Title:
**Design Optimization for Socialized Additive Manufacturing Supported by Cloud Database**

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Introduction:
The advancement of additive manufacturing (AM) or 3D printing is leading a revolution in manufacturing technology by switching the dominating subtractive manufacturing to a mixture of additive-subtractive manufacturing [6]. AM enables customers to actively participate in manufacturing, which makes individualized production feasible. This triggers a new manufacturing paradigm, namely social manufacturing (SM) [8], which has drawn great research attention in recent years. In SM, 3D printers are distributed nodes inside a tremendous network, which are further classified as socialized manufacturing resources (SMRs) [4]. SM is supposed to improve the efficiency in the utilization of SMRs, which is an upgrade from the traditional manufacturing scheme in a rigid and closed manner.

One of the novel characters of SM is that the production capability of the producers can be shared among the network. On the other hand, there are many process parameters involved in AM that affect the quality of the printed part [5], and different machines that have the same raw material and process parameter setup may lead to different mechanical performances of the same end product. Therefore, it is necessary to build a database that contains the capability of the producers, as well as their proprietary process-material property linkage, especially considering that topology optimization is deeply involved in this SM network. Therefore, this paper proposes an approach to establishing the producer database and introduces the mechanism how customers, designers, and producers interact with the database in the SM environment. A case study of the design and manufacturing process of a coat hanger is conducted to verify the proposed approach.

Main Idea:
*Concept of Design for Socialized Additive Manufacturing*
Based on the data of a 3D model, AM is a process to fabricate an object by joining materials layer upon layer [2]. Thus, AM can achieve near-zero material waste and release more freedom for topology optimization-based design which used to be highly restricted by conventional manufacturing methods [10]. Topology optimization is an innovative method to design the optimal part without initial guess [11]. In essence, topology optimization is a freeform material distribution scheme, which makes it different from size and shape optimization and other design methods. As a result, topology optimization has become the major design method for products made by AM. To implement topology optimization, the mathematical model that contains objective function and constraints should firstly be established according to the design to be optimized. Geometrically, the design domain needs to be discretized, and boundary conditions as well as preserved volumes should be assigned. Then, the domain displacement can be calculated by numerical methods such as finite element method, finite volume method, and finite difference method [1]. The sensitivity analysis has to be conducted before

optimization to derive the sensitivity of the objective function towards various parameters. Subsequently, an optimizer should be selected to update the virtual density variable that indicates the new material distribution. The calculation stops if the convergence criteria are satisfied and the optimized design can be obtained.

In terms of manufacturing itself, there are a number of techniques to conduct AM, such as stereolithography (SLA), fused deposition modeling (FDM), selective laser melting (SLM), direct metal deposition (DMD) [7]. Taking FDM process for example, numerous studies have been conducted to investigate the process parameters in FDM because they can significantly affect the part properties like mechanical strength, dimensional accuracy, tolerance control, surface roughness, build time, and etc. As a result, small enterprises in short of knowledge and testing may not be able to produce parts with desired performance. The same issue applies to other AM processes.

The commercial application of AM promotes the formation of the service-oriented SM paradigm wherein anyone that owns a 3D printer is theoretically a manufacturer [8]. In SM, one of the fundamental aspects is the manufacturing service capability (MSC) [3] which should be shared in the whole system to support the demand-capability matchmaking [9]. Hence, for manufacturers in SM with AM as their main business, a database containing the printer configurations and capabilities needs to be established and shared among all the participators in SM. In this way, consumers can provide requirements for desired product functions and designers in the design community can respond to the requirement by providing their design proposals. Accepted design proposals will be rewarded, and capable manufacturers in the manufacturing community can be matched based on the design proposal and the printing capability information stored in the cloud database. Consumers can make their final decision on the manufacturer based on time, costs, and other factors. Capable manufacturers can choose whether to respond to the offer provided by the consumer. Finally, the products are fabricated based on mutual agreement and delivered to consumers. This process is proposed as design for socialized additive manufacturing (DFSAM), which is conceptually shown in Fig. 1.

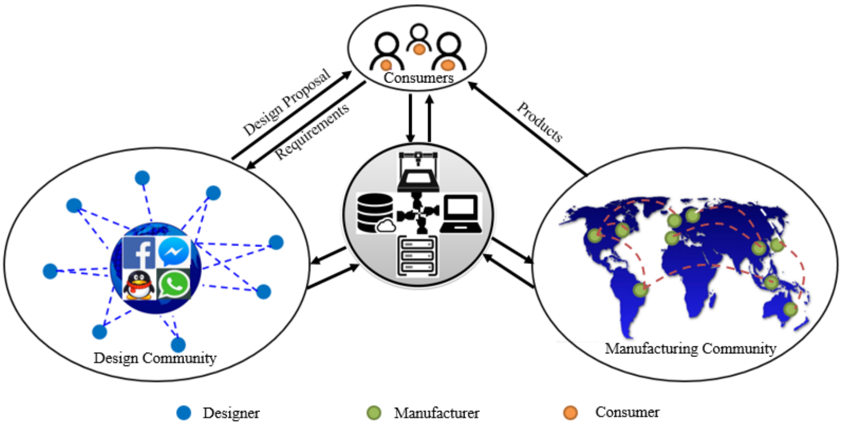


Fig. 1: Mechanism of the SM system based on AM.

*Feature based system modeling*

The proposed system is implemented based on feature modeling techniques which are widely used in concurrent and collaborative engineering [12]. As shown in Fig. 2, functional features are firstly extracted from consumer’s requirements. Subsequently, conceptual design features can be created by topology optimization according to the objects and constraints from functional features. To be ready for production, the conceptual design features which are essentially the conceptual material distribution are transformed into detailed design features by further processing in CAD software. It should be highlighted that the associative capability feature based on the associative feature concept [13] is designed to establish the links between detailed design features and additive manufacture features. The double-sided arrow indicates that, based on the information conveyed by associative capability features, detailed design features are mapped into machine readable data which are further used to match the additive manufacture features stored as manufacturing capabilities like printer configurations and types in the cloud database. Manufacturers with the matched capabilities who reach an agreement with the customer can complete the production and make the final delivery.

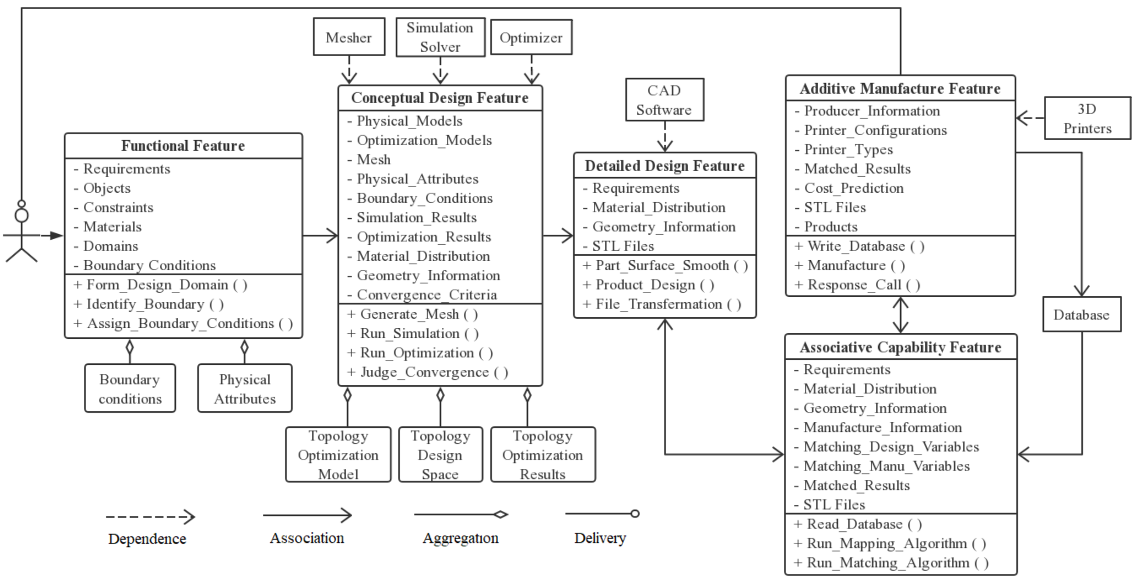

Fig. 2: Feature model of the proposed system.

*Case study*

To verify the effectiveness of the proposed system, the design and manufacturing of a coat hanger in DFSAM is studied in this subsection. Firstly, consumers post their demands for coat hangers which should satisfy requirements like size, strength, weight, cost, and lead time. The interested and available designers in the design community can respond to the call and start the design process. Some important design information is extracted from consumers' requirements and further employed in topology optimization. For instance, the strength and weight requirement are transformed into minimum compliance objective as well as the volume fraction constraint; the product size is used to guide the feasible design domain setup; the properties of the selected material are applied in the solving process of topology optimization. After completion, the concept contour of the coat hanger can be obtained, which is further embodied through detailed design to meet the functional and aesthetic requirement. The candidate designs are evaluated and ranked by consumers. The designer of the selected design will be credited, and the STL file of the selected design is generated based on the detailed design to be used as the input to the manufacturing process.

The printing capabilities of the producers in the manufacturing community are stored in a format shown in Fig. 3. A code is developed to map the implicit information from the detailed design model into machine readable data which has the same structure as the data stored in the database. Thus, the design data can be processed by an algorithm developed to match the producers' capabilities including printer type and quantity, printing dimension, motor precision, nozzle diameter, material options, and etc. The manufacturing time and costs of the matched producers can be further calculated based on the corresponding information in the database. Consumers select the capable producers based on their schedule and budget. At last, a deal can be made if the capable producers accept the offer from the consumers and the design from the design community.

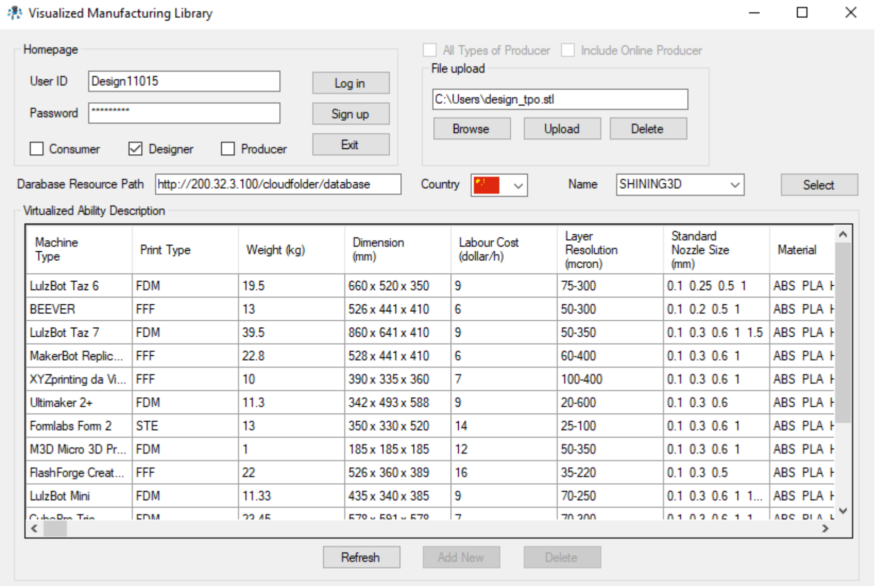


Fig. 3: User interface of the database.

## Conclusions:

The proposed system builds up links from consumers' needs to available producers. Similar to classic social manufacturing systems, accessibility, capability, time, and cost are the key criteria of searching for the match. Beyond that, design for social manufacturing is the main theoretical contribution of this paper. Unlike conventional manufacturing technology, wherein a well-engineered product is the input of the social manufacturing network, this newly proposed system has the functional requirement as the input, employs a topology optimization procedure to transform the input into an embodiment design, and then, reaches the end node, the producer. This newly proposed system takes the full advantage of the marriage between additive manufacturing and topology optimization, to provide customized high-performance design solutions.

On the other hand, a major challenge has to be addressed to make the system well rounded. Topology optimization has to utilize the machine data shared by the downstream producers, for example the material properties and machine maximum working space. Therefore, the topological design would be producer-specific, i.e., different design solution will be generated for a different 3D printer, which indicates that the total computational cost would be proportional to the producer amount. For a large manufacturing network, the computational cost would be expensive, and what's worse is the resulted bad customer experience. Delayed response to customer requirement lowers the value of the system. Therefore, concurrent topology optimization technique should be developed to address this issue, i.e., the topology optimization program should read the data from multiple producers, and then develop the optimization formulation by simultaneously configuring the multi-source data. In this way, the optimal structural design and the best producer can be simultaneously derived as the topology optimization output. The benefit is obvious that only 1/N of the computational cost is still required if data from N producers are configured into a single topology optimization problem. Sampled concurrent topology optimization algorithm and numerical examples will be demonstrated in the future work.

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