Emergence of new technologies in the designing and fabrication of patient-specific removable partial dentures (RPDs): A case study

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Abstract—**Application of 3D technologies brings new innovative tools that support design process of custom implants and dentures, more specifically related to the field of dentistry. These new tools, which allow easier and faster designing process of patient-specific removable partial dentures (RPDs), enables them to be widely accepted as a more preferable choice to use. In this paper, implementation of 3D technologies will be presented through a case study for designing and fabrication of patient-specific RPDs. The entire process will be presented and elaborated, starting from the designing stage of a 3D model of a patient-specific RPD using advanced tools, all the way to a verification stage using RP (Rapid Prototyping) technologies. This approach enabled a more convenient design and faster delivery time of a manufactured RPD, but also by using less expensive equipment to achieve this.**

I. INTRODUCTION

Recent technological developments in the fields of computer-aided design (CAD) and additive manufacturing (AM) technologies, and their introduction to the field of dentistry, have allowed the complete 3D digitization of a dental cast, design of removable partial dentures (RPDs) and their manufacturing [1]. The traditional manufacturing of RPDs presents a more complex process, which is acceptable to errors, but it is also time consuming. The use of 3D technologies, especially in the combination with rapid prototyping (RP), delivers a more effective method for fabrication of RPDs.

RPD presents a removable replacement for missing teeth and surrounding tissues. RPD usually have replacement teeth fixed to an acrylic base that matches the color of patient's gums. The acrylic base may cover a metal framework. They often have some form of clasp that attaches to patients natural teeth, as this holds the denture in place.

II. OVERVIEW OF LITERATURE

When it comes to the first removable prosthesis, it was manufactured in 1994 da it was based on 3D laser lithography [2]. After that, there have been progress in the overall design and fabrication of partial dentures and the removable prosthesis duplication technique was improved using CAD/CAM with a computerized numerical control (CNC) system [3]. Then, the incorporation of 3D printers in fabrication of individual physical flasks was also introduced [4]. Dental impressions of both maxilla and mandible were also being subjected to different 3D digitizing methods such as laser scanning [2, 3]. Also, cone beam computed tomography (CBCT) is used for the modification of previous dentures [5]. There are several different approaches in designing a partial denture, and many authors have dealt with this question. Authors in [6] used a technique that uses a surveyor, gutta percha points, and a CAD/CAM guided implant surgery system to predetermine and transfer the ideal angulation of the implant to be placed. Authors in [4] explored a method for fabricating removable complete denture aided by CAD/RP technology. 3D crossing section scanner and laser scanner were respectively applied to obtain the surface data of artificial teeth, edentulous models and rims made in clinic. In this study, AMT and classic denture materials were effectually combined to achieve making removable complete denture aided by CAD/RP technology. A more detailed paper on current published literature investigating the various methods and techniques for 3D scanning and designing was presented by authors in [7]. The purpose of this paper was to present a comprehensive review of the current published literature investigating the various methods and techniques for 3D scanning, designing, and fabrication of CAD/CAM generated restorations along with detailing the new classifications of CAD/CAM technology. When it comes to accuracy of manufactured RPDs, authors in [8] evaluated the fit of RPD clasps fabricated by means of 4 different CAD/CAM systems and compared those fittings with the conventional lost-wax casting technique (LWT). Their conclusions were that when compared with the LWT, milling techniques enabled fabrication of RPDs with comparable or better fit, while RPDs fabricated with rapid prototyping techniques showed distinct fitting irregularities. RP technologies do bring a new way of RPD fabrication, however, authors in [9] investigated the mechanical properties and microstructure of RPD clasps manufactured using selective laser melting (SLM) technique.

III. MATERIALS AND METHODS

This approach, which will be presented in this paper, focuses on a 3D digitization of a casted dental model using a close-range photogrammetry structure from motion (CRP SfM) method, designing of RPD and testing and evaluation of the design using RP technologies.

From the workflow (figure 1) it can be seen that the first step presents sketching of the RPD shape onto the casted dental model made by a dentist. When the desired shape is achieved, the casted dental model is ready for the next step and that is 3D digitization. 3D digitization presents a way to convert the physical object into the digital 3D model. This process can be achieved by using various 3D digitization methods. CRP SfM digitizing method presents a good alternative to a high-end 3D scanners available on the market [10, 11]. The price of these setups can be drastically low when compared to other 3D scanners, which is also a reason for their recent popularity and choice for use.

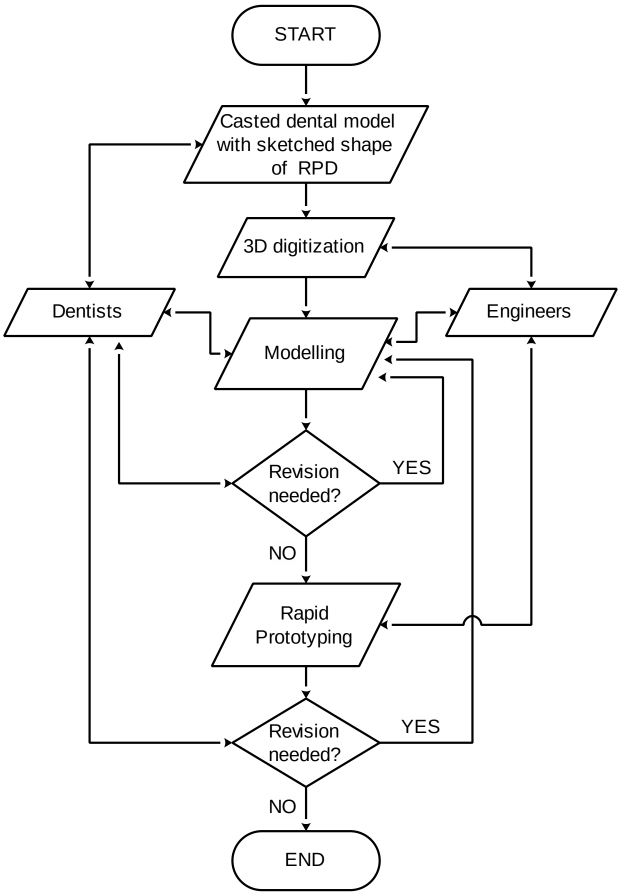


Figure 1. Presented workflow

Another reason why CRP SfM method was chosen was because it can also acquire and export texture of the object that has been 3D digitized. Manually drawn shape of an RPD by a dentist on the dental cast model will later serve as a guide for tracing the lines and designing of the RPD (figure 2).

For photogrammetric 3D reconstruction, Canon EOS 1200D DSLR camera and the manually driven turntable were used. In total 90 photos were captured.

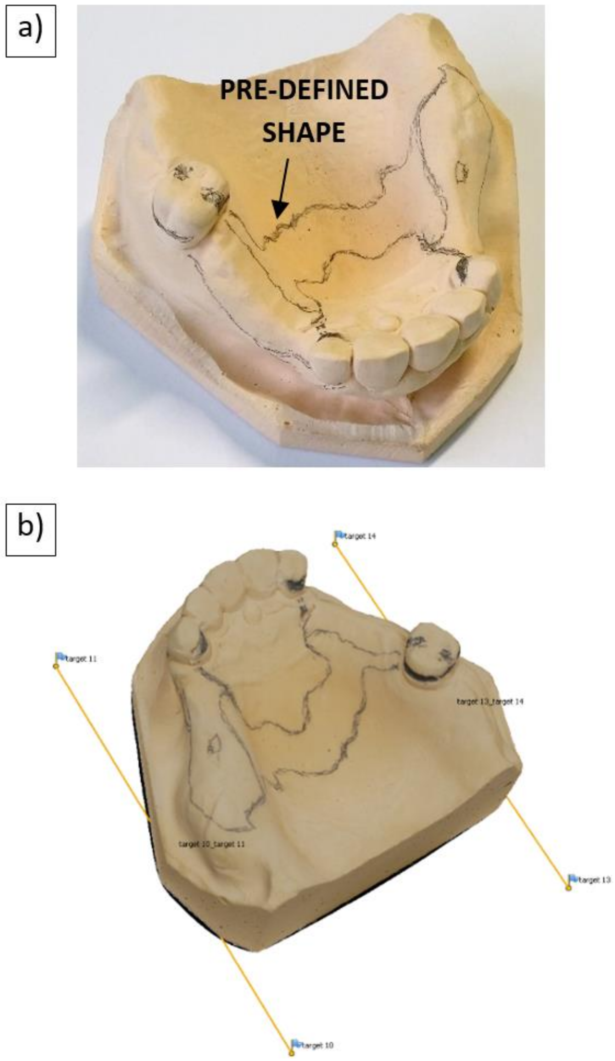


Figure 2. Showing a) dental cast with manually drawn sketches and b) 3D digitized object with applied texture in Agisoft Photoscan software

Photos were arranged in 5 circular rings, where each ring contained 18 photographs equally distributed in a circular pattern. These rings formed a spherical shape around the casted dental model. The first ring was set at the turntable plate level in order to capture the outside shape of the casted dental model. The second and third ring served to ensure required overlapping between photographs. Forth and the fifth rings were captured in order to cover the top side of the casted dental model. Captured photos were processed using Agisoft Photoscan software, and as a result the 3D model was obtained. Because of photogrammetric 3D digitization are scaleless, scale markers were used during 3D digitizing by CRP SfM method in order to get the accurate 3D model of dental cast [12]. After the proper scale was set, texture from photos was applied and 3D digitization of the dental casted model was completed.

After the 3D model of the dental cast was obtained, the next step is the designing of the RPD. The software used for this purpose was Meshmixer by Autodesk. This software allowed a more intuitive and user-friendly approach with a variety of different tools for freeform surface modeling.

A. Designing of RPD

The lines were traced onto the model directly in Agisoft PhotoScan software (figure 3a) and the final shape of the RPD was obtained, which will serve as a base for its design (figure 3b).

Figure 3. Showing a) textured 3D model obtained from CRP method with traced lines for cutout and b) cutout shape of the RPD base required for further modelling

After the initial base was extracted, the next step was to add thickness to the surface base. This was performed with the Offset operation inside Meshmixer software. The base surface was offset initially by a value of 1.5 mm to allow manipulation of the surfaces during freeform modelling.

B. Design process of clasp, saddle, occlusal rest and connector

The design process of the RPD is shown in Figure 4. The first step was to offset the base surface by 1.5 mm and create a new offset surface (figure 4a), thus adding the material for designing and shaping of the RPD. After that, the next step was to address special attention to clasp (retainer), connector, saddle and occlusal rest areas. The clasps and occlusal rest areas were smoothed and rounded so that the final fabricated RPD model does not create any discomfort for the patient. This was done on all four areas where the RPD was in contact with the teeth (figure 4b, 4c and 4d). The perforating holes with diameter of 2, 1.5 and 1 mm were also added on both sides of the saddle (figure 4e) with an equidistant spacing between them. The total of 14 holes on the left side and 9 holes on the right side of the saddle were added.

One important feature to modify is a relief which should be created in the area without teeth. This is important because in order to prevent the connector from directly resting the surfaces on the soft tissues. Here the relief was created by selecting the area of the retainer and it was lifted by 0.5 mm. Also, the thickness on the saddle where it sits on the alveolar ridge was also lifted up by a 0.2 mm. The final result of designing is shown in Figure 4f.

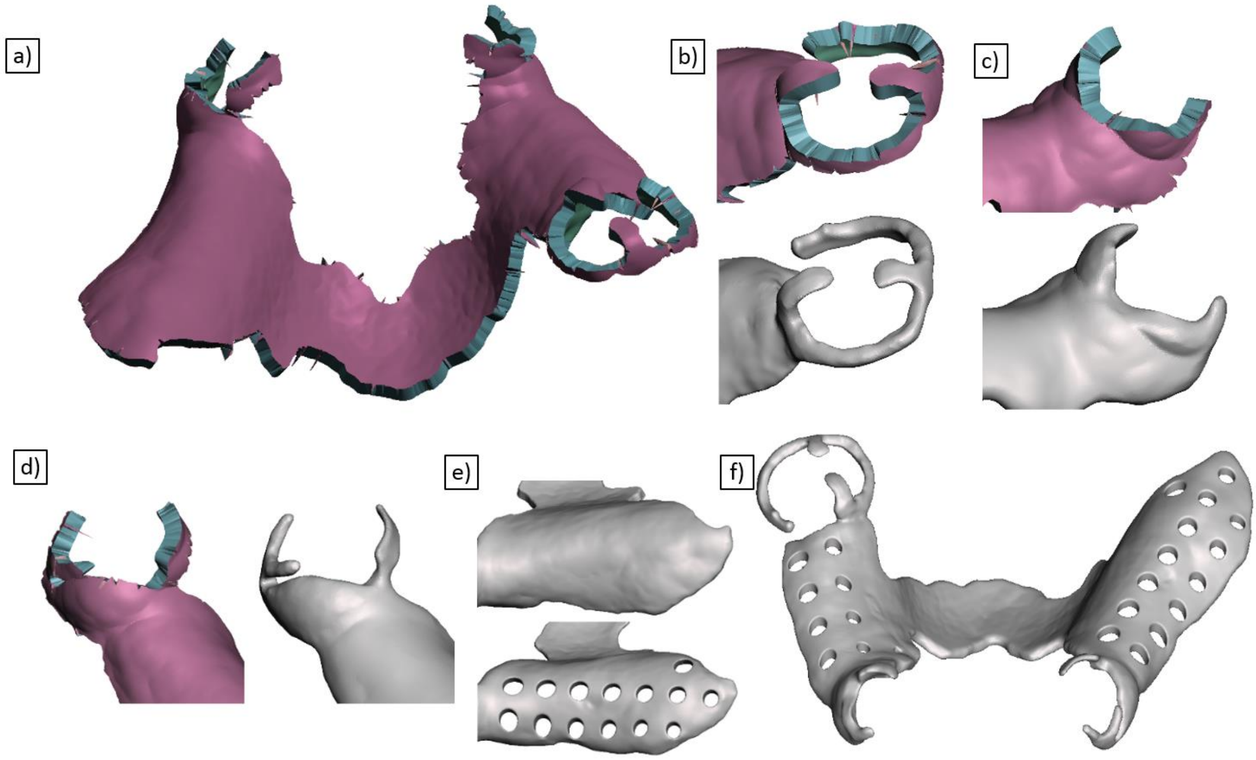


Figure 4. Showing a) initial offset of the base surface, b), designing of rest, c) and d) designing and modifying of the clasps, e) perforating the rest on RPD f) completed design of RPD

C. 3D Printing

Stereolithography (SLA) 3D printing, also known as resin printing, produces 3D models out of photopolymers. Taking the form of a resin, these are polymers whose molecules link together when exposed to light in a process called photopolymerization [13]. Desktop SLA 3D printer used for printing, and its basic schematic representation along with technical specifications are presented on figure 5 and Table 1, respectively.

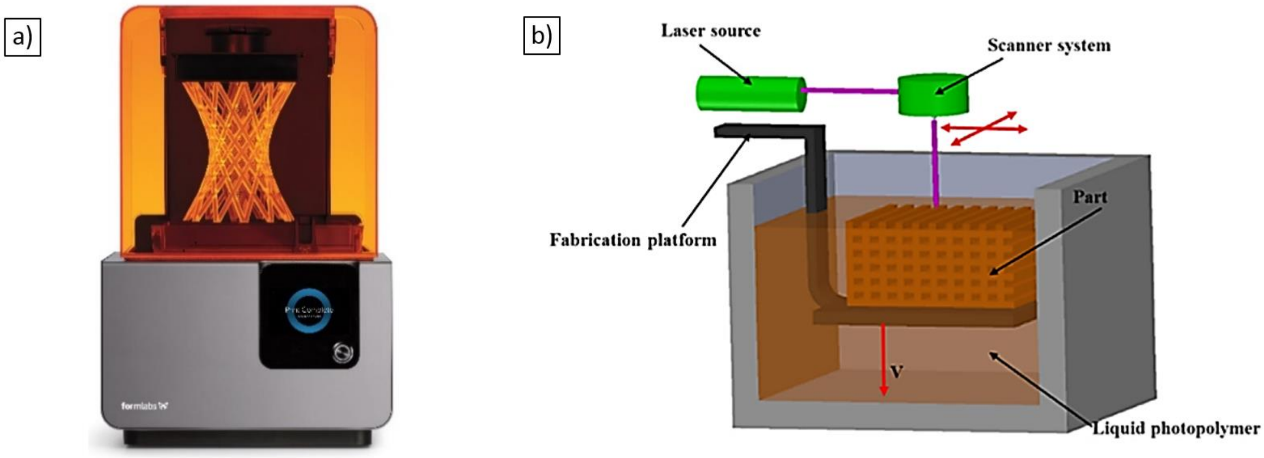


Figure 5. Showing a) by Formlabs Form 2 SLA 3D printer, b) schematic representation of a typical SLA setup [13]

TABLE 1.
FORMLABS FORM 2 SLA 3D PRINTER SPECIFICATIONS

Specifications	
Dimensions [cm]	35 × 33 × 52
Weight [kg]	13
Build volume [mm]	145×145×175
Laser Spot Size [µm]	140
Layer Thickness [µm]	25 –100
Laser Power [mW]	250

Furthermore, some post-processing and additional modifications were required in order to clean the transition of the surfaces along RPD. Different factors needs to be taken into account such as: wire clasps around the teeth, occlusal rests, connector for transition of surface from the RPD to the pellet and number of perforated holes required.

After this stage, the next step is the verification of the physical RPD by dentists, upon which a 3D model of the RPD is being 3D printed. This step is also crucial, as it may reveal any need for final corrections or modifications that needs to be performed before the final fabrication of RPD.

The 3D model of RPD was 3D printed using Formlabs Form 2, SLA 3D printer (figure 6a). The STL model was sliced into 0.05 mm layer thickness. Then, the SLA technique uses a UV light to solidify a polymer model. After solidification, the physical model of the RPD was carefully removed from the machine platform to be cleaned in isopropanol. In this stage, there was no need for post curing using ultraviolet light for full polymerization, as this first version was only an initial test model. Printed RPD with the casted dental model is shown on figure 6b.

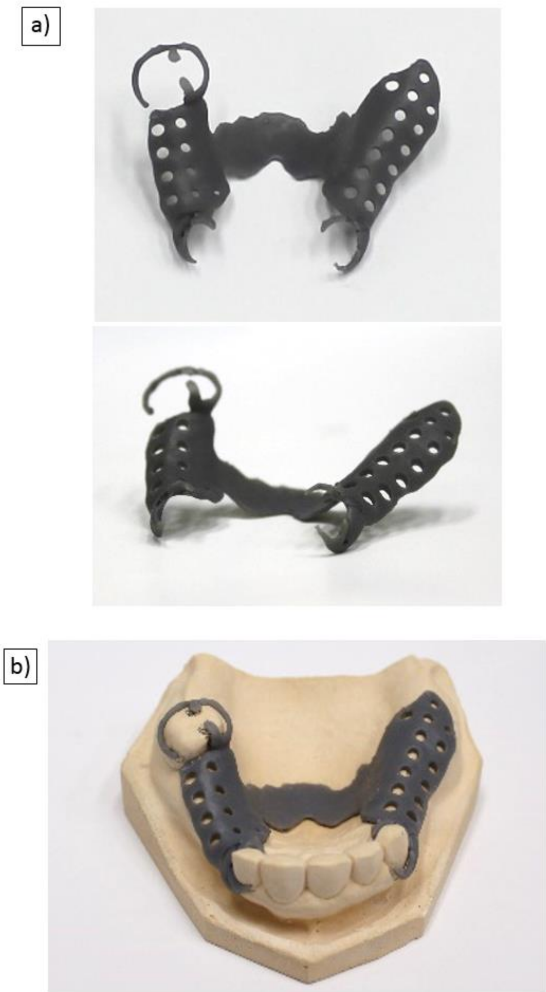


Figure 6. Showing a) 3D printed RPD and b) visual inspection of RPD fitting on the 3D model of the dental cast

D. Revision of the design of RPD

After the printed model came back from the visual inspection of the dentist, some minor features needed to be corrected in order to complete the design according to dentist's instructions. Modifications were performed at the clasps on both sides where some excess material was removed for better fit of the RPD. Also the modifications were performed on thinning of the connector and saddle, but also on thinning of some of the edges of the RPD. Figure 7 shows the modifications performed on the RPD.

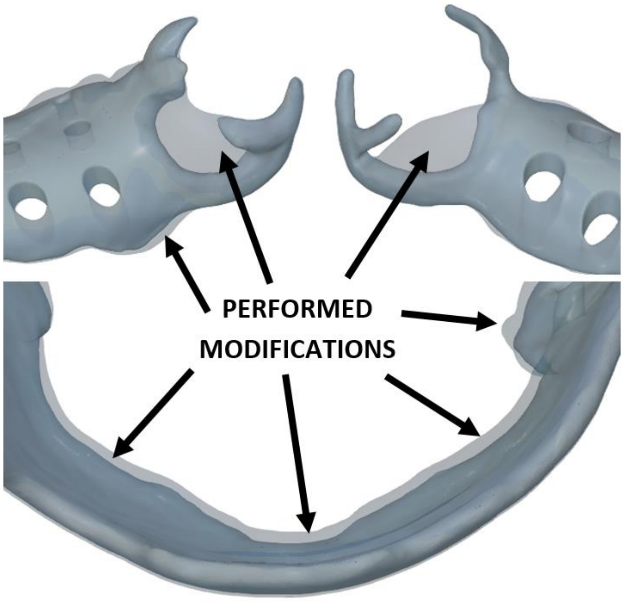
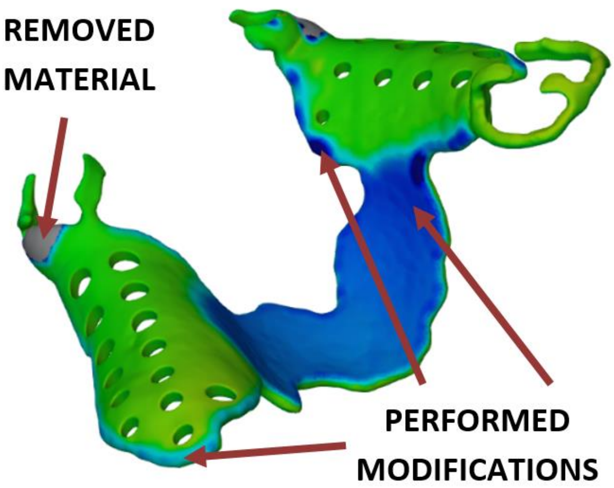


Figure 7. Performed modifications on the revised 3D model of RPD

For a better clarification on the modifications requested and performed on the design of RPD, a color deviation was performed in GOM Inspect (GOM GmbH) software where first design of RPD was used as a nominal 3D model, and the STL file of the final version of the RPD was used as an actual 3D model that was compared against it (figure 8).



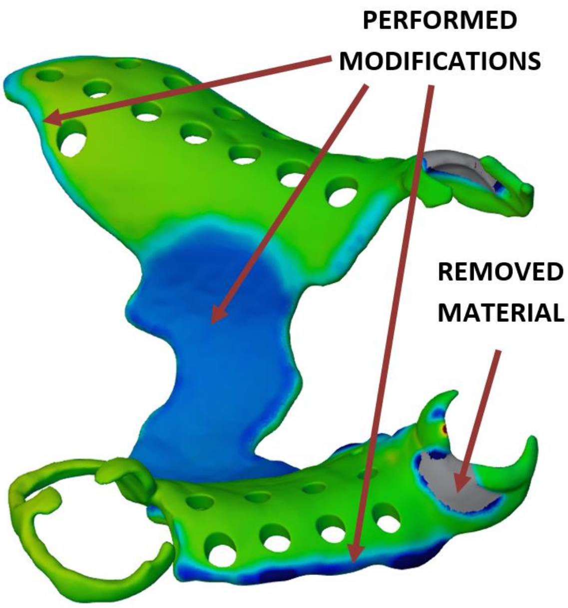


Figure 8. Color deviation showing performed modifications on the revised 3D model of RPD

From figure 8 it can be seen that the major corrections and modifications are marked in blue color, meaning that those areas are where the thinning of the RPD material occurred in second revision. Also two marked areas of clasps are removed, therefore no color deviation is present on those areas.

After the deviation inspection the second modified design of RPD was printed again on SLA 3D printer for final inspection and confirmation from a dentist. Revised printed model of RPD is shown in figure 9.

Figure 9. Final design of RPD printed on SLA 3D printer

IV. CONCLUSION

In this study, the use of CRP SfM 3D digitizing method proved to be able to deliver the 3D model of the dental cast, with the required level of dimensional accuracy. This 3D digitizing method also enables the acquisition of applied texture that reveals the initial design sketch of the RPD. This, along with the application of advanced tools for modeling and designing of RPD, was able to deliver the desired shape and design of the RPD for its fabrication. As a last step, RP technology, i.e. SLA 3D printer, was used in order to verify the design, but also to check its functionality. In this paper the focus was on bringing closer the use of 3D technologies and RP technologies together by 3D digitizing and designing a patient specific RPD in a much faster, cheaper and convenient way, suitable for its use with the patient.

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REFERENCES

[1] M.S. Bilgin, E.N. Baytaroğlu, A. Erdem, E. Dilber, "A review of computer-aided design/computer-aided manufacture techniques for removable denture fabrication," European Journal of Dentistry, vol. 10, pp. 286–291, 2016.

[2] Y. Maeda, M. Minoura, S. Tsutsumi, M. Okada, T. Nokubi, "A CAD/CAM system for removable denture. Part I: Fabrication of complete dentures," International Journal of Prosthodontics", vol. 7, pp. 17–21, 1994.

[3] N. Kawahata, H. Ono, Y. Nishi, T. Hamano, E. Nagaoka, "Trial of duplication procedure for complete dentures by CAD/CAM," Journal of Oral Rehabilitation, vol. 24, pp. 540–548, 1997.

[4] Y. Sun, P. Lü, Y. Wang, "Study on CAD&RP for removable complete denture," Computer Methods and Programs in Biomedicine, vol. 93, vol. 266–272, 2009.

[5] M. Kanazawa, M. Inokoshi, S. Minakuchi, N. Ohbayashi, "Trial of a CAD/CAM system for fabricating complete dentures," Dental Materials Journal, vol. 30, pp. 93–96, 2011.

[6] T.L. Kwun, M. Razzoog, "Technique for transferring the path of insertion of a removable partial denture to a CAD-CAM-generated implant surgical template," Journal of Prosthetic Dentistry, vol. 117, pp. 475–477. 2017.

[7] T.F. Alghazzawi, "Advancements in CAD/CAM technology: Options for practical implementation," Journal of Prosthodontic Research, vol. 60, pp. 72–84, 2016.

[8] C. Arnold, J. Hey, R. Schweyen, J.M. Setz, "Accuracy of CAD-CAM-fabricated removable partial dentures," Journal of Prosthetic Dentistry. vol. 1, pp. 1–7, 2017.

[9] S. Yager, J. Ma, H. Ozcan, H.I. Kilinc, A.H. Elwany, I. Karaman, "Mechanical properties and microstructure of removable partial denture clasps manufactured using selective laser melting, Additive Manufacturing, vol. 8, pp. 117–123, 2015.

[10] T. Luhmann, "Close range photogrammetry for industrial applications," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 65, pp. 558–569, 2010.

[11] G. Guidi, S. Gonizzi, L.L. Micoli, "Image pre-processing for optimizing automated photogrammetry performances," ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 2, pp. 145–152, 2014.

[12] T. Luhmann, C. Fraser, H.G. Maas, "Sensor modelling and camera calibration for close-range photogrammetry," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 115, pp. 37–46, 2016.

[13] X. Wang, M. Jiang, Z. Zhou, J. Gou, D. Hui, "3D printing of polymer matrix composites: A review and prospective," Composites Part B: Engineering, vol. 110, pp. 442–458, 2017.