Validation in dental 3D printing

Specifics and importance of coordination and validation of process parameters for digital workflows

3D printing has continuously developed in recent years into additive fabrication, also known as additive manufacturing (AM). So it is no longer just about the manufacture of models or “prototypes”, but rather parts that are produced for load-bearing, technical, medical and industrial applications. While the technology was only accessible to industrial users in the early days due to the complexity and costs of the required equipment, 3D printers are now actually quite affordable for private users, too.

There are now many methods that make it possible to build three-dimensional objects. All of them have specific advantages and disadvantages. What they have

in common is that the material is usually applied layer-by-layer, creating three-dimensional workpieces. This layer-by-layer construction is controlled by a computer using liquid or solid materials and based on digitally available data for the desired object geometry (see CAD/CAM). Physical or chemical hardening or melting processes selectively solidify layers and connect them to form a three-dimensional object. Typical materials for 3D printing are plastics and resins, metals and ceramics. Although 3D printing is a shaping process, no special tools are needed that machine the workpiece in direct contact or reproduce its respective geometry (as a negative), as is the case, for example, with casting moulds [IPH]. This makes additive fabrication so attractive when one-offs, i.e. individual pieces, are needed, as is the case in dental and medical technology, but also with jewellery or in small series production or the make-to-order production of parts. Unlike all production processes requiring a subtractive processing of the workpieces (cutting, milling, etc.), the economic efficiency in additive manufacturing increases with the increasing complexity of the component geometry and the decreasing required quantity of pieces.

ADDITIVE MANUFACTURING IN THE DENTAL FIELD

The general considerations of additive manufacturing make it clear that this process is very well-suited for dental applications, since here – as in hardly any other field – custom workpieces with a high shape complexity are needed as custom-made items. So it is not surprising that 3D printing is also enjoying increasing popularity among dental users. However, the manufacture of dental medical products by using additive manufacturing also places increasing requirements on the components and the validity of the workflow. 3D printing enthusiasts of the so-called 'maker scene', i.e. private individuals, who in the best sense can be designated as creative tinkerers and who develop solutions to problems together and implement do-it-yourself projects, are usually not concerned with such precise and exact requirements, as is the case with medical products. This also concerns areas such as prototype and model construction.

DLP TECHNOLOGY IN DENTAL ADDITIVE FABRICATION

These days, the DLP procedure is used by professional users to produce dental printed objects via additive manufacturing. Although a comprehensive overview of all existing processes would go well beyond the limits of this article, the key features and advantages of DLP technology (Digital Light Processing) should be summarised to exhibit the technological reasons for this development. Light-curing resin formulations are processed in 3D printers.

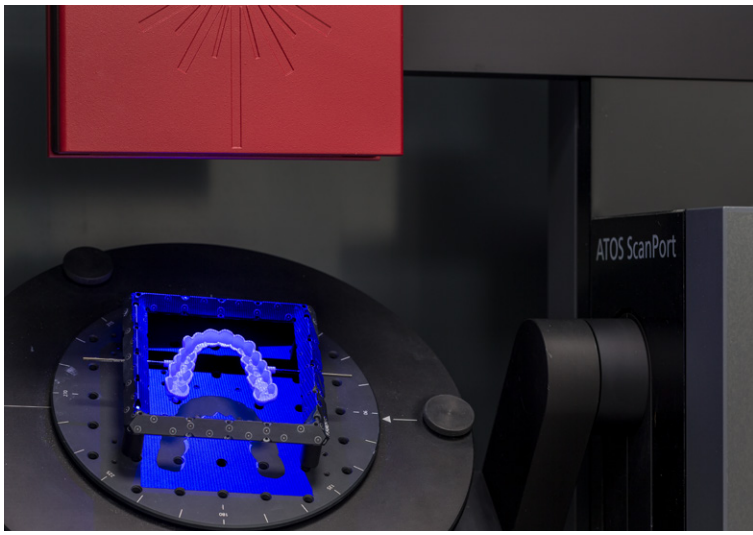
Dentists and dental technicians have known about light-curing materials for decades and they often use them in their daily routine, with great success. These light-curing materials are cured with a blue light of about a 450 nm wavelength, especially when they are used intraorally, such as with filling composite. The DLP 3D printers DMG 3Demax and DMG 3Delite work with UV light of 385 nm and the shorter wavelength makes them precise. It is possible to safely use UV light in 3D printing, since the user and patient do not come into contact with this radiation. The exposure and curing of the 3D printing formulations in the printer occur in layers, which can be as thin as in the range of a few tens of microns. Each of these layers from which the object is built is a high resolution image in the layer with a resolution corresponding to a full HD projector. Since this exposure occurs on a much smaller area than,

for example when projecting images or films, the size of a pixel, i.e. the resolution, is at 68 microns and lower. High accuracies can also be achieved here. This layer-by-layer curing with light above all creates very dense objects without a cavity or porosities, which makes them ideal for intraoral applications.

PRINTING ACCURACY AND VALIDATION

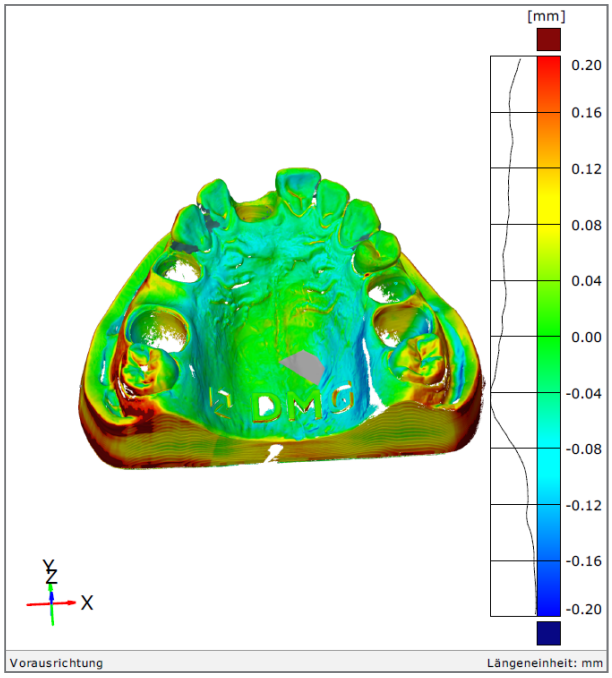
In this article, we present the validated DMG DentaMile workflow that achieves results that meet the high requirements of dental technicians and dentists with respect to biocompatibility, stability and precision. The DentaMile validated workflow was developed at DMG according to strict criteria and is reviewed in our application centre so that the highest quality is always achieved. It is important to emphasise here that the focus is on the entire workflow. Each component of the entire workflow influences the end result. The cornerstone for accuracy and precision is laid in the 3D printer, but the cleaning of the green part and especially the post-curing also affect the end result. The green part in the 3D printing process is the printed object that is created in the 3D printer and that is removed from the 3D printer after the build job is complete. The green part is not yet fully cured and does not yet have the final material properties. It is finished curing using UV light after it has been cleaned of residual resin that is still adhered.

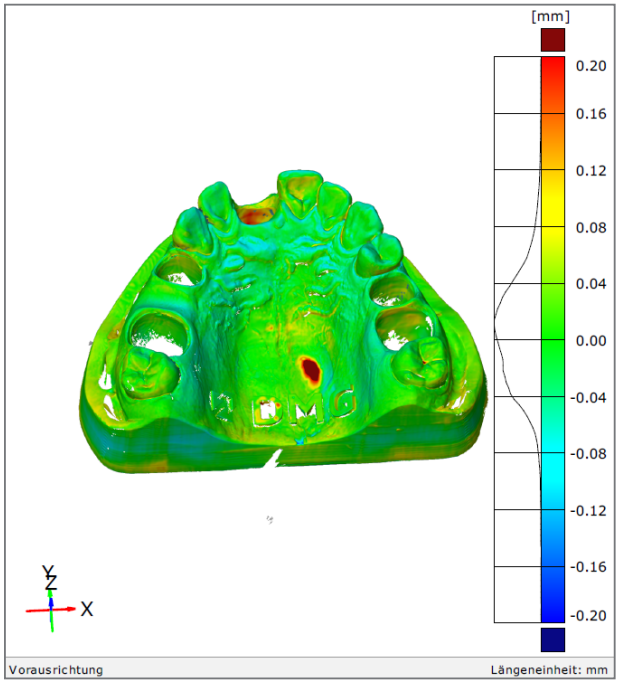
Last but not least, the manufacturing process of the printed object cannot be viewed separately from the design of the objects. The design also plays a crucial role with respect to the end result. That is why it is important to consider all of the workflow steps and coordinate them with each other to achieve the optimal end result.



1 Object is scanned

For accuracy, the specification of the XY resolution is often used first. In the DLP procedure, this XY resolution corresponds to the projected pixel size. For example, a projected pixel size of 68 µm results in a device accuracy of +34 µm with respect to the resolution. However, the resolution or size of a pixel are not sufficient per se to assess the accuracy of a printed part. There are many other factors that influence accuracy, including (to name a few) the correct calibration of the printer and post-processing units, the cleaning of the components after printing and the shrinkage of the resin during polymerisation. Especially since a large proportion of the shrinkage occurs during post-curing and not in the printer itself, it is important, among other things, to consider the entire process and to only assess the accuracy by measuring the final component. It is ultimately only this accuracy that is decisive for the user. The accuracy of the detection of objects must be more accurate than the clinical acceptance limit by at least one order of magnitude to be able to reliably assess the process based on data. The accuracy of commonly used dental desktop and





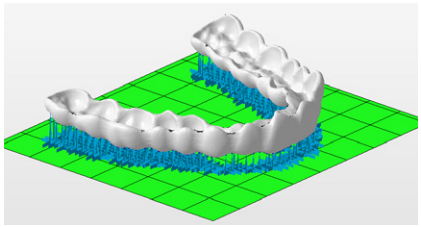
2a and **2b** model with different

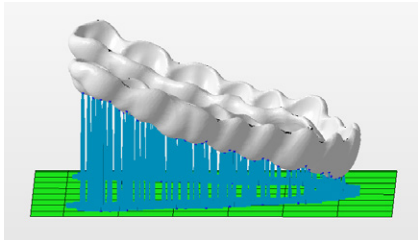
handheld scanners is often insufficient for this purpose. That is why the required 3D coordinate measurements in the Digital Application Centre of DMG Digital Enterprises SE are done with an industrial scanner with a probe deviation of about 3 µm (Fig. 1).

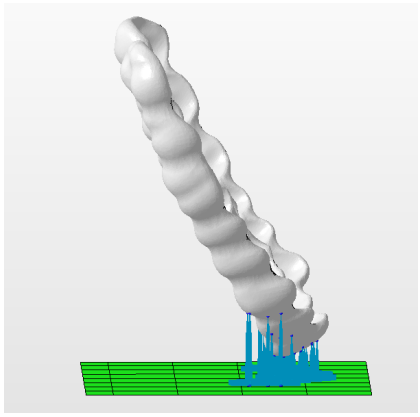
Such precise measurement processes can be used to assess the components in their overall three-dimensional form. This allows for a much more practical assessment than would be possible, for example, with a purely one-dimensional measurement of test cuboids. Figure 2 shows the importance of this check for practical users. A model with a faulty parameter adjustment and a model with an optimal parameter adjustment are compared with each other. Significantly irregular deformations can be seen in the non-optimised model to the left. There are areas that deviate into the positive (red) and those that deviate into the negative (blue-purple). A situation like this cannot be corrected by the user, for example by scaling his or her digital input data, and must therefore be avoided.

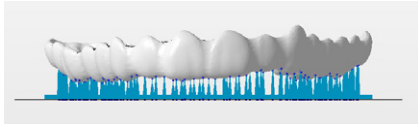
In the case shown, the irregular deformation has been caused by the post-curing. This highlights that it is extremely important to take the entire workflow into consideration. The effect would not be recognisable if only the green part were considered. It is therefore important that all steps of the production process be taken into consideration and that the material and control parameters of the devices used are coordinated with each other. It is only through the careful implementation of the printing parameter development backed by objective measurement data, together with the corresponding recommendations for action, that a cohesive workflow is achieved, which produces accurate and reliable objects for the user with a high level of reproducibility.

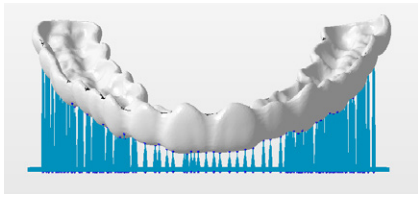
As shown in Figure 3 for the example of an occlusal splint, different arrangements of the objects in the build area are also checked here, since this can also affect the dimensions. The mechanical end properties of the component are also a product of correct cleaning and above all post-curing. The green part taken directly

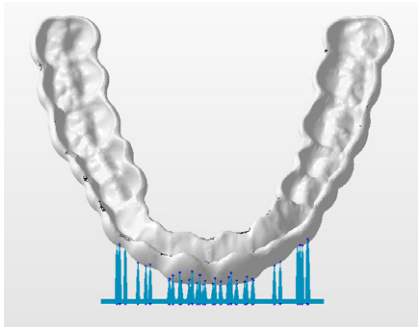










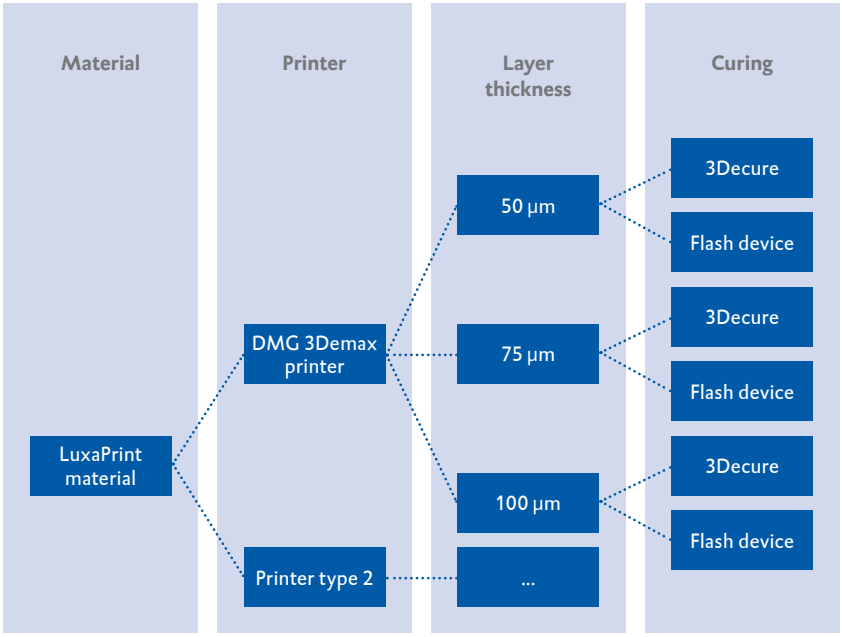


3a to **3f** alignment of the splints
In Netfabb, including supporting structures

from the printer usually does not yet have the desired end properties, for example with respect to hardness, elasticity or mechanical strength. Aspects have been shown so far that are decisive for the dimensionally accurate production of mechanically robust objects. In the case of manufacturing medical products with additive manufacturing, biocompatibility of the finished printed object is also a key factor. In addition to the Medical Device Regulation (MDR), the European ordinance on medical devices, various globally harmonised ISO standards must also be taken into consideration. The tests described there are implemented in order to obtain a safe product for use on or in the patient. If the user were to deviate from the tested post-treatment of printed objects, a biocompatibility would no longer be ensured or would have to be tested separately. This also highlights the importance of complying with the specified workflows.

All of the checks described above must be done separately for every desired combination of process parameters and devices. Based on a material to be validated, every 3D printer that is to be provided for a valid process must be taken into consideration separately.

The different layer thicknesses from which the print is built must also be taken into consideration. This also applies to any cleaning process, for example whether this is done manually, in an ultrasonic bath or in a cleaning device, and with which medium. As already described above, post-curing also plays a crucial role here, which is why every post-curing device is to be validated separately. Simple post-curing devices only



4 Schematic diagram of the parameter development tree

have the duration of post-curing as the default, while advanced devices, such as the DMG 3Decure, have exposure durations and intensities for different wavelengths as well as a temperature and evacuation of the exposure chamber that can be controlled. This usually results in a large number of combinations that all need to be checked with the corresponding amount of effort. Figure 4 summarises this in a tree view, providing a visual impression of the complexity.

SUMMARY

General considerations regarding dental 3D printing were presented and it was shown why DLP technology is particularly suitable here. A practical example was used to show how important the coordination and validation of process parameters and the exact measurement of the created components is for obtaining precise results. Another key point is ensuring biocompatibility. A validated workflow can only be achieved if all relevant aspects are correctly merged.

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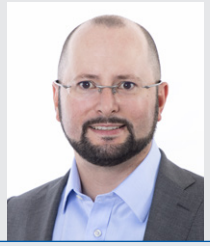

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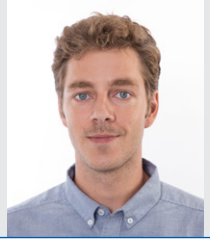

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