. These needs brought Formlabs Co. into life [5]. The company designed the SLA method Form 1 printer by the end of 2012 – on figure 3 – which can be operated without any industrial background, marking the beginning desktop SLA printers' revolution.

Figure 3: Formlabs Form 1 SLA printer

[3] Filament: A plastic thread having a strong resemblance to spaghetti. Base material of FDM and FFF 3D printers.

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

III. SLA TECHNOLOGY

Laser stereolithography (SLA, stereolothography) and 3D printing in general, is the invention of Charles W. Hull, an American citizen. In 1986 he designed the first SLA printer and patented the method itself [6][7]. The main idea of SLA is the polymerization of the base material through radiation, in other words, the originally liquid photopolymer is solidified as an effect of UV radiation, as shown in figure 4.

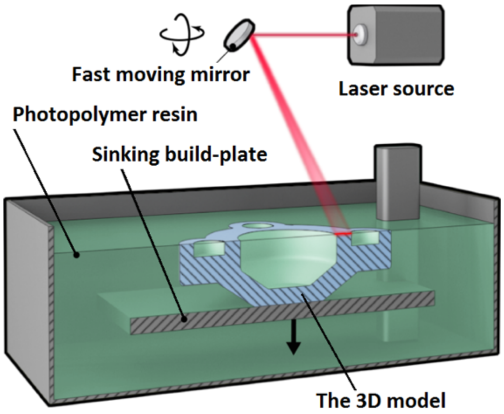

Figure 4: Working mechanism of laser stereolithogrphy

A vertically mobile bed is in the tank containing the liquid photosensitive resin. In the beginning of the printing process the bed is submerged one layer deep into the resin, the degree being 100-25 µm. A laser beam goes through the liquid material right above the bed in accordance with a pre-set programme/code/blueprint, solidifying and cross-lining the liquid material. Following it the bed lowers one layer deeper; a new layer of resin is placed upon the previous one and the computer operated laser goes through this new layer (binding them together) according to the digital model. This process continuous until the building of the product is finished layer by layer. At the end of the process the product is raised out of the tub (the place, where the printer works) and dried. The unnecessary pieces are removed from the model by a chemical bath. In most of the cases there is a need for a final drying in a Black-light unit; following that, supporting material[4] and supporting pieces are removed. If further improvement is needed due to still not perfect surface quality sanding is applied [1][7].

Out of the existing 3D printing methods SLA provides with the highest available resolution of products (in some cases the degree is 6 µm) and surface quality. Layers of base materials on models produced with this method are not perceptible to the eye; any kind of geometrical form and shape is available. Owing to the different kinds of base materials, which can be used in the process, the characteristics of finished products vary in wide range. Highly flexible rubberlike elements can be produced all along solid and resistant ones. Items, being resistant to 300C°, can as well be produced as tools and models used in healthcare, which meet high expectation standards.

SLA is without any question the most versatile 3D printing method of all, although its price was the highest of all of those until the recent past. Operating such equipments requires a large amount of money as well as expertise; moreover, base materials were very expensive. By the end of 2012 SLA had been only available for wealthy companies. This tendency changed by Formlabs.

IV. STEREOLITHOGRAPHY IN THE LIVING ROOM

Realizing the disadvantages and barriers of SLA printers and possibilities in high quality additive production, students of the MIT established Formlabs Co. in 2011 with the help of investors. Their aim was to design such an SLA printer, that is easy to use; is able to 3D print and models without compromises, remaining affordable for small companies, home users and educational institutions as well.

Aiming to build the machine a campaign, called Kisckstarter[5], was initialized and became one of the most successful of them of all times, grossing over 2.95 million USD, resulting in the birth of the world's first desktop SLA 3D printer, Form 1. Initial success were followed by many later in time, as users of the machine gave feedback on the product, thus in 2014 a renewed version of Form 1 released. It was the Form 1+. Although having better specification and performance than its predecessor, due to the lack of a mechanical closed system there was a need to regularly, meaning every few weeks, disassemble and clear/dust the sensitive, fragile mirrors. In 2015 the production of this third generation of this printer, Form 2, was initialized. Figure 5 shows Form 2. It is the most successful SLA printer up to date, lacking any kind of problems and flaws [5].

Figure 5: Formlabs Form 2 3D printer

As opposed to FDM or any other methods, Formlabs machines use isotropic[6] binding between layers, resulting in terms of smoother surface features. Form 2, being able to use high deegre exactitude in stereolithography, marks out from the market of 3D printers with it price-value proportion and its easy usability. Prior to the appearance of Formlabs family the price of a reliable, SLA operational 3D printer was at least 10 million HUF, but nowadays they can be purchased for a little more than 1 million HUF. Low procurement prices and easy operation of

[4] Support: Columns the purpose of which is to underpin the model and connect it to the bed; made of the same material as the printed model.

[5] Kickstarter: Publicly financed company of American origin, the aim of which is to help realizing creative ideas

[6] Isotropic: independent of dimensional directions.

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

Form 2 provide access to digital production even for the smallest industrial units [8].

I have been paying close attention to the market of 3D printers. I have followed numerous Kickstarter campaigns, cheering for the creative engineers and creative designers to fulfil their projects. I witnessed the appearance of Form 1, having faith, that one day I will have the opportunity to acquire a SLA printer. Form 2 has been available in Hungary since 2016. Ever since the first day of selling this type I have been thriving to get my own unit. I could come over these desires in the autumn of 2017, when an opportunity through the Ministry of Human Resource made it possible for me to do so, collecting a scholarship and financial support. Owing to this I could buy my very first SLA printer.

The title of this chapter is not metaphorical, since I do have my own SLA printer in my living room, where it stands by and can be operated without any difficulties or technical knowledge. Ever since its first start-up – I have been using it for half a year now – I have come over some reliable information about how it really works.

One of the greatest advantages abreast to the previously mentioned one is the fact that its component parts can easily and fast be modulated, replaced. In the case of Form 1 and Form1+ the resin had to be refilled manually, when it came to service, but with Form 2 it is much simpler, only because all you have to do is connect the cassette/tank containing the resin into its place in the machine. During the process of printing resin is loaded into a resin tank[7] without having any interaction with component parts of the printer. If we would like to change the base material of the process, we simply remove the cassette and the resin tank in order to be replaced with the new units required by the new printing process. At the same time we do not need to clean the system. The bed itself – where the model is built- is removable as well, so a totally new project can be initiated through a couple of easy steps.

A. A. The Structure of the Printer

Figure 6. shows the structure of the printer itself.

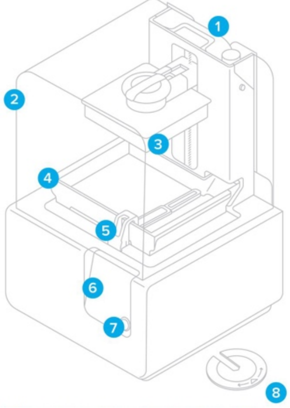

Figure 6: Form 2 printer components

[7] Resin Tank: A tank with a very thin layer of coating containing resin. The laser beam irradiates the resin inside making it cross-linked, connecting it to the bed.

The replaceable cassette (1), the bed (2), the resin tank (3) and the unit, which is responsible for smoothing the resin layer, (5) can be disassembled and replaced with one single step/movement in order for the printing process to be continued easily and without any stops. A housing element (2) protects the resin from black-light radiation and consequently solidification, the touch-screen (6) provides the comfortable handling, printing process can be initialized with the only manual switch (7) on hte printer and with the help of the calibrating device (8) the printer can be set horizontally.

B. B. Working Mechanism of the Printer

The mechanism of the printer is shown in figure 7. A previously designed model with support elements, made in PreForm software, is uploaded into the unit's memory through WiFi or USB connection. After initializing the printing process the systems starts to fill the resin tank with base material from the cassette element. While printing the level of the resin is constantly monitored, refill is automated. The smoothing element makes mixing movement from each side to the other in order to eliminate any air bubbles in the resin and to provide the process with the best liquid quality.

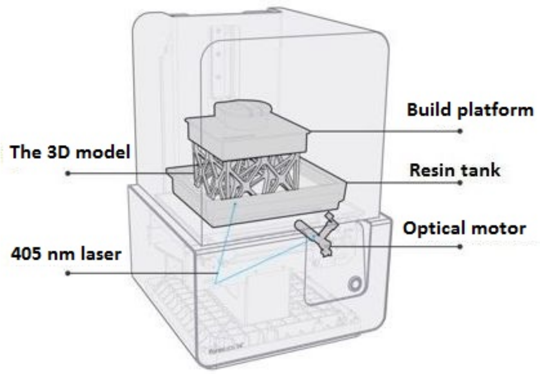

Figure 7: Working method of a Form 2 3D printer

As soon as the resin reached the optimal temperature, the bed lowers into the resin according to a pre-set degree (25, 50 or 100 μm); following this the laser beam goes through the resin and irradiates it forming a cross-line structure of the model, solidifying and attaching it to the bed. Then the bed rises from the resin, the smoothing element mixes the base material. Following it the bed lowers into the resin again, but with smaller degree – and the process is repeated until the whole model is finished. In the case of the base material running low during the printing process, the system detects it and indicates it to the operator. This takes as long as the needed cassette is replaced.

At the end of the process the not solidified parts are removed in a isopropyl-alcohol bath, then following the drying process the support elements are cut off and post production treatment of the model (filing and sanding, if needed) is due. Some base materials require black-light hut after the printing process to acquire their final characteristics.

Owing to the modulated structure of the printer – forecasting the reducing of time in a possible mass production – at the end of a printing process the bed is simply replaceable with a new one, meaning that the printing pro-

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

cess can start all over again immediately, thus while the additive process are in work, we can finish with post production treatments of a printed model. If we want to work with a different base material we can switch the resin tanks quickly, making the production much faster and optimized.

V. Usable Base Materials

One of the biggest advantages and opportunities of Formlabs SLA systems – all along the previously mentioned ones – is the wide range of available base materials. We meet a scale this wide neither in the case of FDM systems, nor in that of any other 3D processes.

A. A. Standard resin

We can change 4 colours of resin, each having different characteristics. Model made of *grey* resin show the smallest details and depths. In my personal experience components made of grey resin can be used as a base for making positives (so called "protosamples")[8] for printing processes in the case of vacuumcasting[9]. The reason for this is that this material show no reaction towards silicone casts, moreover it is resistant to heat up to 90C° and applied pressure. *Black* resin in figure 8 was developed to design and print models with the highest details, requiring 25 µm of precision. It is used for making action figures and scale-models.

Figure 8: Formlabs black resin 3D printed figures

Prints made of *white* resin keep their homogeneity and silky colour following any kinds of post production treatments (sanding, removing support elements). *Transparent* resin has got the characteristic of being fully glassy after being polished, meaning that it can be used for making optical lenses, as shown in figure 9.

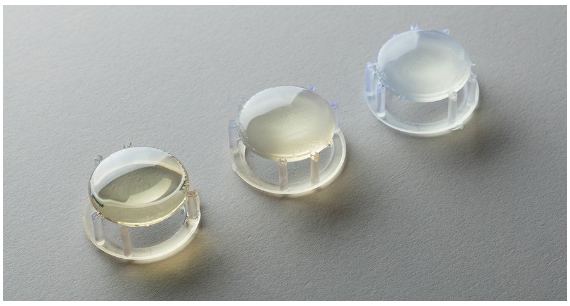

Figure 9: Lenses made of transparent resin following proper polishing

Standard base materials need no black-light treatment after printing; they solidify and remain lasting on their own.

The group of resin above can be used not just for making prototypes, but in some cases final pieces, elements and models can be made out of them, reaching up to hundreds in number.

B. B. Engineering Base Materials

1) Flexible models

Elements made of this special resin have got a special rubber like felling when we touch them. The resin itself is very versatile and resistant, thus flexible and compressible component parts can be printed out of it at the same time. It can be perfectly use for printing unique handles, non-skidding jacket of prototypes and end-user products, or if you like producing special keyboards. The jacket of the moisture-meter in figure 10 is black, its keyboard being printed out of flexible resin. Technology using flexible resin for this product's keyboard, being very thin but resistant at the same time, suited well the task; The model printed corresponded both in aspects of functionality and looks of the final product, which will go into mass-production later on. Models made of flexible resin require black-light post production treatment [8].

Figure 10: Fully functioning prototype of a moisture-meter by Wöhler

2) Resistant components

This base material is highly resistant, designed purposefully for industrial usage. It is recommended for printing snap fits, massive prototypes and jigs. They are resistant to sudden and high degree force vectors. Figure 11. shows the buckle made of this material.

[8] „Protosample": In the process of vacuum casting it is called the 'positive' and the silicone form is the 'negative'.

[9] Vacuumcasting: In the process the masterpiece, or model, is placed in dual-component liquid silicone; after taking air bubbles away with the help of vacuum the silicone coating is placed into heated hut, where at 40C°it solidifies. Following this the masterpiece is taken away and the silicon form can be used to print 25-40 prints at most [9].

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

Figure 11: Safety buckle made of resistant resin

3) Permanent Prints

The polypropylene-like[10] material is ideal to be used when we intend to make objects subjected to high physical strain. [10] Formlabs' resin, Durable, fits these kinds of requirements: can be bent without breaking, has got a smooth and shiny surface when finished. Its final features come to life through black-light treatment.

4) Stiff material.

Stiff materials are base materials with additional glass. Their advantages are their solidity and ability to keep shape. They are used to print thin walls, details and functional prototypes.

5) High temperature resistant elements

Out of all the SLA printed models component parts made of this special resin are outstanding concerning their temperature resistance. In some cases they are able to resist to 289C°. They are used to print models for vacuum casting and parts for die-cast methods. Models made this way are far cheaper than those made of aluminium or steel, and are more lasting than silicone models. As shown in figure 12. tools or models made of this material van be used to mould thermoplastic[11]. Tools printed this way can be mounted in 3D printers and be used to print ABS, polypropylene or polyamide (nylon) component parts [11]. After printing black-light treatment is needed.

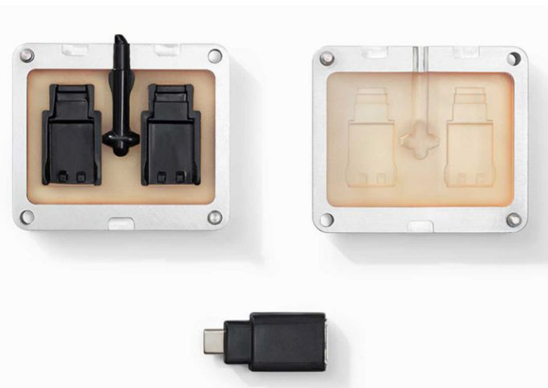

Figure 12: Proto-tool in metal coating, made of 289C° high temperature resistant resin [11]

C. Jeweller use

Owing to recent development in 3D printing SLA method is getting more and more popular amongst jewellers besides industrial use. Using Formlabs resin combined with the outstanding quality of 3D printing ability, jewellery models for precision casting, models for testing and masterpieces as well. The reason for this is the characteristic of this material: in the process of moulding it vanishes without any traces, practically sublimating, making it possible to print pieces of the highest details.

Figure 13: Ring model made of Formlabs casting base material. On the left: prior to post printing treatment; on the right: after post printing treatment [12]

Additional material results in perfection only if we strictly keep the manufacturers' instructions, including radiation/post production treatment in a black-light hut at a 405nm frequency – depending on the model – for 8-12 hours. Following this the colour of the prints became deep navy blue, replacing a lighter colour as shown on figure 13. If the process is as successful as it should be following the moulding all people have to do is polishing the surface without any post production treatments [12].

D. Dental printing

For dental printing there are three different available base materials for Formlabs SLA printers. Dental laboratories are able to produce models that are 100% match the features and shapes of patients, such as bridges, section models or crown models with dismountable screws. All these can be printed in a way that saves time and money.

The existing biocompatible dental resin is of very high quality, meets the requirements of the strictest ISO regulations, can be used to print models for surgeries, dental aids and component parts. Uniquely this base material can officially touch blood, so it is highly suitable for making dental drill models. Figure 14 shows one of these models.

Figure 14: Dental drilling model made of biocompatible resin with titanium rings

The transparent biocompatible model in figure 15. is made of the above mentioned resin. Other elements of similar use are also able to easily replace old-fashioned braces due to their high degree of breaking and wearing resistance [13].

[10] Polypropylene: Used for making switches, power point sockets, bumpers, coating of kitchen equipment; a crystal-texture material.

[11] Thermoplastic: Plastic, which is built by chain-molecules; it is constantly softens while warming; has no exact melting point.

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Figure 15: Special dental brace being able to put directly on teeth made of transparent biocompatible resin

Dental engineers and workers praise 3D SLA printing and talk approvingly about the possibilities of this technology. A Form 2 3D printing unit can be acquired for a bit more than a million HUF, the cost being the fragment, about the tenth, of what a decent and reliable dental 3D alternative is sold for. It means that for the price of an original dental printer we can operate a minilab of more printers of Formlabs. These machines are produced in Hungary, so in the case of a sudden malfunction we do not have wait a long time for the unit to be fixed and our work to be continued. Praising words of dental technicians, who use these units show the reason for existence of Form 2 printers, stating that these units made production of dental parts incredibly faster and easier [14][15].

As in the case of many companies making 3D printers, SLA printers tend to have a closed system, meaning that the units can only be operated with the resin of the producing company, narrowing the possibilities of end-users intentionally and artificially keeping prices of resin at a very high state. As opposed to this Form 2 3D printers have got an 'open mode' setting, which enables the system and the user to use resin of any other brands, without the risk of losing warranty in the process.

VI. Post production treatment

Anybody, who has finished 3D printing processes before, knows very well that between initializing the printing process and receiving the final product numerous steps happen. After the printed model is finished and removed from the bed there may be a need for some kind of surface treatment or removing support elements. In the case of stereolithographic 3D printing there is a need for isopropyl bath in every case and sometimes the use of black-light huts is requested. The success of 3D printing relies on a well planned process, which, being more and more optimized, presents us with the best results.

Since the very beginning of 2018 supplementary devices, which optimise and automates sequences after printing, have been available in Hungarian distribution, this way they decrease time needed for manual tasks and bringing 3D printing to perfection [16]. Ultrasound washing device and black-light huts are newer steps towards the automation of additional manufacturing technologies.

A. Automated washing device

My personal experience shows, that washing by hand or uniquely made black-light huts do not bring the expected results in most of the cases. After we remove the models from the bed they must be placed in a sealed tank of isopropyl alcohol for a certain amount of time. The washing liquid must be stirred in the whole of the process in order for the remaining resin to be removed from the model's surface. If we do with our hands there is a chance for damage in the printed model or resin can be left in the tiny drilled holes on the model, which later can pour out of them in the black-light hut, causing further damage or distortion of the surface of the model. In addition time s a key factor: if thinner elements or parts are exposed to washing liquid for a longer time than they require, further damage or distortion can occur. Removing them earlier from the liquid can result in terms of contamination left on the surface of the model. If we leave the tank open, in order to constantly stir the alcohol, health issues might occur in the course of time, since it is highly unhealthy to breathe in steaming/vaporizing alcohol. Apart from this, a growth in expenses can be detected, since replacing steaming/vaporizing alcohol is costs much in time.

Figure 16. shows a fully automated ultrasound washing tank, called Form Wash. There is no need for us to remove prints from the bed: we can place the model with the bed into the washing tub of the machine and through a timing device we can set the exact time which is required for the current base material to be washed off properly. The device constantly stirs the washing liquid until the pre-set time period is due, at the same time we can look for other works to do. Following this the model is automatically raised out of the tank and drying phase is initialized.

Figure 16: Form Wash automated washing unit

The density of the alcohol in the tank is monitored by a special hydrometer, meaning that if the washing liquid should be replaced Form Wash sends a sign. The package comes with a practical container, where we can keep tools for cleaning. At first it does not seem important or useful, however, through time and use photosensitive resin can produce a first sticky then solid layer, which leads to amortisation.

B. Black-light post production treatment hut

In the case of some printing materials it is needed expose models to black-light, at the proper frequency and temperature, in order for the models to possess the desired features, concerning solidity, temperature resistance and flexibility. Abreast to special base materials, models made of standard resin can be made more resistant through UV radiation/Black-light treatment. In figure 17,

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

an UV hut named Form Cure specializes in the company's own base materials, UV light frequency being 405 nm, precise temperature management and a rotating tray, providing proper treatment for the models. The producer sets the required time for radiation and temperature for every base material. We can set every parameter according to the manufacturer's notice. This way we can gain the best characteristic and top quality of products [17].

Figure 17: Form Cure UV post printing hut

I have experienced the need for proper black-light post production treatment (post printing treatment) many times. Lacking the proper frequency, the rotating bed and the temperature not being 80C°, all along with the huts having been home-made in most of the cases lead to some kind of shortcoming, sometimes the model not being able to use at all. Models treated in a box without heated units often turned out to have not solidified parts in the thicker regions of the models. Uneven black-light radiation caused deformity without exception, since the model leant into the direction of the highest degree of UV radiation. My colleagues and I experienced in the process of using the resin marked 'Tough' in the making of a thin grid scheme that due to uneven radiation the scheme came out wavy at the end. Using other standard base materials we came across the same experience with the same element/print so we presumed the resistance of the gray resin being low. This way we experienced the need for proper UV radiation in our work as well.

Abreast to Form Wash Form Cure is an important step in the direction of automation. Systems requiring the smallest degree of intervention make the work of production engineers much easier by giving further momentum to this direction of additive technologies.

VII. Presenting the System Through an Actual Printing Project of Mine

Base materials used in stereolithograpic printing can have negative side effects concerning health (e. g. resin touching one's skin; breathing in alcohol during the washing process). The closed system of Form 2 minimise getting in touch with chemicals, making their use much safer in our environment.

Since I do not have my very own UV hut, I prefer using standard base materials at home, because they do not need to be treated after the printing process. In most of the cases I use gray resin, since he vast majority of m projects printing scale-models, figures, uniquely designed small-sized tools, jewellery prototypes or models for moulding/casting.

A. Choosing the models

As I had to choose the model I had wanted represent, I endeavoured to take geometry, possible system settings and different ways of shaping into consideration. The most precise resolution is shown in figure 18. through a screw-tool made with a 25 μm layer thickness. On the right we can see a printing, made for using as a moulding-model, with the highest – 100 μm – layer thickness.

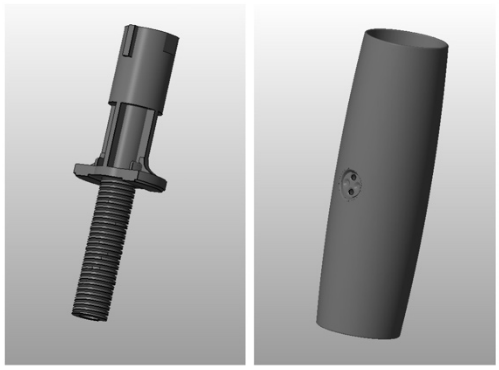

Figure 18: Graphic models of the screw-tool and the moulding masterpiece

At the end of the printing process in spice of the difference in layer thickness no traces of being terraced were seen. This result is highly dependent on the precise orientation of the model. We have to emphasize resolution when we choose the model to be printed. 'Stl' files in the cutter software have got the feature to have small quality, being fragmented, which feature is going to passed onto 3D printed models as well. Since SLA printing is a highly detailed process considering resolution, the smallest angularity can be witnessed on the surface of models.

B. Cutting, orientation

There is a need to 'cut' models in a software – just like in the case of SLA methods – after designing or choosing them. Cutting here means the process of tearing the model into layers with the help of software. We can do it with the help of PreForm software. Prior to loading/choosing the model we have to set the type of the base material and the desired resolution. If we want to work with defective models, the software can solve problems or correct flaws in most of the cases through the 'built-in' correctional program. We have to pay accentuated attention to cavernous models. If there is no external opening, through which still liquid resin can leave the model, problems may occur during printing or after solidifying.

We have to place models in a way that the surfaces of them are parallel to the dimensions of the bed in the least degree. In figure 19 we can see an example of this manner, where a 45° rotation is used for orientation.

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

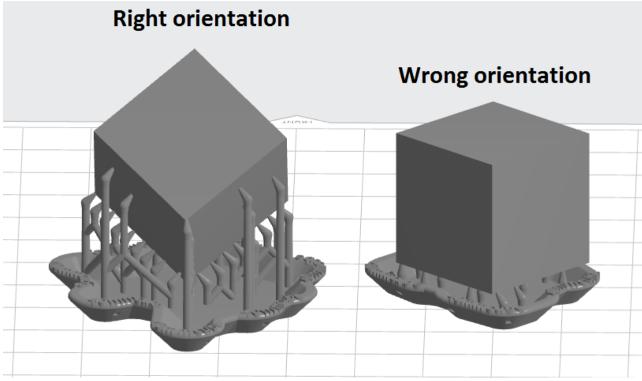

Figure 19: Proper and improper model orientation

If a layer includes a wide plane forces may distort it, ruining the model in the process. In figure 22 we can see that the degree of lean of the cylindrical form is higher than that of the screw-tool.

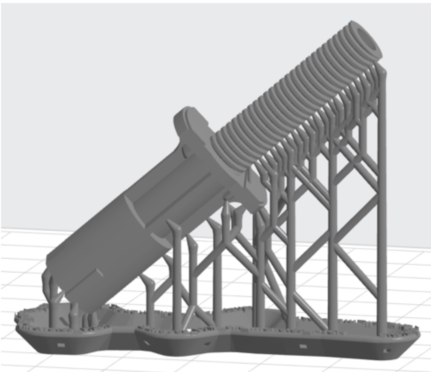

Figure 20: In the case of a highly leaned model every rim requires support elements

The reason for this is the differing resolution of these models: due to the unique model-making method of SLA technology in the case of the screw-tool not only the main parts should be supported, but every single rim as well, making the process significantly expensive and the after printing work phases being longer – like in figure 20. In the case of 100 µm resolution this cylindrical form is much simpler, making a sharper lean angle possible.

C. Forming of supports

Forming the appropriate support for models is a important as the appropriate orientation. We need supports for providing the connection of the model with the bed, and to underpin the printed model, evenly distributing the weight of the print and fixing it in the whole of the process. When forming the layers in SLA printing – depending on the resolution – small 'islands' can come to life, as shown in figure 21. They must be found and underpinned or fixed to the bed with the help of a support element prior to the printing process. If we let them be loose without fixing them they may float away and cause problems while printing or even during later printing processes, as they may connect to other elements, cause damage to the surface or ruin upcoming models.

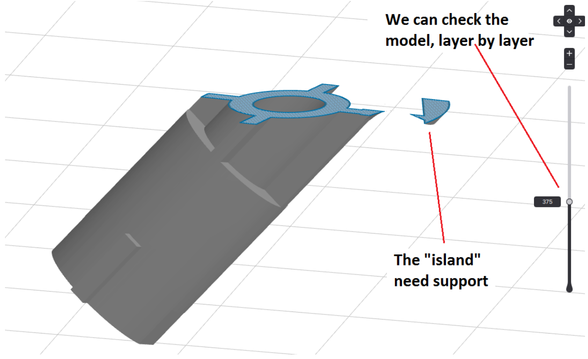

Figure 21: It is important to check the model layer by layer and support 'islands' without underpinning

We can set the thickness and height of support elements depending on the size and weight of the intended print. Besides, we have give the optimal number of underpins: if we use less than required, the walls of our prints will deform themselves because of their own weight, however, if we use more than required the process of removing them is going to be longer, more difficult and more expensive. Generating support elements is automatically made by the cutter program, but if we want to reach for the best quality it is practical to make them by hand.

D. Setting the correct resolution

By setting the correct resolution parameters we not only influence the quality of the printing process, but also the time of it. Since the laser beam of Formlabs printers monitors and irradiates the special coating of the bottom part of the resin tank a consequent need for replacement of this element is unavoidable after the use of 1,5-2 litres of resin. The more a part of the tank is exposed to the laser beam, the more worn it gets. If the printing process does not require differing settings in the case of different elements, it is practical to use the settings with thicker layer parameters.

In the case of the above mentioned cylindrical element it would have been wrong to use setting with 50 µm (or even smaller) of layer thickness. The surface of the model became perfect with the roughest settings without any traces of lines or stages. The same is true for the screw-element: setting the program to 50 µm layer thickness resulted in terms of perfect printing and functionality.

Figure 22: Finished models

Through these examples it is clear that operating a 3D printer and creating perfect and functioning model relies not only on the hardware, but a lot of other features and

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

circumstances. These flaws can be overcome only through the expertise and experience of the operator. Choosing the prefect orientation of the model is difficult even for the well-experienced users as well. This is the most critical point of SLA printing: a couple of degrees distinguish success from total failure and high expenses.

VIII. THE DIRECTION OF DEVELOPMENT: USING PRINTER-FARMS FOR MASS PRODUCTION

Those who have met 3D printing in real life know that the process itself is very slow. Precise SLA systems need hour to produce 1-2 cm tall models. Despite this 3D printing is constantly and unstoppably heading towards mass production. Reflecting back onto the past couple of years one can see, that 3D printing meant prototype making, and, although promising innovation came to life day by day, using additive technologies for mass production had to wait due to its slow rate of speed.

By the middle of 2017 endeavours aiming for 3D printers to produce in line with another printer became mature. It includes connecting 3D printers together with central operating systems. As a result of fast developing of additive technologies and the need for high producing rate and production speed printer-farms came to life, appearing in the FDM domain at first. Figure 23 shows the previously described system. The point of such farms is not using a 'super-printer' with high building speed and gigantic bed, but simply using standard printers with central control.

Figure 23. FDM printing farm at work

These units are not home-built ones. Setting in line the already existing printers printing capacity can drastically increase without the growth of expenses, since the task is to connect already existing technologies instead of creating unique innovations. A lot of companies, such as MakerBot and Pruse, use this method for speeding up their production rate, as seen in figure 23 [18].

Engineers of Formlabs recognized the same possibility. The idea of parallel printing came to life in the form of Form Cell in 2017, seen in figure 24. It is not in the experimental phase. It is a well developed modular, complex system without restrictions; the maker's process managing solution, which automates and set repeated working phases in parallel. Form Cell is a complex robotized system, consisting of an optimised, in accordance with the needs of the printing process, number of Form 2 printers, Form Wash huts and Form Cure UV huts. The system automates manual task of Form products, meaning that it can finish a printing project from the very beginning – printing, relocating the model to the washing unit then to the UV hut, initialising new printing sequence. All these are based on a previously set/programmed printing method, requiring only one operator. This way, Formlabs created a fully automatic digital factory [19][20].

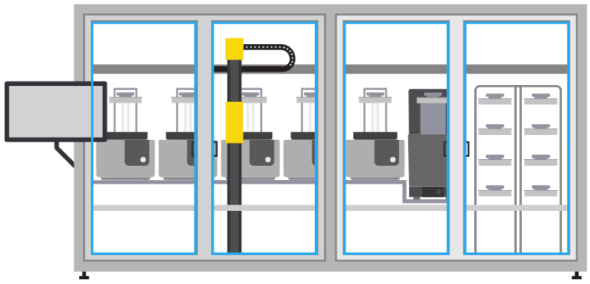

Figure 24. Build of a Formlabs printing farm

Although the price and printing time of each product are still favourable, expenses do not rise, even if we talk about personalized and unique pieces of different kinds in a printing process. An example: in 2017 a conference was hosted by Formlabs at MIT, where they intended to give mass produced 'Pic Cristal' pens as gifts for the hundreds of visitors. Since it was a digital conference and the partakers were familiar the presented methods and technology, the engineers decided to manufacture personalized presents instead of mass produced PR materials.

Since personalization can be done with Formlabs' digital factory without any extra costs it was obvious, that through parametric methods more than 700 unique piece options were generated, meaning that every guest could get a uniquely designed pen. The whole of the production lasted for only a week with the help of the printer-farm, seen in figure 25.

Figure 25: Form Cell in production

The three-day designing and testing was done by a single operator; the one and a half day printing method was executed by a printing-farm of seven Form 2 printers. Post treatment and assembling was carried out by 2 persons. During designing phase engineers made simple files, which did not require any support for the pens or their caps either – this way optimising working process and eliminating the possibility of mistakes. (21)(22)

IX. CONCLUSION

The example in the previous chapter shows how fast additive technology advances, arriving from prototype making to uniquely designed pieces in the course of a couple of months. Systems develop day-by-day and the technological direction point towards a fully automated

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

era. 3D printing is nowadays utilized by factories and industries without any exceptions. Traditional production declines rapidly as there are newer and newer ideas in stereolithography, SLA or metal-printing.

High quality 3D printing technologies are available for more and more people; with the spreading of stereolithography new opportunities are open-up for small industrial units, by this, changing the face of the market. The wide range of base materials makes it possible for companies to produce elements at home as opposed to the time, when there was a need for contractors to produce the desired elements.

With the appearance of printing-farms the decrease of expenses and time is emphasised, 3D printing technology without any question broke into the domain of mass-production.

References

[1] Gábor Krupa: A 3D nyomtatás otthoni lehetőségeinek vizsgálata SolidWorks-ben megtervezett mintadarab szabadon fejleszthető eszközzel történő kinyomtatásán és tesztelésén keresztül. Thesis, Gábor Dénes College, 2015. pp. 17-18.

[2] Gábor Krupa: A 3D nyomtatás otthoni lehetőségeinek vizsgálata SolidWorks-ben megtervezett mintadarab szabadon fejleszthető eszközzel történő kinyomtatásán és tesztelésén keresztül. Thesis, Gábor Dénes College, 2015. pp. 15.

[3] Webpage of CraftUnique Ltd. A Craftbot 3 3D nyomtató specifikációi. https://craftunique.com/category/craftbot-3-3d-printer. Last visit: 06.05.2018.

[4] Endre Dienes: A Craftbot 3 3D nyomtató műszaki leírása és paraméterei. Bitshapes Ltd., Budapest, 2018. http://bitshapes.hu/shop/nyomtatok/craftbot-3-3d-nyomtato. Last visit: 06.05.2018.

[5] The history of Formlabs, 2014 – 2018. https://en.wikipedia.org/wiki/Formlabs. Last visit: 06.05.2018.

[6] Charles Hull, the inventor of stereolithography. 2008 – 2018. https://en.wikipedia.org/wiki/Chuck_Hull. Last visit: 06.05.2018.

[7] Charles W. Hull: Apparatus for production of three-dimensional objects by stereolithography, US4575330A no. patent, 1986. https://patents.google.com/patent/US4575330. Last visit: 06.05.2018.

[8] Freedee Printing Solutions: Funkcionális prototípusok asztali SLA 3D nyomtatással többféle alapanyagból. Budapest, 26.04.2016. http://www.freedee.hu/funkcionalis-prototipusok-asztali-sla-3d-nyomtatassal-tobbfele-alapanyagbol/. Last visit: 07.05.2018.

[9] 3D factory: vákuumöntés. Budapest, 2018. http://www.3dmanufactory.hu/3d-nyomtatas-vakuumontes/vakuumontes/. Last visit: 07.05.2018.

[10] Norbert Miskolczi: Műanyagok kémiája és technológiája. Pannon University, Veszprém, 2012. https://www.tankonyvtar.hu/hu/tartalom/tamop412A/2010-0012_muanyagok_kemiaja/ch15s02.html. Last visit: 08.05.2018.

[11] Freedee Printing Solutions: Hatékony célgépgyártás 3D nyomtatóval. Budapest, 11.24.2017. http://www.freedee.hu/hatekony-celgepgyartas-form-2-3d-nyomtatoval/ Last visit: 08.05.2018.

[12] Freedee Printing Solutions: Precíziós öntés a Formlabs kiégethető műgyantájával. Budapest, 23.06.2017. http://www.freedee.hu/precizios-ontes-a-formlabs-kiegetheto-mugyantajaval/. Last visit: 08.05.2018.

[13] Freedee Printing Solutions: Széleskörű 3D nyomtatás Form 2-vel a Dent-Art-Technik Laborban. Budapest, 30.10.2017. http://www.freedee.hu/szeleskoru-fogtechnikai-3d-nyomtatas-a-form-2-vel/. Last visit: 09.05.2018.

[14] Zsolt Ádám, Kerámia Dental Fogászati központ: Beszámoló a láthatatlan fogszabályozásról Form 2 3D nyomtatóval. Székesfehérvár, 29.03.2017. http://www.freedee.hu/lathatatlan-fogszabalyozas-form-2-3d-nyomtatoval/. Last visit: 09.05.2018.

[15] Dr Attila Mühl dentist, Mühl Stomatology, beszámoló a Freedee Printing Solutions Kft. részére - 3D nyomtatás a Mühl Fogtechnikai Laborban. Budapest, 04.04.2017. http://www.freedee.hu/3d-nyomtatas-a-muhl-fogtechnikai-laborban/. Last visit: 09.05.2018.

[16] CNC Media, Szabolcs Naphegyi: Bővül a Formlabs termékpaletta, itt a Form Wash és a Form Cure. Budapest, 07.06.2017. http://www.cnc.hu/2017/06/bovul-a-formlabs-termekpaletta-itt-a-form-wash-es-a-form-cure/. Last visit: 09.05.2018.

[17] Formlabs: Form Wash + Form Cure, stronger parts, less effort. United Kingdom, 2018. https://formlabs.com/tools/wash-cure/. Last visit: 09.05.2018.

[18] Freedee Printing Solutions: A párhuzamosítás a 3D nyomtatás jövője? Budapest, 26.05.2018. http://freedee.blog.hu/2017/05/26/a_parhuzamositas_a_3d_nyomtatas_jovoje. Last visit: 09.05.2018.

[19] Prím Online: A Formlabs ismét felrázza a 3D piacot. Budapest, 21.06.2017. http://hirek.prim.hu/cikk/125680/. Last visit: 09.05.2018.

[20] Formlabs: Form Cell, Automated 3D print production, powered by the Form 2. United Kingdom. 2018. https://formlabs.com/3d-printers/form-cell/. Last visit: 09.05.2018.

[21] Freedee Printing Solutions: Nyomtatott tollakkal lepte meg konferenciavendégeit a Formlabs. Budapest, 31.08.2017. http://freedee.blog.hu/2017/08/31/nyomtatott_tollakkal_lepte_meg_egy_konferencia_vendegeit_a_formlabs. Last visit: 09.05.2018.

[22] Aashman Goghari: 7 Days, 700 Pens: Parametric Design for Customized Conference Swag. United Kingdom, 29.08.2017. https://formlabs.com/blog/parametric-design-customized-conference-swag/. Last visit: 09.05.2018.

Figures

Figure 1.: Working mechanism of an FDM 3D printer, self-made figure, Budapest 2018.

Figure 2.: CraftUnique CraftBot 3 3D printer. Source: https://www.bettshow.com/bett-products-list/craftbot-3 Last visit: 12.05.2018.

Figure 3.: Formlabs Form 1 SLA 3D printer. Source: https://www.pinterest.co.uk/pin/175851560421886361/ Last visit: 10.05.2018.

Figure 4.: Working mechanism of laser stereolithogrphy. Manufacturing Guide: Stereolithography, SLA. Additive manufacturing method in which an ultraviolet laser is used to solidify a liquid polymer layer by layer. Source: https://www.manufacturingguide.com/en/stereolithography-sla Last visit: 12.05.2018.

Figure 5.: Formlabs Form 2 3D printer. Source: https://www.creativetools.se/hardware/3d-printers-and-accessories/3d-printers/formlabs-form-2 Last visit: 12.05.2018.

Figure 6.: Form 2 3D printer components. Labels taken away. Source: https://support.formlabs.com/hc/en-us/articles/115000011510-Quick-Start-Guide Last visit: 12.05.2018.

Figure 7.: Working method of a Form 2 3D printer. Sompop Benchairt, Daniel Whitley: Has 3D printing for the dental office arrived? Formlabs internal diagram. Source: https://www.dentistryiq.com/articles/2017/01/has-3-d-printing-for-the-dental-office-arrived.html Last visit: 12.05.2018.

Figure 8.: Formlabs black resin 3D printed figures. Artstation.com. Source: https://www.artstation.com/artwork/6NEdr Last visit: 12.05.2018.

Received: 11 June 2018
Accepted: 31 June 2018
Published: 15 July 2018

Journal of Applied Multimedia 2./XIII./2018
DOI: 10.26648/JAM.2018.2.001

Figure 9.: Lenses made of transparent resin following proper polishing. Formlabs.com: How to create transparent 3D printed parts with clear resin. Source: https://formlabs.com/blog/3d-printing-transparent-parts-techniques-for-finishing-clear-resin/ Last visit: 12.05.2018.

Figure 10.: Fully functioning prototype of a moisture-meter by Wöhler Company. Freedee Printing Solutions: Funkcionális prototípusok asztali SLA 3D nyomtatással többféle alapanyagból. Budapest, 26.04.2018. Source: http://www.freedee.hu/funkcionalis-prototipusok-asztali-sla-3d-nyomtatassal-tobbfele-alapanyagbol/ Last visit: 12.05.2018.

Figure 11.: Safety buckle made of resistant resin. Freeform4U. Source: https://www.freeform4u.de/formlabs-form2-kunstharz-belastbar-1l-resin-in-der-kartusche.html Last visit: 12.05.2018.

Figure 12.: Proto-tool in metal coating, made of 289C° high temperature resistant resin. Freedee Printing Solutions: Már így is lehet: kisszériák olcsón, gyorsan, akár fröccsöntött minőségben. Source: http://www.freedee.hu/mar-igy-is-lehet-kisszeriak-olcson-gyorsan-akar-froccsontott-minosegben/ Last visit: 12.05.2018.

Figure 13.: Ring model made of Formlabs casting base material. On the left: prior to post printing treatment; on the right: after post printing treatment. Freedee Printing Solutions: Precíziós öntés a Formlabs kiégethető műgyantájával. Source: http://www.freedee.hu/precizios-ontes-a-formlabs-kiegetheto-mugyantajaval/ Last visit: 12.05.2018.

Figure 14.: Dental drilling model made of biocompatible resin with titanium rings. Freedee Printing Solutions: Széleskörű fogtechnikai 3D nyomtatás Form 2-vel a Dent-Art-Technic laborban. Source: http://www.freedee.hu/szeleskoru-fogtechnikai-3d-nyomtatas-a-form-2-vel/ Last visit: 12.05.2018.

Figure 15.: Special dental brace being able to put directly on teeth made of transparent biocompatible resin. Formlabs: Professional materials for digital dentistry. Source: https://formlabs.com/materials/dentistry/ Last visit: 12.05.2018.

Figure 16.: Form Wash automated washing unit. Formlabs: Form Wash + Form Cure, stronger parts, less effort. Source: https://formlabs.com/tools/wash-cure/ Last visit: 12.05.2018.

Figure 17.: Form Cure UV post printing hut. Unic-3d.com: Formlabs Form Cure. Source: https://unic-3d.com/en/3d-printing-accessories/204-formlabs-form-cure.html Last visit: 12.05.2018.

Figure 18.: Graphic models of the screw-tool and the moulding master-piece. Self-designed models. Self-taken photos. Budapest, 2018.

Figure 19.: Proper and improper model orientation. Self-designed models, self-taken photos. Budapest, 2018.

Figure 20.: In the case of a highly leaned model every rim requires support elements. Self-designed models, self-taken photos. Budapest, 2018.

Figure 21.: It is important to check the model layer by layer and support 'islands' without underpinning. Self-designed model, self-taken photo. Budapest, 2018.

Figure 22.: Finished models. Self-designed component parts, self-taken photo. Budapest, 2018.

Figure 23.: FDM printing farm at work. 3D printing.com, Michael Graham: A look at 3D printing as a production technology: https://3dprinting.com/3d-printing-use-cases/3d-printing-as-a-production-technology/ Last visit: 12.05.2018.

Figure 24.: Build of a Formlabs printing farm. Formlabs: Form Cell, Automated 3D print production, powered by the Form 2. Source: https://formlabs.com/3d-printers/form-cell/ Last visit: 12.05.2018.

Figure 25.: Form Cell in production. Formlabs: Form Cell. Source: https://i.ytimg.com/vi/Vv1B4C__I8s/maxresdefault.jpg Last visit: 12.05.2018.