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## MULTI-SCALE TOPOLOGICALLY OPTIMIZED COMPONENTS MADE BY CASTING AND ADDITIVE MANUFACTURING

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**Key words:** Additive manufacturing, topological optimization, manufacturability, 3D-printing, design of castings

### 1. Introduction

The onset of additive manufacturing has enabled production of very complex component geometries, even straight to metal. Strictly taken, casting methods with traditional style patterns, moulds, and other types of permanent tooling are not capable of feasibly producing these type of geometries, while different direct manufacturing methods have their own challenges [1]. E.g. regarding component size, batch size, speed etc., these production processes are on complete different ends of the spectrum. However, taking a more wholesome approach where different methods are used complementary rather than exclusively, one could feasibly manufacture components that might have seemed unnecessarily complex, or even contrived, earlier.

Topological optimization is one method where such highly complex, almost organic looking geometries arise. Topological optimization is a method where material placement is optimized within a specific design space and is based on specific loads and boundary conditions [2]. In most cases, topological optimization is more about studying a concept to be refined rather than a tool to produce final designs. This is mostly due to the method itself not having anything to do with manufacturability by default. Advances in different manufacturing technologies and simulation capabilities might very well change all that. Constraints and penalization can be used to promote more processable geometries [3]. To demonstrate some possibilities of mixing manufacturing processes, three cases of topology-optimized components manufactured through applying casting and additive manufacturing routes are presented in this work.

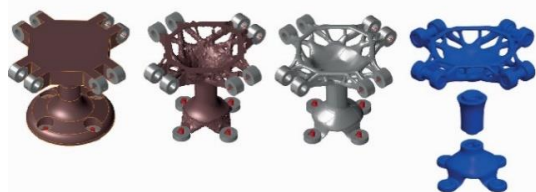


Fig. 1. From left to right, propeller hub design space, raw data, smoothed geometry and final design split into 3 pieces for 3D-printing

### 2. Experimental work

Investment casting methods lend themselves nicely to the production of intricate shapes, as the process is based on lost patterns. 3D printable waxes and plastics are easily integrated into contemporary industrial processes without the need for major changes. Fig. 1. shows process stages of a hypothetical propeller hub geometry optimization and design to be produced with investment casting. In this case, the nature of the process meant that the final design was to be a positive shape. The final 3-part design was 3D printed in wax and used as a pattern in conventional investment casting process and cast in aluminium.



Fig. 2. A-arm design space, raw data and smoothed geometry

Fig. 2. shows process stages of a hypothetical automotive A-arm optimization process, designed to be manufactured with sand casting. Sand casting is one of the most traditional industrial production methods, capable of producing small to massive components. The needed negative mould shapes are often produced through permanent patterns and core-boxes. Thus, manufacturing many raw topologically optimized shapes would require almost absurd use of cores. Methods like sand binder jetting can alleviate those problems, as there is not as much need to contemplate design parameters like undercuts, drafts etc.

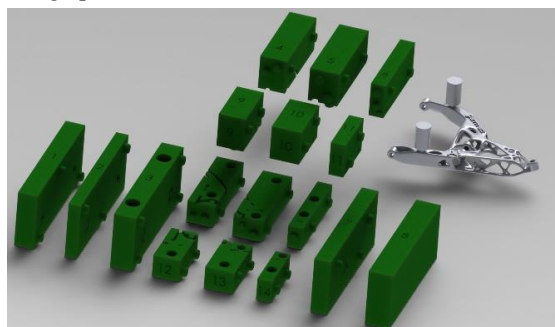


Fig. 3. Multiple piece mould construction

For the A-arm, the process required a negative geometry, a mould cavity to be designed for sand printing. To substantiate the claim that parting lines and other basic casting design viewpoints are not as important as in a traditional process, the cavity geometry was simply split in multiple parts. The heavy splitting mostly helps in cleaning unbound sand from complex cavities. Fig. 3. illustrates the used multi-part mould assembly. The final component size was roughly 60x40x10 cm (LxWxH). Fig. 4. shows the cast component.



**Fig. 4. Final cast a-arm**

If a pick-the-best-of-everything style of design thinking is taken into the extreme, additional possibilities come into play. Mixing and matching materials produced with different processes is possible. Demonstrating this approach, the propeller hub geometry was reused. The more intricate top part was 3D printed in wax, and investment cast, the middle shaft machined, and the base additively manufactured with laser sintering. These separate parts were made in stainless steel, namely AISI 316, and later laser welded to complete the assembly. The resulting component is shown in Fig. 5.



**Fig. 5. Multi-part assembly pictured on the left and a straight cast design shown on the right**

### 3. Discussion

Approaches like topological optimization are often associated to processes like metal 3D printing, as manufacturing complex geometries lend themselves nicely to many additive processes. There has been relatively little focus on optimized components made as

castings, although the processes fit nicely together if even traditionally mouldable manufacturing constraints are considered [4]. However, there are many modern technologies to be taken advantage of in both additive manufacturing, and metal-casting fields. Straight to metal printing generally still has challenges like size and material restrictions compared to castings, although the situation is constantly changing in a developing market.

Using additive manufacturing as a tool alongside conventional casting processes can spawn a best-of-both-worlds kind of a situation. The three different cases presented in this work are examples of such possibilities. The small-scale propeller hub is easily producible through casting, metal printing and even a big mix of many processes. The bigger A-arm is big enough to present challenges to metal, wax or plastic printing but not as a sand mould print. Although the concept of topological optimization itself is nothing new, a lot current research is being made partly influenced by all the new additive manufacturing methods. As with simulation approaches, one should always have a healthily questioning mind on the performance of algorithms, applied methods and inner workings of the software used [5].

### 4. Conclusion

Three distinctive styles of component manufacturing were studied in this work. The following conclusions can be made from the findings

- The use of wax patterns in a conventional investment casting process is a viable way to produce topologically optimized complex components, as the process uses lost patterns
- Sand mould printing is one conceivable way to achieve complex geometries in much larger scales
- Mixing of different production methods such as casting, machining, welding and additive manufacturing of metal parts is possible using suitable materials

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