Transactions on Additive Manufacturing Meets Medicine
Trans. AMMM, Vol. 4, No 1, Article ID 639, 3 Pages

Infinite Science Publishing

Original Research Article

A topology optimization workflow for interfaces with anatomy-based designs

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Abstract: Generative design and especially topology optimization tools can greatly decrease production time and costs of additive manufacturing. Routine use of generative design workflows has rapidly increased over the last years in many different areas of mechanical design and additive manufacturing. Anatomically integrated applications have proven to be more challenging due to the difficulty of combining the high variability and complexity of anatomical structures with the necessary rigidity and simplicity of parameters for accurate topology optimization. As demonstration of this method three different support structures for the patient specific ***Lü****beck* ***N****euro-****A****ngiography* ***S****imulator (Lu:NAS) were designed and SLA 3D printed. The topology optimization resulted in a 66 % decrease of resin usage and 39 % shorter printing time compared to the manually designed original geometry while retaining equivalent structural support of the anatomical model. Therefore, this method presents a simple and fast approach to effectively integrate topology optimization into a variety of anatomy-based design and 3D printing workflows, lowering associated costs significantly.*

I. Introduction

The use of generative design methods in mechanical design workflows has been shown to provide a large range of advantages. Especially topology optimization (TO) of CAD parts can greatly decrease design expense, production time and material cost of additive manufacturing [1].

While routine use of TO has rapidly increased in most areas of mechanical design, anatomically integrated applications have proven to be more challenging. Anatomical structures often comprise high variability and complexity and are therefore not well suited to the necessary rigidity and simplicity of parameters for accurate topology optimization. Nevertheless, significant progress was achieved in some specialized areas such as refinement of orthodontic protheses [2].

Our aim was to generalize the integration of TO tools into a CAD workflow for anatomy-based designs and enable its use for a broad spectrum of applications.

To demonstrate this method three different support structures for the high precision and patient specific **Lü**beck **N**euro-**A**ngiography **S**imulator Lu:NAS [3,4] were designed and manufactured.

II. Material and methods

All TO operations were performed using Fusion 360 (Autodesk, San Rafael, California, USA), further processing of the optimized designs continued in NetFabb Premium 2022 (Autodesk). Preparation for 3D printing was performed in PreForm 3.24.2 (Formlabs Inc., Somerville, Massachusetts, USA) and printing carried out on a Form 2 SLA printer (Formlabs Inc.) using 100 µm layer height of clear v4 photopolymer resin (Formlabs Inc.). Postprocessing on all models included wash-out, drying and UV-curing using Formlabs Inc. Form Wash and Form Cure, respectively.

The TO-integrated workflow is comprised of two steps, where the first is carried out in Fusion 360 and the second in Netfabb Premium.

After identification of the necessary positions for antomical-technical interfaces a simplified representation of the anatomy at these sites is created. In this case different quantities of cylinders were chosen and placed in the generative design workspace of Fusion 360 in combination with a reference geometry. Finally, the material with most similar properties to Formlabs clear v4 resin, HP 3D HR CB PA 12, was selected and the TO was performed accordingly. All steps are demonstrated in fig. 1. The resulting data were CAD-converted, exported and transferred to Netfabb Premium.

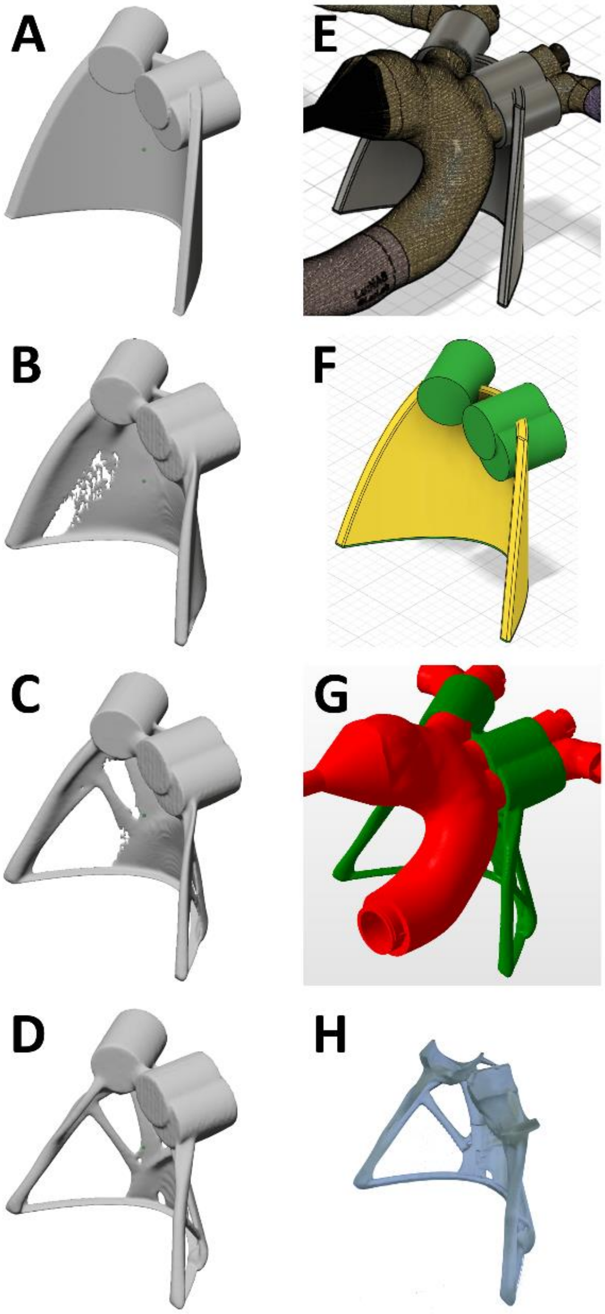

Figure 1: A to D shows the generation progress, E the cylinder layout, F the generation inputs, G the Boolean operation – red parts are subtracted from green, and H the final design after printing.

Now, the anatomical model, in our case the arterial phantom, was reintegrated into the design using boolean-style digital model subtraction. This method ensures either perfect fit between the anatomy-based and TO-designed parts or enables their digital fusion. The resulting models were manually finished and prepared for printing. Formlabs PreForm software was used to determine both resin usage and printing times for the optimized and the original topology. All models were 3D printed and postprocessed. The resulting support structures are shown in fig. 2.

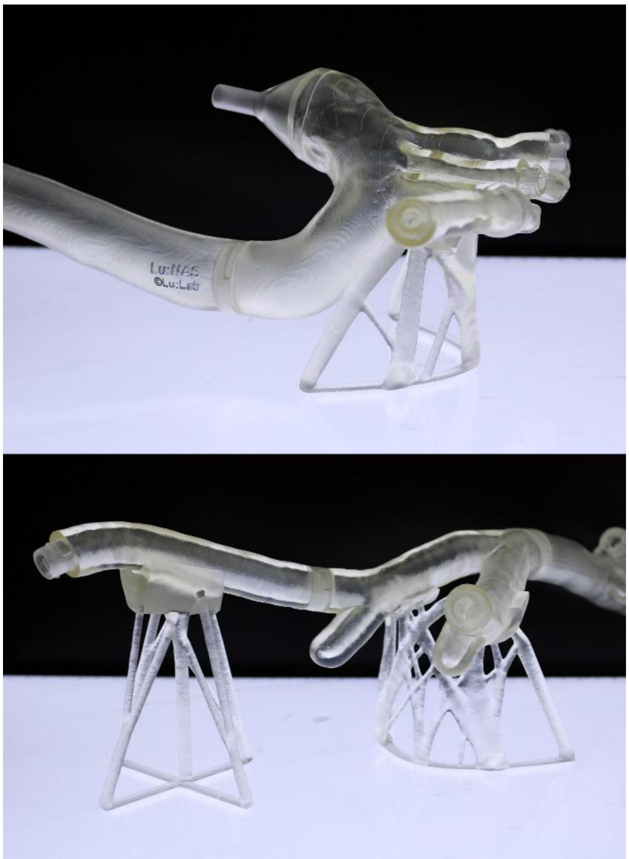

Figure 2: All three support structures in application at the Lu:NAS.

III. Results and discussion

Comparison of resin usage and estimated printing times shows 66 % (172.75 ml vs. 58.09 ml) resin and 39 % (10:45 h vs. 6:30 h) time savings.and resulted in the same stability compared to the initial design. Stability testing was performed during multiple applications and neurointerventional training sessions with the Lu:NAS. Here, participants of two hands-on courses trained coilembolization of cerebral artery aneurysms with the Lu:NAS and there was no loss of stability and no material insufficiency despite a total training time of 16 hours. In further studies, it is imperative to verify the stability of TO in use on anatomically oriented 3D printed models with objective methods. In particular, force analyses are conceivable to make the results more objective and reproducible. In the application at the Lu:NAS, however, the factors of time saving and cost reduction were in the foreground with comparable stability in the application, so that no further analyses have been carried out for the time being. For further analyses, it is also necessary to apply a TO algorithm that is optimized for the clear resin of Formlabs.

The effect of shorter printing times is less significant when only few copies are printed because the duration of any TO increases with model complexity and should be taken into consideration. Printing material savings however remain high at any scale.

Other neuro-applications may include improving topologically optimized patient-specific segmental bone replacements [5]. Instead of measuring data points for TO generation and transferring those to another application all planning steps would be carried out according to the method we described in Fig. 1. Here TO is first performed using an auxiliary structure, and in a second step the integration of anatomical precision is performed using Boolean operations. This method could improve the design and fabrication of patient-specific 3D printed implants.

IV. Conclusions

This method facilitates the integration of TO into a variety of anatomy-based workflows by creating interfaces between anatomical models and topology optimized CAD parts. The use of commercially available applications over specialized, in-house designed software further broadens applicability and ease of workflow integration. As our exemplary models demonstrate, approx. 66 % material cost savings are easily achievable without compromising part quality. Future improvements might include further increase of associated savings and demonstrating a variety of possible applications.

Acknowledgments

Development of the simulator is supported by the “Förderstiftung des UKSH”. Fraunhofer IMTE is supported by the EU (EFRE) and the State Schleswig-Holstein, Germany (Project: Diagnostic and therapy methods for Individualized Medical Technology (IMTE) – Grant: 124 20 002 / LPW-E1.1.1/1536). The University of Lübeck is supported by the EU (EFRE) and the State Schleswig-Holstein, Germany (Project: INKA, Grant: 123 19 039 / LPW-E1.1.2/1495 and Project TANDEM III-CIC: Grant: 124 20 003 / LPW-E1.1.1/1521).

Author’s statement

Authors state no conflict of interest. All methods were carried out in accordance with relevant guidelines and regulations. The use of the clinical data was approved by the institutional review board of the University of Lübeck (registry number 20-121a) in this single-center retrospective study with waived individual consent. Informed consent was waived by the same ethics committee that approved the study.

References

[1] J.-C. Cuillière, Towards the Integration of Topology Optimization into the CAD Process, Computer-Aided Design and Applications, 11:2, 120-140, 2014 DOI: 10.1080/16864360.2014.846067

[2] J. Park, Topology optimization of fixed complete denture framework, Int. J. Numer. Meth. Biomed. Engng., 00:1–13, 2019 DOI: 10.1002/cnm.3193

[3] H. Schwenke, A. Kemmling, P. Schramm, High-precision, patient-specific 3D printed models of brain aneurysms for training and therapy planning in interventional neuroradiology, Trans. AMMM, 1:1, 2019, Article ID S03P02, DOI: 10.18416/AMMM.2019.1909S03P02

[4] H. Schwenke, L. Calopresti, T. M. Buzug, P. Schramm, T. Friedrich, Modular simulation of neuroangiography and endovascular interventions in neuroradiology, Trans. AMMM, 3:1, 2021, Article ID 578, DOI: 10.18416/AMMM.2021.2109578

[5] A. Sutradhar, Designing patient-specific 3D printed craniofacial implants using a novel topology optimization method, Med Biol Eng Comput, 54, 1123–1135, 2016, DOI: 10.1007/s11517-015-1418-0