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Integrated Design in Additive Manufacturing Based on Design for Manufacturing

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Abstract**—**Nowadays, manufactures are encountered with production of different version of products due to quality, cost and time constraints. On the other hand, Additive Manufacturing (AM) as a production method based on CAD model disrupts the design and manufacturing cycle with new parameters. To consider these issues, the researchers utilized Design For Manufacturing (DFM) approach for AM but until now there is no integrated approach for design and manufacturing of product through the AM. So, this paper aims to provide a general methodology for managing the different production issues, as well as, support the interoperability with AM process and different Product Life Cycle Management tools. The problem is that the models of System Engineering which is used for managing complex systems cannot support the product evolution and its impact on the product life cycle. Therefore, it seems necessary to provide a general methodology for managing the product's diversities which is created by using AM. This methodology must consider manufacture and assembly during product design as early as possible in the design stage. The latest approach of DFM, as a methodology to analyze the system comprehensively, integrates manufacturing constraints in the numerical model in upstream. So, DFM for AM is used to import the characteristics of AM into the design and manufacturing process of a hybrid product to manage the criteria coming from AM. Also, the research presents an integrated design method in order to take into account the knowledge of layers manufacturing technologies. For this purpose, the interface model based on the skin and skeleton concepts is provided, the usage and manufacturing skins are used to show the functional surface of the product. Also, the material flow and link between the skins are demonstrated by usage and manufacturing skeletons. Therefore, this integrated approach is a helpful methodology for designer and manufacturer in different decisions like material and process selection as well as, evaluation of product manufacturability.

Keywords**—**Additive manufacturing, 3D printing, design for manufacturing, integrated design, interoperability.

I. Introduction

ADDITIVE Manufacturing and its different technologies were derived from rapid prototyping. These techniques have been evolving over three decades in the industry [1]. AM is like a revolution in the ways products are designed, manufactured, and distributed to end users in the academic and industrial environment [2]. The main difference which distinguishes AM with other conventional process is the 'layer by layer' manufacturing by adding material(s), which makes AM capable to realize extremely complex geometries. This unique characteristic of AM changes the design and it makes the designer free of constraints to design complex products. Also, it is necessary to consider all the manufacturing constraints as soon as possible to create an integrated approach. By this way, it helps the designer and manufacturer in their decisions to provide the better solution to comply with the desired product shapes [3]. It is better to consider these issues in design stage and provide an integrated design based on the concurrent engineering aspects. In other researches, DFM is used for other manufacturing processes to ease manufacturing by optimizing manufacturing, quality, productivity, reliability, cost, time of production and time to market [4]–[9]. Recently, researchers provided some approaches to apply DFM approach for AM [3], [10]–[24]. In these researches, they provided a new approach named Design For Additive Manufacturing (DFAM) but in fact DFAM is not a new concept; it is just applying the DFM approach for AM like another manufacturing process. Also, due to these researches, an integrated approach of DFM for AM is not presented till now. So, our objective is to provide an integrated and complete DFM approach for AM to manage the new manufacturing criteria coming from AM to create an interoperable process into product development in order to help designer and manufacturer in their decisions. For this purpose, DFM-Skin and Skeleton approach which was presented for traditional manufacturing process [4], [9] is used to define the different attributes of design and manufacturing process. Skin and skeleton model is used to model AM. In Section II, AM and its criteria will be explained. In Section III, the integrated design and DFM approach will be described in summary and in Section IV, a brief literature review is presented about the DFM approaches for AM which were presented by other researchers. Then, proposed approach of the paper will be explained comprehensively in Section V. Finally, the conclusions and future works are provided.

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II. Additive Manufacturing

Rapid prototyping is created to help the realization of what engineers have in mind in 1980's [25]. Nowadays, this technology has other names like 3D printing and AM. The main advantage of AM is to create almost any possible and complex geometry without using the fixtures, tooling, mold or any other additional auxiliary [26] and by increasing the complexity, the cost is not increasing contrary to traditional production methods. The fundamental attribute of AM is fabricating parts by creating layers successively which are cross-sectional. For this purpose, the process is started from a tree-dimensional solid model which is modeled by CAD model or it is achieved by reverse engineering, then the model based on the appropriate resolution is sliced into the thousands of layers. Finally, each layer is created via different technologies of AM which are explained comprehensively later [2]. AM can be utilized in short-term prototype manufacturing and small-scale series production, multi-material parts, as well as, tooling application [27]. It is like a cure for the ills of manufacturing systems such as intermediation, stock flows, divergence of functions, workforce, productivity and labor cost savings [28]. Generally, this type of manufacturing is combination of flexibility, speed and low cost which make this type of manufacturing so disruptive and interesting [28].

STL (STereoLithography or Standard Tessellation Language) file format as a standard is used to adapt all the CAD models to different AM technologies. There are another file types like SLC, SLI, CLI, HPGL and IGES [29] but the STL is the standard for every AM process. STL file creation process is to convert the continuous geometry in the CAD file into small tringles, this process is not accurate but the smaller triangles are closer to the reality [30], [31].

AM has found appropriate status between different methods of production due to its different benefits including producing complexes geometries without any additional cost, accuracy, flexibility, positive impact on sustainability, geographically delocalized production, less waste in material, no need for additional tooling, re-fixturing, etc. [28]. Despite these advantages, AM is encountered with different disadvantage including interdependency between the material and physical process, limitation in material selection, no efficiency for serial production, longer design process than manufacturing process, capacity limitation, mechanical property limitations, surface finishing problem and quality assurance as well as, the problems for post process machining [28].

Different available technologies of AM can be categorized in different groups based on the ASTM International standard which is show in Table I. Each category uses special kind of technology for production, Also, the printing ink and power source for fabrication are different based on the different materials and their characteristics, according to these differences, different properties and levels of quality are created [2].

TABLE I
CLASSIFICATION OF AM PROCESSES BY ASTM INTERNATIONAL STANDARD [2]

Categories	Technologies	Printed Ink	Power source	Strengths/downsides
Material Extrusion	Fused Decomposition Modelling (FDM) Contour Crafting	Thermoplastics Ceramic slurries Metal pastes	Thermal Energy	Inexpensive extrusion machine Multi-material Printing Limited part resolution Poor surface finish
Power Bed Fusion	Selective laser Sintering (SLS) Direct Metal Laser Sintering (DMLS) Selective laser Malting (SLS) Electron Beam Melting(EBM)	Polyamides Polymer Atomized metal powder (17-4PH) Stainless steel Cobalt chromium Titanium (Ti6A-4V) Ceramic powder	High-powered Laser Beam Electron Beam	High Accuracy and Details Fully dense parts High specific strength & Stiffness Power Handling & recycling Support and anchor structure Fully dense parts High specific strength and stiffness
Vat Photo polymerization	Streolithography (SLA)	Photopolymer Ceramics (Alumina, zirconia, PZT)	Ultraviolet Laser	High Building Speed Good Part resolution Over curing, Scanned line shape High cost for supplies and materials
Material Jetting	Polyjet/Inkjet Printing	Photopolymer/wax	Thermal Energy/Photo curing	Multi-material Printing High surface finish Low-strength material
Binder Jetting	Indirect Inkjet Printing (Binder 3DP)	Polymer Powder (Plaster, Resin, Ceramic Powder, Metal powder)	Thermal Energy	Full color object printing Require infiltration during post processing Wide material selection High porosities on finished parts
Sheet laminate-on	Laminated Object Manufacturing (LOM)	Plastic Film, Metallic Sheet, Ceramic Tape	Laser Beam	High surface finish Low material, machine, process cost
Direct Energy Deposition	Laser Engineered Net Shaping (LENS) Electron Beam Welding (EBW)	Molten Metal powder	Laser Beam	Repair of damaged/worn parts Functionality graded material printing Require post-processing machine

For one technology to another, different criteria such as part orientation, manufacturing direction and material behavior, slicing strategy and layer thickness , speed and post-processing procedure are important to get an efficient production and accurate model [31]. For example, in Fused deposition modeling, the most important criteria are the layer thickness, road width, air gap, deposition speed, infill density, infill and support structure, etc. which must be determined to provide an efficient process.

Today, AM is used in different domains such as light weight machines, aeronautic, biomedical, architectural modelling, art and specially in customization production [25] and other scopes that everyday different progress is adding. Therefore, it is necessary to improve the performance of the AM in different aspects. In the next section, the Integrated Design as a method for improving the AM by integrating the design step and manufacturing constraints is described.

III. Integrated Design

According to the standard (NF X50-415,94), Concurrent Engineering or Simultaneous Engineering is the process of taking into account the needs of each different stages of the product life cycle simultaneously [32]. Therefore, concurrent engineering aims to integrate product life cycle knowledge earlier during the design process and different engineering activities must be integrated together and performed in parallel rather than in sequence [9], [33]. So, the iteration between the design activities which create the advantages in time, quality and cost is reduced. The strategy of concurrent engineering is to integrate the material and manufacturing constraints into the design procedure as well as, tool utilization must be computer-based to ensure the accuracy [4]. Since, the design is the most important stage in the product life cycle and simultaneous engineering is related to the design step, it is necessary to explain the integrated design.

There is a need to determine the design step in detail to define a product. Also, by optimizing the design stage the total cost can be reduced up to 70% thereby the production cost is optimized significantly [4]. Integrated design is an approach considering all aspects of the product life cycle in its design like functions, analysis, manufacturing, assembly, recycling, etc. [34]. In this approach, the design solution is based on the material constraints, attributes and designer experiences. The integrated design is illustrated in Fig. 1.

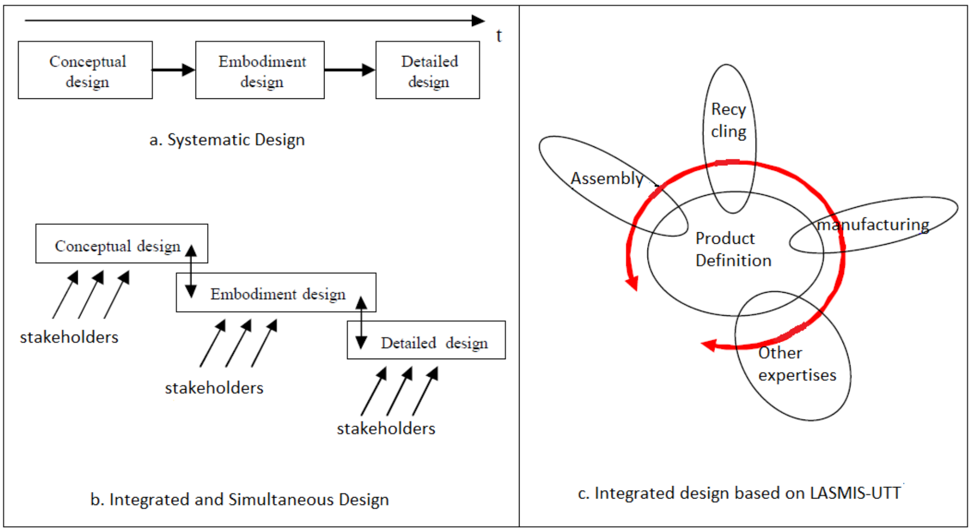

Fig. 1 Integrated Design [4]

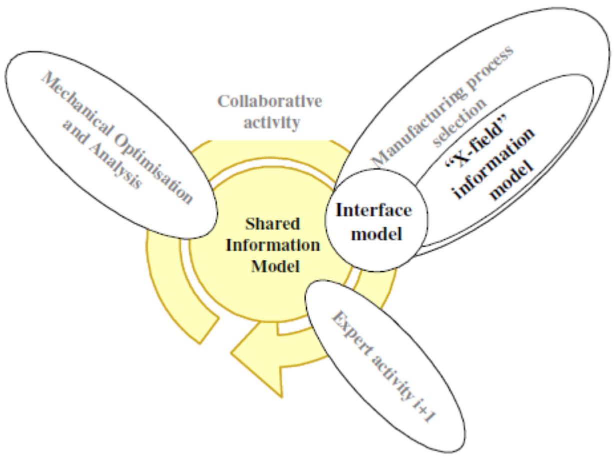

Fig. 2 Design for x in concurrent engineering [9]

According to Fig. 1, indeed, the simultaneity is presented by overlapping stages of the design process and integration through the involvement of professional actors and stakeholders on each step. This approach is known as the design for X (DFX) where X represents the different professional activities. In the part c, this design approach is presented according to the work of our research team-LASMIS. DFX emphasizes the intervention of different expertise profession in the product definition [4]. Therefore, DFX which is linked to the concurrent engineering or it can be treated no longer independently, is assessing and integrating "x-field" information. In Fig. 2, the status of DFX in concurrent engineering framework is shown[9]. In this research, DFM approach is used to provide an integrated framework for AM which will be explained in the rest.

Generally manufacturing is a sequence of processes for transforming raw or partially processed material into a final product that has value for the customer [35]. The manufacturing processes are chosen during the conceptual design of the product. The all pre-defined design constraints including the manufacturability of the part using the company's or suppliers existing machines and processes must be met in design phase [36]. Also, various studies show that detecting and rectifying the errors in the design phases of the product cost less than when rectifying at manufacturing or further downstream stages [37]. So, manufacturing and assembly must be considered during product design as early as possible in the design cycle [4]. Since, about 70% of manufacturing costs of a product (cost of materials, processing, and assembly) are determined by design decision. Therefore, handling manufacturing problems in the design stages has influence on the cost, time and quality [37] , these issues underscore the need for approach of DFM to integrate the product design and process planning and manufacturing into one common activity in order to design a product that is easily and economically manufactured. So, The DFM approach which is chosen for our study will be explained in the next section.

A. DFM

DFM as an integral methodology aims to simplify the manufacturing process, increase the productivity and minimize cost while maintaining the product quality in desirable level [36]. This technique is used to optimize the product and process concepts during the design phase of a product to ensure ease of manufacture [38] by optimizing the manufacturing, quality, productivity, reliability, cost, time of production and time to market [4]. Generally, the products which are designed based on the DFM approach contains less number of parts that can be assembled more easily in a shorter time and with higher quality [4]. The benefits of DFM can be summarized as:

- Improving the quality of new products during developing period including design, technology, manufacturing, service, etc. [6].
- Cost reduction, including cost of design, technology, manufacturing, delivery, technical support, discarding, etc. [6].
- Reduction in time of development for new products including time of design, manufacturing preparing, and repeatedly calculation [6].
- Improving manufacturing by ensuring the quality and reliability [7], [38].
- The manufacture participation in the upstream process [7], [38].
- Improving the communication between the departments [7], [38].

DFM is considering the limitations related to the manufacturing at the early stage of the design, the design engineer must select among the deferent materials and technologies and estimate the manufacturing time and cost quantitatively and rapidly among the different schemes. They compare all kinds of the design plans and technology plans, then the design team will make revises as soon as possible at the early stage of the design period according this feedback information and determine the most satisfied design and technology plan [6].

The Systematic DFM approach involves the range of activities such as the selection of processes, materials selection and evaluation of the manufacturability of a product which is shown in Fig. 3 [4].

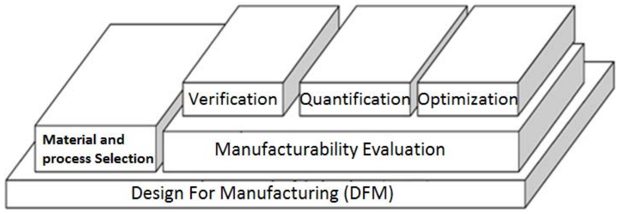

Fig. 3 Systematic Approach for DFM [4]

The DFM activities are described as:

- The selection of processes and materials which are the most important factors in design solution for manufacturing. It is necessary to consider the design optimization during the selection of process activities [4], [39].
- The evaluation of manufacturability consists of analysis and evaluation of the ability to produce and design with the necessary requirements and with minimum cost and time. For this purpose, it is necessary to decompose the product to sub-elements (for example surface, dimension, tolerance, etc.) due to the manufacturing data, this evaluation consists of three step as follow:
- Verification: Manufacturability determination of products including: [40]
  - Identification the design intention and manufacturing capacities.
  - Accepting the compatible concepts with existed solutions, if the manufacturing is complex.
  - Rejecting the design plan which requires expensive changes in the production system.
- Quantification: The parameters must be quantified like cost, Time, quality [7].
- Optimization: Optimization must be done based on three levels of Human (competence), means (machines, tools and software), Product (design) [41].

IV. State of Art

A. AM in DFM

Since AM is a technology that produced the parts directly from the design stage, it seems necessary to provide an integrated framework for DFM approach to consider all manufacturing and design aspects as soon as possible in order to improve the productivity. Different researches proposed an approach named DFAM approach as a new approach, but actually DFAM is not a new approach, it must be considered that AM is a manufacturing process like others and DFAM is just applying DFM approach for AM. In one of these research, A new design for AM method is provided which supports part and specification modelling, process planning and manufacturing solution based on the process-structure-property-behavior model [10]. In another research [11], a framework for DFM consists of four steps of representing design requirements, determining manufacturing rules coming from the requirements, structure the problem repository, retrieving and ranking the DFM problems is provided. Another approach based on the process-structure-property-behavior model is proposed which Unit Cell-Based Design approach is used to achieve the minimum weight, desired compliance distribution and for finding the optimal size Particle Swarm Optimization (PSO) algorithm is used [12]. Also, It is interesting to combine AM with another traditional manufacturing process to utilize the advantages of these technologies simultaneously to provide a better solution for design and manufacturing. Therefore, for the first time an approach for DFM which combines AM with machining process in a hybrid modular vision is presented to choose the best way to obtain each module [13]. Also, it is a need to provide a knowledge-based support tool for AM and it is developed for providing a DFM approach for AM. So, they provided an environment database named Wiki for documentation and using DFAM knowledge [14]. In another research, an approach is proposed which consists of global analysis for finding the geometrical dimensions due to the dimension constraints, permitting the fulfillment of the dimensional and geometrical specification due to the AM process characterization and capabilities and finishing process characteristics to determine the functional volumes and finally determining the physical and assembly requirement based on the AM process capabilities to determine the linking volumes including Functional Volume (FV) and Manufacturing Direction (MD) [15]. In another research [16], the approach contains determining functional specification, part orientation, design area, functional optimization and manufacturing path optimization to consider manufacturing part and CAD model at the same time. Another DFM approach for AM is also provided and it is including specification analysis, preparing the initial shape, definition the parameters' set, parametric optimization and validation of the shape [17]. Also, a Geometric DFX for AM is provided to considers 3D parts as input and automatically analyze all the manufacturability issues based on the predefined rules based on the machine and AM type like maximum part size, thickness, minimum feature size, rib reinforcement check, … [18]. A systematic search is presented for identifying the components of design for AM based on the criteria including integrated design, individualization, lightweight design and efficiency. These components are analyzed due to the different requirements to develop DFM in both technological and economical direction [19]. Moreover, in another one [20], Multi-criteria decision making approach is used to select the best solution for design which is obtained by the method including specification analysis, initial concept, interpretation of result and design evaluation. Also, a multi-level design method for AM is developed and CAD model design requirement and manufacturability are considered as inputs and topological optimization are adapted consequently to find the optimal structure in macro-level and lattice structure in meso-level [21]. another approach [22] is also presented which consists of design specification including analysis of initial CAD model based on the functional and performance requirements and design process including function integration, structure optimization, verifying the design solutions due to the process constraints. A Design for Rapid prototyping approach [23] is provided to allow the design of parts satisfying both DFA and DFM in the earliest phase of the design but this possibility will limit a priori costly late changes. A new two-dimensional approach is proposed for process chains modelling for AM to support the process selection, concurrent engineering and DFM in the early phase of design [24]. In order to overcome the poor dimensional accuracy, another DFM approach is also provided and mathematical formulation is used to formalize the dimensional deviations to redesign of component knowing the prediction of the obtainable dimensional deviation. The modifications are carried out in the design step to compensate the deviations to improve the accuracy and the methodology is applied to mathematical definition of the surface. For this method, there is not a need to fabricate the part and perform measurement to gain the model, it just requires to apply this method directly before CAM environment [3].

According to this literature review analysis, there is a need to present a complete and integrated approach of DFM for AM. So, our objective is to provide an integrated approach to show AM process from the first step in detail in order to show and manage the new manufacturing criteria coming from AM in order to get an interoperable process with product development. This methodology must take into account AM characteristics and criteria into the design and manufacturing hybrid process of a product. Generally, our research scenario which shows AM integration in product development is illustrated in Fig. 4.

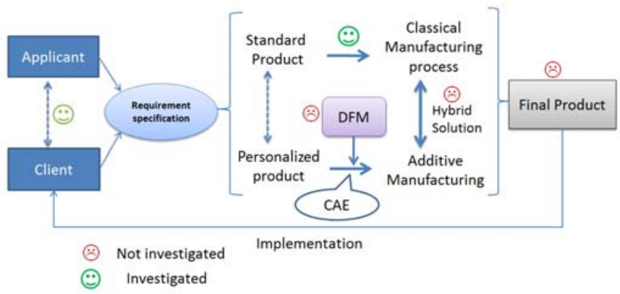

Fig. 4 Research Scenario

As shown in Fig. 4, the first step is determining the required specification for each product due to the knowledge of the specialist as well as, the user which is performed in other researches [42], [43]. Due to the capability of AM in customization production, the personalized products are used to produce with AM technologies due to our presented approach. Since, there is no integrated methodology to consider the criteria and characteristics coming from AM in the design and manufacturing steps simultaneously, the DFM approach must be applied in order to facilitate the design and manufacturing procedure concurrently. There are the gaps in the performed researches in proposing DFM approaches and also using hybrid solution for production which are illustrated by sad smiles. Therefore, our aim is to present a detailed and integrated approach for DFM to help designer and manufactures to find the best solutions for their process and producing the hybrid products. In the next section, the proposed DFM approach will be presented.

V. Proposed Methodology: Applying DFM Approach for AM

According to other researches [4], [9] which were performed to present an integrated DFM approach, DFM-Skin and Skeleton approach seems helpful in providing an integrated DFM approach. Since fabrication must be considered in product definition, this approach is used to model manufacturing process based on the manufacturing database, simulation, design characteristics and product definition as well as, the software for production definition. Therefore, for presenting an integrated DFM approach for AM, DFM-skin and skeleton approach is provided. Till now, this approach was used for another Manufacturing process in previous researches [4], [9] but in this research, it is utilized to model the AM manufacturing process, as well as, the product concurrently. As shown in Fig. 5, AM is modeled by the skin and skeleton model and these skin and skeleton are provided due to the attributes which are defined based on AM process and product definition simultaneously. This model must be integrated into the interface model to provide a model that considers all the manufacturing and product attributes at the same time and this integration is useful to present the product solutions and process alternatives due to the manufacturing constraints. In the rest, this approach is described in the detail.

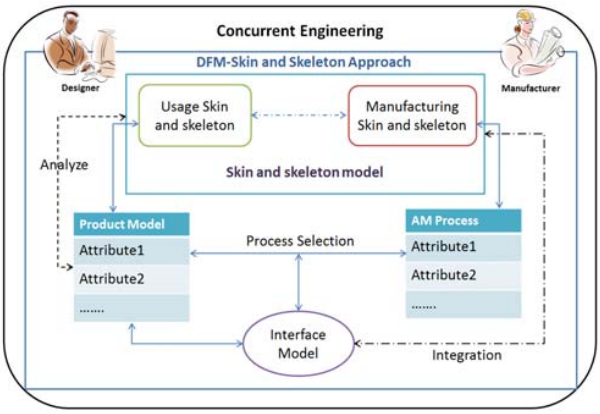

Fig. 5 Proposed DFM-Skin and Skeleton approach for AM

The interface model which can be considered as an output for this approach represents the minimum information required and it supports the synthesis of both design and manufacturing attributes. This approach provides a data exchange between the usage and technological database like functional data and technological selection as well as, process and manufacturing database. Based on [4], [9], [44], two types of interface model including usage and manufacturing interface model are presented. The usage interface model which shows the requirement and manufacturing one is a kind of manufacturing information model.

In our approach, skin and skeleton model are utilized to model AM. According to the [4], [9], [44] skin used to describe the functional surface of product and skeleton are for presenting the flow trajectory. Moreover, two kinds of the skin and skeleton features are existed: Usage features and Manufacturing features. These features are described as:

- **Usage skin:** usage skin is the surface which energetic flows circulate through it. For defining the usage skin, functional surfaces resulted from technological components selections are used. This skin supports the geometric attributes and tolerance.
- **Usage skeleton:** this skeleton is a kind of energetic flow (mechanical, electrical, magnetic, etc.) which circulates in the product.
- **Manufacturing skeleton:** This skeleton is flow trajectory processed during manufacturing. It is assumed that every manufacturing process is based on a material flow.
- **Manufacturing Skin:** This skin is the surfaces which are generated by manufacturing process. These features are partly issued from manufacturing skeleton by a sweeping operation.

Specific set of attributes are associated with skin and skeleton features. Skin attributes are including the shape, tolerance, and roughness as well as, material direction. For the skeleton attributes, initial section form, final section form, section variation and neutral fiber can be mentioned. In addition to these attributes, an extra attribute for material flow direction such as removal, addition or deformation are presented for manufacturing skeletons.

In summary, the proposed approach consists of Providing Design Requirement, Functional structural model, Skin and Skeleton Model, Selecting alternative solutions. In order to use this approach for AM technologies, this approach must be adapted to the AM attributes. For creating the usage Skin, the topological optimization is used to create and design usage skin that, in addition to complying specific mechanical performance, should be less expensive [45], [46] by optimizing the structure and amounts of the material rather than primary model. The usage skeleton can be defined by the surface that material flows through it. Since, AM is a method that produces the parts by adding the material in layers, the material sense is considered as adding.

The manufacturing skin is defined by the CAD model which is converted to the suitable format like STL, STEP due to the utilizable machine. Since, the AM process generates the complex forms in once time, the manufacturing skin is integrated in one part as a complex form.

The manufacturing skeleton is created by determining the manufacturing parameters like part orientation, slicing strategy, nuzzle speed and diameter, road width, raster angle, air gap, raft and support material characteristics, infill density, temperature and post-processing, etc. Different alternative solutions for manufacturing are provided by choosing the different values for these parameters and different technologies can be presented for manufacturing technologies. The attribute values must be determined for the appropriate technologies to present a best way to produce the part.

Overall, the main benefit which encouraged us to use these modelling concepts is to take into account the manufacturing knowledge very early in product definition.

VI. Conclusion and Future Works

In this article, an integrated approach is provided for AM based on the DFM approach to apply Concurrent Engineering aspects through several AM technologies. DFM approach is used to consider the manufacturing constraints in the design stage as soon as possible. DFM skin and skeleton is rather used for modeling (or representing) AM process in the earlier step of product development. It helps to create a geometry model by integration the design and manufacturing attributes simultaneously. This approach is including skin and skeleton of usage for providing the desired part based on the design attributes and also manufacturing skin and skeleton based on the manufacturing attributes and constraints. It provides a data exchange between the usage and technological database like functional data and technological selection as well as, process and manufacturing database. According to these databases, the interface model is created to support both of the design and manufacturing attributes concurrently in order to define a product. Based on this method, different alternative solutions for design and manufacturing are provided and DFM specialist must select the best solution according to the desired specification.

For the future work, to show the capability of this approach, it will be applied on the Hook bag. For this purpose, the manufacturing and usage skin and skeleton are provided based on the DFM and Concurrent Engineering aspects. The experimental methods and Mathematical model and meta-heuristic algorithms as decision making tools can be used to provide the best solution for design and manufacturing processes.

References

[1] D. L. Bourell, M. C. Leu, and D. W. Rosen, "Roadmap for additive manufacturing: identifying the future of freeform processing," *Univ. Tex. Austin Austin TX*, 2009.

[2] W. Gao, Y. Zhang, D. Ramanujan, K. Ramani, Y. Chen, C. B. Williams, C. C. L. Wang, Y. C. Shin, S. Zhang, and P. D. Zavattieri, "The status, challenges, and future of additive manufacturing in engineering," *Comput.-Aided Des.*, vol. 69, pp. 65–89, Dec. 2015.

[3] A. Boschetto and L. Bottini, "Design for manufacturing of surfaces to improve accuracy in Fused Deposition Modeling," *Robot. Comput.-Integr. Manuf.*, vol. 37, pp. 103–114, Feb. 2016.

[4] A. Skander, *Méthode et modèle DFM pour le choix des procédés et l'intégration des contraintes de fabrication vers l'émergence de la solution produit*. Troyes, 2006.

[5] K. G. Swift and J. D. Booker, *Process Selection: from design to manufacture*. Butterworth-Heinemann, 2003.

[6] X. Xie, "Design for manufacture and assembly," *Utah Dept Mech.*, 2003.

[7] G. Boothroyd, "Product design for manufacture and assembly," *Comput.-Aided Des.*, vol. 26, no. 7, pp. 505–520, Jul. 1994.

[8] J. Elgueder, F. Cochennec, L. Roucoules, and E. Rouhaud, "Product-process interface for effective product design and manufacturing in a DFM approach," in *3rd International Congress Design and Modelling of Mechanical Systems*, Tunisia, 2009, p. 8p.

[9] A. Skander, L. Roucoules, and J. S. K. Meyer, "Design and manufacturing interface modelling for manufacturing processes selection and knowledge synthesis in design," *Int. J. Adv. Manuf. Technol.*, vol. 37, no. 5–6, pp. 443–454, Jun. 2007.

[10] D. W. Rosen, "Computer-Aided Design for Additive Manufacturing of Cellular Structures," *Comput.-Aided Des. Appl.*, vol. 4, no. 5, pp. 585–594, Jan. 2007.

[11] S. Yim, "A retrieval method (DFM framework) for automated retrieval of design for additive manufacturing problems," Citeseer, 2007.

[12] C. Chu, G. Graf, and D. W. Rosen, "Design for Additive Manufacturing of Cellular Structures," *Comput.-Aided Des. Appl.*, vol. 5, no. 5, pp. 686–696, Jan. 2008.

[13] O. Kerbrat, P. Mognol, and J.-Y. Hascoët, "A new DFM approach to combine machining and additive manufacturing," *Comput. Ind.*, vol. 62, no. 7, pp. 684–692, Sep. 2011.

[14] Z. Doubrovski, J. C. Verlinden, and J. M. P. Geraedts, "Optimal Design for Additive Manufacturing: Opportunities and Challenges," 2011, pp. 635–646.

[15] R. Ponche, J. Y. Hascoet, O. Kerbrat, and P. Mognol, "A new global approach to design for additive manufacturing," *Virtual Phys. Prototyp.*, vol. 7, no. 2, pp. 93–105, Jun. 2012.

[16] R. Ponche, O. Kerbrat, P. Mognol, and J.-Y. Hascoet, "A novel methodology of design for Additive Manufacturing applied to Additive Laser Manufacturing process," *Robot. Comput.-Integr. Manuf.*, vol. 30, no. 4, pp. 389–398, Aug. 2014.

[17] B. Vayre, F. Vignat, and F. Villeneuve, "Designing for Additive Manufacturing," *Procedia CIRP*, vol. 3, pp. 632–637, 2012.

[18] T. Kannan, "Design for additive manufacturing," Jul-2013. (Online). Available: http://geometricglobal.com/wp-content/uploads/2013/11/Geometric_Whitepaper-Additive-Manufacturing_July-2013.pdf.pdf. (Accessed: 27-Apr-2016).

[19] C. Klahn, B. Leutenecker, and M. Meboldt, "Design for Additive Manufacturing – Supporting the Substitution of Components in Series Products," *Procedia CIRP*, vol. 21, pp. 138–143, 2014.

[20] K. Salonitis and S. A. Zarban, "Redesign Optimization for Manufacturing Using Additive Layer Techniques," *Procedia CIRP*, vol. 36, pp. 193–198, 2015.

[21] Y. Tang, J.-Y. Hascoet, and Y. F. Zhao, "Integration of Topological and Functional Optimization in Design for Additive Manufacturing," p. V001T06A006, Jul. 2014.

[22] S. Yang and Y. F. Zhao, "Additive manufacturing-enabled design theory and methodology: a critical review," *Int. J. Adv. Manuf. Technol.*, vol. 80, no. 1–4, pp. 327–342, Sep. 2015.

[23] N. Boyard, M. Rivette, O. Christmann, S. Richir, "A design methodology for parts using additive manufacturing", In: International Conference on Advanced Research in Virtual and Rapid Prototyping (VRAP), Portugal, 2013-10-01, High Value Manufacturing: Advanced Research in Virtual and Rapid Prototyping: Proceedings of the 6th International Conference on Advanced Research in Virtual and Rapid Prototyping, Leiria, Portugal, 1-5 October, 2013

[24] M. K. Thompson, A. Stolfi, and M. Mischkot, "Process chain modeling and selection in an additive manufacturing context," *CIRP J. Manuf. Sci. Technol.*, vol. 12, pp. 25–34, Jan. 2016.

[25] K. V. Wong and A. Hernandez, "A review of additive manufacturing," *ISRN Mech. Eng.*, vol. 2012, 2012.

[26] Y. Zhang, A. Bernard, R. K. Gupta, and R. Harik, "Evaluating the Design for Additive Manufacturing: A Process Planning Perspective," *Procedia CIRP*, vol. 21, pp. 144–150, 2014.

[27] J. Stampfl and M. Hatzenbichler, "Additive Manufacturing Technologies," in *CIRP Encyclopedia of Production Engineering*, L. Laperrière, G. Reinhart, and T. I. A. for P. Engineering, Eds. Springer Berlin Heidelberg, 2014, pp. 20–27.

[28] C. Cozmei and F. Caloian, "Additive Manufacturing Flickering at the Beginning of Existence," *Procedia Econ. Finance*, vol. 3, pp. 457–462, 2012.

[29] J. W. Halloran, V. Tomeckova, S. Gentry, S. Das, P. Cilino, D. Yuan, R. Guo, A. Rudraraju, P. Shao, T. Wu, T. R. Alabi, W. Baker, D. Legdzina, D. Wolski, W. R. Zimbeck, and D. Long, "Photopolymerization of powder suspensions for shaping ceramics," *J. Eur. Ceram. Soc.*, vol. 31, no. 14, pp. 2613–2619, Nov. 2011.

[30] R. Noorani, *Rapid prototyping: principles and applications*. John Wiley & Sons Incorporated, 2006.

[31] J. Gardan, "Additive manufacturing technologies: state of the art and trends," *Int. J. Prod. Res.*, pp. 1–15, 2015.
[32] "NF X50-415, « Management des systèmes - Ingénierie intégrée - Concepts généraux et introduction aux méthodes d'application »,1994.
[33] G. Sohlenius, "Concurrent Engineering," *CIRP Ann. - Manuf. Technol.*, vol. 41, no. 2, pp. 645–655, 1992.
[34] S. Tichkiewitch, "De la CFAO à la conception intégrée," *Rev. Int. CFAO Infogr.*, vol. 9, no. 5, pp. 609–621, 1994.
[35] G. Pahl, W. Beitz, J. Feldhusen, and K.-H. Grote, "Conceptual Design," in *Engineering Design*, Springer London, 2007, pp. 159–225.
[36] D. Effa, O. Nespoli, and S. Lambert, "Using the Case Method to Facilitate Learning of Design for Manufacturing and Cost," *Proc. Can. Eng. Educ. Assoc.*, 2015.
[37] R. Rajadhyaksha, "Turning designs into reality: The Manufacturability paradigm," *Geometric Ltd.* May, 2012, (online) available: http://geometricglobal.com/wp-content/uploads/2013/03/Turning-designs-into-reality-The-Manufacturability-paradigm1.pdf
[38] A. R. Venkatachalam, J. M. Mellichamp, and D. M. Miller, "A knowledge-based approach to design for manufacturability," *J. Intell. Manuf.*, vol. 4, no. 5, pp. 355–366, Oct. 1993.
[39] J. Corbett, M. Dooner, J. Meleka, and C. Pym, *Design for manufacture: strategies, principles and techniques*. Addison-Wesley Reading, MA, 1991.
[40] D. T. Koenig, *Manufacturing Engineering: Principles for Optimization: Principles for Optimization*. CRC Press, 1994.
[41] S. Arimoto, T. Ohashi, M. Ikeda, S. Miyakawa, and M. Kiuchi, "Development of Machining-Producibility Evaluation Method (MEM)," *CIRP Ann. - Manuf. Technol.*, vol. 42, no. 1, pp. 119–122, 1993.
[42] J. Nicolás and A. Toval, "On the generation of requirements specifications from software engineering models: A systematic literature review," *Inf. Softw. Technol.*, vol. 51, no. 9, pp. 1291–1307, Sep. 2009.
[43] M. Wilson, "Chapter 6 - Specification Preparation," in *Implementation of Robot Systems*, Oxford: Butterworth-Heinemann, 2015, pp. 133–146.
[44] L. Roucoules and A. Skander, "Manufacturing process selection and integration in product design. Analysis and synthesis approaches," in *Proceedings of the CIRP Design seminar, Grenoble*, 2003.
[45] N. Gardan and N. Gardan, "Knowledge Management for Topological Optimization Integration in Additive Manufacturing, Knowledge Management for Topological Optimization Integration in Additive Manufacturing," *Int. J. Manuf. Eng. Int. J. Manuf. Eng.*, vol. 2014, 2014, p. e356256, Feb. 2014.
[46] N. Gardan and A. Schneider, "Topological optimization of internal patterns and support in additive manufacturing," *J. Manuf. Syst.*, vol. 37, pp. 417–425, Oct. 2015.

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