Additive Manufacturing and 3D Printing Datasets Visualization, Simplifications, Enhancements, Optimizations, and beyond...

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Abstract

Additive Manufacturing (AM) and 3D Printing (3DP) technologies are currently used to create a wide variety of shapes and components directly from three-dimensional computer-generated models. AM and 3DP possess the right characteristics for the production, or "direct manufacturing," of many "ready-to-use" elements for a vast number of consumer applications. One main aspect related to these technologies is design flexibility. Complex components can be produced cost-effectively and in a timely manner, usually in just "one step." Analyzing, and improving, geometric constraints associated to initial design intent can translate into better visualization, dissemination, manufacturing and new production paradigms.

Introduction

AM and 3DP denote processes that embrace a wide range of materials and derivative processes employed to build parts suitable for end-use service. The virtually unlimited design freedom enabled by these technologies allow the creation of shapes, and the integration of features and function, that previously required complex, costly, and long lead-time tooling processes (Graybill, B., et al, 2013).

The seemingly new technology, its origins dating back to the late 1980s, entail formation processes for developing solid objects by the sequential delivery of energy and/or matter to specified points in space to produce a part, even using different colors or materials, as opposed to subtractive manufacturing methodologies. AM and 3DP done in parallel batch production can provide a large advantage in speed and cost compared to alternative manufacturing techniques such as plastic injection molding or die casting. Results may involve custom parts, replacement parts, short run production, or series production. When the part is used in the development process only, the appropriate term is Rapid Prototyping (Laser Institute of America, 2013).

The term Rapid Prototyping (or RP) was used widely to describe technologies which created physical prototypes directly from digital data. Users of the RP technology came to realize that the term was inadequate, and that it did not effectively describe all aspects of the technology.

Improvements in the quality of the output from current hardware have proved that there is a much closer link to the final product. RP also overlooked the basic principle of the technologies: the additive approach. Many parts are in fact now directly produced through AM so it is not reasonable to label them just as "prototypes (Gibson, et al, 2010)."

As the technology becomes more available and sales of equipment keep growing due to substantial price drops, the proliferation of AM and 3DP devices are generating another Industrial Revolution (The Economist, 2013).

Computer-generated Models

AM and 3DP processes begin with the creation of computer generated models of the parts to be produced. Three-dimensional computer models tend to accelerate the understanding of objects, from different perspectives, greatly enhancing visualization. Multiple parts can be viewed together as assemblies and examined for proper fitting. As models are refined and validated, they can be transformed into tangible elements through AM or 3DP techniques. Tangible parts, in the hands of their developers, further enrich perception and the understanding of the design intent. Perception can simply be defined as becoming aware of the external world through the action of the senses (Pizlo, 2008).

The graphic information created by means of modeling software, normally referred to as Computer Aided Drafting/Design (CAD), is converted into a Standard Tessellation Language (STL) file. Developed by 3D Systems Inc., the STL format has become the industry's *de facto standard* for AM and 3DP. The format approximates the surfaces of a model with a set of finite triangles –distributed over the external faces of the model– by which the object is represented (3D Systems, Inc., 2013).

Visualization of STL Data

Inherently, the tessellation process will generate point sets for every triangle (or facet) required to represent the object using the Cartesian coordinate system. Facets are connected to other facets, and each facet-defining point (vertex) is registered as many times as needed. The same XYZ coordinate values will be present several times, thus duplicating or replicating data.

STL Files tend to be large, particularly for complex designs, and are not aimed for visualization or assessment. One of the many trends in the industry is to explore methods to quickly visualize and verify surface integrity through universally accessible platforms (i.e., a web browser). The information can be disseminated without ambiguities or the need for specific programs.

The STL format, in standard plain ASCII character-encoding, can easily be analyzed. Point data can be identified, minimized, and used for visualization purposes. Streamlined STL-data can be used to communicate design information among members of a development team; members might include designers, engineers, administrators, and even customers. Not everyone needs access to the same data, but all require suitable information to understand end-results.

Also, in cases where inconsistencies are present in a STL file (particularly gaps), due to modeling errors or loose tessellation tolerances, streamlined STL-data can eliminate the problems and rendered an improved, corrected model, based on refinements and adjustments of point data and the enhanced connectivity maps.

The end objective is to create a physical reproduction of the computer generated model by AM or 3D Printing equipment, the polygonal mesh that represents the object has to be consistent. Consistency in this case is denoted by the concept of a *water-tight* surface. The facets generated by the tessellations of the STL format approximate all the elements related to the external faces of an object exactly in that way, producing a water-tight surface model. Understanding (and visualizing) the water-tight concept is key to understand how the AM or 3DP equipment work, and even some of their limitations.

Surface Enhancements and Optimizations

As previously implied, several traditional industrial processes used to manufacture parts are based on a systematic subtraction of material from a piece of stock. In contrast, AM produces parts through a successive addition of material layer-by-layer. The technology offers a unique freedom for the design and manufacturing of components.

The implications of how AM is changing the entire product development process relates primarily to fabrication capability: producing complex geometries that cannot be fabricated by any other means. One of the main consequences, or new paradigms, centers in the application of topology optimization methods. Topology optimization methods are aimed to redefine material distribution problems to generate an optimal functional shape.

Generally, topology optimization methods are used to assess design features of elements to be produced with traditional manufacturing processes, such as machining or casting -where the part is produced by material removal or by formative processes-. These approaches have significant constraints that must be taken into account during the design stages to ensure manufacturing feasibility (i.e., tool access in the case of machining, or the need for part removal from a mold in the case of casting or molding). These constraints limit optimal topology and a compromise has to be made between optimality and ease of manufacture (Brackett & Hague).

Significant efforts have been made in recent years to process metals in addition to polymers, and there are now several commercial devices able to produce end-use parts.

Due to the layering manufacturing approach, parts of significantly greater complexity can be produced compared with traditional processes, and the increased complexity generally does not have a significant effect on the cost of the process, providing designers a greater freedom to conceptualize parts closer to optimum than what was possible with traditional processes.

Topology optimization is a powerful approach for determining the best distribution of material for a design. Often, the optimized topology is complex and due to manufacturing constraints commonly requires either simplification following the optimization process or constraining of the design to permit manufacturability.

AM enables the manufacture of the topology irrespective of the complexity and the cost of production does not usually increase with complexity. In fact, sometimes the cost can decrease with increased complexity.

While manufacturing constraints for AM produced parts are less restrictive than for traditional manufacturing, there are still some that require consideration. Many of the AM constraints could be just labeled as manufacturing considerations, as they do not necessarily constrain the design (i.e., surface finish). Depending on the specific component applications, weight savings can be the primary objective rather than a reduction in manufacturing costs. In cases where the components will mate with other components, or when very high accuracy is required, post machining may be necessary. Therefore, machining constraints would be useful to ensure the tooling can attain access to the relevant features of the component.

The main actions to be carried out, following topology optimization, are to interpret, enhance, and if necessary modify, the optimized topology with accurate Finite Element Analysis (FEA).

While currently considered a niche area of manufacturing, its applicability is expected to increase, it is a relatively new approach to manufacturing and is seeing rapid development. AM offers great potential for physically realizing designs of greater optimality than possible with traditional manufacturing approaches.

An additional aspect to be considered is the use, or need, of supports. Depending on geometry (or "orientation" while processing), some shapes or features might require supports. Supports are used when the shape, or feature, cannot support itself during processing. Processing with supports is required when material must be deposited where there is no or insufficient material on the previous layer (including steep overhanging surfaces, straight overhangs, and fully suspended islands). Features that require support structures involve another important area of analysis, enchantments, and optimization. Visualization of the “new” shapes (require for the processing of the computer-based models) require an additional development of perception.

A good portion of the analysis and pre-processing of DDM or 3DP parts is related to the need for support structures and their pots-processing cleanup. Although possible to reduce the amount of supports needed, by modifying the minimum angles of support (usually less than 45°), or part orientation during processing, it is possible to define minimal columns of support lattice to hold up the overall shape.

Beyond...

Design for manufacturing and assembly (DFMA) has typically meant that designers should tailor designs to eliminate manufacturing difficulties and minimize manufacturing, assemblies, and logistics costs. However, the capabilities of AM technologies provide an opportunity to rethink DFMA.

The characteristics of geometric complexity and suitability for low volume production combine to yield substantial benefits in many cases for consolidating parts into a smaller number of more complex parts that are then fabricated using an AM process. This has several significant advantages over designs with multiple parts.

First, dedicated tooling for multiple parts is not required. Potential assembly difficulties are avoided. Assembly tooling, such as fixtures, is not needed. Fasteners can often be eliminated, and is even possible to design consolidated parts to perform better than assemblies.

Reduced assemblies could represent a game-changer for many of the established products in which AM process are now being introduced. The complex forms created through AM can be a single piece that replaces what is currently an assembly of many pieces. Savings could include eliminating all the work (human) effort, as well as any fastening methods involved, and all the extra features and materials that once were added to the design solely for the sake of assembly operations.

Conclusions

AM and 3DP technologies have prompted many new industrial paradigms, despite the fact that than pre-and even post-processing operations are still required. Nonetheless, within the next few years these technologies will keep growing.

CAD models tend to improve the understanding of form, shape, and even interactions (assemblies) of functional elements. Engineer must be able to communicate no only ideas and design intent but also precise instructions or data. Whether the information is empirical or analytical, data must be presented so other people can understand it quickly and easily. The human sensory systems can be trained to understand the underlying shapes to produce functional objects.

Developments related to AM and 3DP technologies promote better understanding of shape, functionality, processing and operation.

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