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DESIGN FOR ADDITIVE MANUFACTURING

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ABSTRACT

Additive manufacturing (AM) is increasingly used in different fields. At first, it was specific to prototyping and proof of concepts. Nowadays, it is used in many areas. AM allows the fabrication of non-removable assemblies in one go, with two or more different materials. The complexity of the parts is not limited with the tool access or other blocking issues of traditional processes. The only limitation is the imagination of the designer. This brings up a change of paradigm when thinking the design of new parts, or the re-engineering of existing assemblies. To benefit from these advantages, a new design approach must be developed; it should take into account the specificities of the process, and help the designer find optimum solutions. The design methodologies have been developed for a long time, they are mostly thought for a specific life cycle or a specific manufacturing process. Because of the differences of AM technologies, the design thinking of these processes is important in the laboratories using AM. The aim of this paper is to present the traditional methodologies, outline the need for a specific one, and present a new methodology concerning the DFAM (design for additive manufacturing), including the factors influencing the design, and the added value compared to the cited methodologies.

Keywords: *Additive Manufacturing, Design, Methodology, Manufacturing Process, 3D Printing*

1. INTRODUCTION

Additive manufacturing is taking a predominant role in different fields. It has been used in prototyping and proof of concepts since the 80's, starting with the SLA (stereo-lithography apparatus) process. The knowledge of the process and the development of the machines are rapidly growing. The advantages compared to traditional process are undeniable (Figure 1). Nowadays, there are a lot of different processes using multiple mechanisms, there is selective laser sintering or melting that fusion a powder bed to manufacture layer by layer a metallic or a polymer prototype. There is FDM (fused deposition modeling), categorized as 3d printing, which is the most used process due to its small cost; and many other different processes that are developed for specific applications. There are also different domestic and industrial machines with different goals. A huge variety of materials can be implemented in those machines, it can be plastic for domestically use, Carbone fiber for automotive and aeronautic field, or titanium for the biomedical tools and implants.

The AM process allows the fabrication of parts without managing the trajectory of tools or thinking the reuse of the molds. This gives many advantages compared to traditional ways of manufacturing (figure 2). It allows an unlimited complexity of the parts. This gives a total freedom for the designer to unleash his imagination and think about creative assemblies, thus respecting the functional specifications of the client. Some prototypes made with AM cannot be realized in another way, for example, a sphere that can move freely inside another sphere, knowing that this assembly is made in one manufacturing operation, without any intervention.

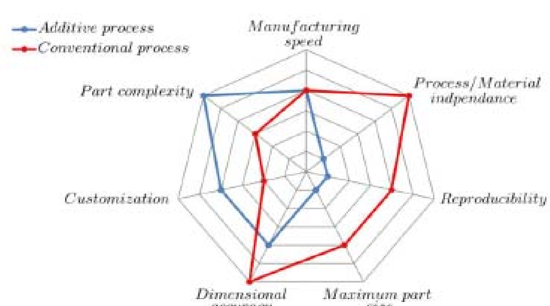

Figure 1: Performance Of AM Compared To Conventional Manufacturing [1]

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Depending on the process, some manageable parameters allow to modify the porosity or the surface condition of the final part. This allows the development of a gradient of material, which can be used in aeronautic field for instance. It will guarantee the mechanical performance; on the second hand, it will ensure the thermal resistance of the component.

The design methodologies have been studied for a long time. They are generally oriented for a special life cycle or a determined manufacturing process, including all the specificities related to it.

The specificity of the AM requires a change of paradigm when thinking the design of a mechanical assembly. New parameters must be taken into account for each process. The first order is to analyze these parameters to include them in the methodology. In the AM field, there is no limitation about the complexity of the design; however, the material cost is higher than the one of traditional processes, that's why the topology of the product must be optimized to have the less possible amount of material. The including of support must also be optimized to gain weight and cost.

2. ADDITIVE MANUFACTURING SPECIFICITIES

2.1 Complex Parts

Some unthinkable designs can be made with AM machines. The internal topology can be optimized to gain weight and still respect the functional specifications. This allows the design of parts that can be integrated in the human body, such as implants that provide a good environment for the bone ingrowth thanks to the porous structure that is similar to the natural bone. These structures have high mechanical performance according to their weight, and they are impossible to do with traditional processes. Even the FDA (United States Food and drug administration) authorized and regulated the use of AM processes for the manufacturing of medical tools. They developed technical considerations for designers.

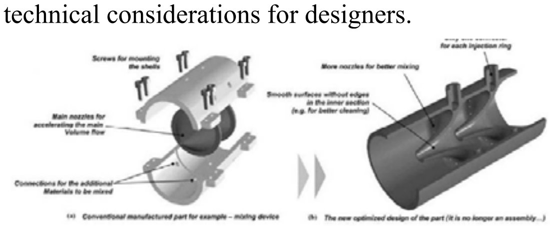

Figure 2: Redesigning an assembly to take the advantage of AM [2]

The complexities of the prototypes that can be implemented in AM machines allow rethinking existing products, which gives the possibility to avoid unnecessary assemblies and to make some prototypes in a one single go (figure 2).

The AM processes are based on the stack of layers of melted material that form the product. The design of these layers is determined by the intersection of the part with equidistant plans, which gives a closed shape. Any part can be represented in this way. On the other hand, the manufacturing of these complex parts is monitored by new procedures that must be integrated to the design methodology.

2.2 Non Removable Assemblies

AM allows the fabrication of non-removable assemblies in one go. The condition is to integrate support (figure 3) between the parts to allow the movement of one relative to the others [3]. When integrating these sup-ports, the designer must take into account the volume of the support and the dissolution, to have an adequate surface condition.

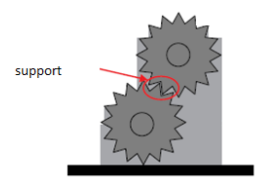

Figure 3: Example of a non-removable assembly [4]

2.3 Multi materials

To optimize the mechanical properties and the cost of a prototype, some AM machines integrate multiple buzzards that can make parts with two or more materials [5]. This technique allows having different performances on the same part. The compatibility of the melting temperature of different materials must be integrated into the design methodology. It can also permit the conception of a graded material, which opens a new research and development area. On the other hand, the designer must study the heterogeneity of the materials to choose the most suitable assembly strategy (figure 4).

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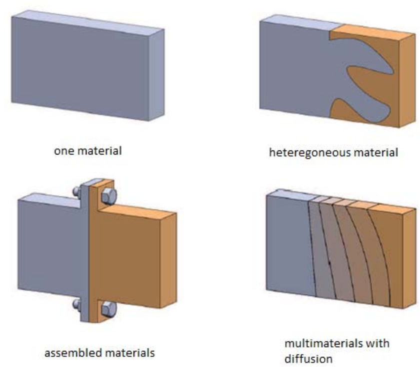

Figure4: Material compatibility according to chemical and physical constraints [4]

2.4 New Limitations

Each process comes with new constraints. In the case of AM processes, the limitations are:

- ✓ In case of closed structure, the material can be stuck inside the part. The evacuation must be anticipated, with the integration of a draining hole for example.
- ✓ Fusion temperature of materials must be managed according to the power of the melting source. In case of multi-materials, the compatibility of the temperature range must be evaluated.
- ✓ Crystal plasticity of the material must be taken into account. The change in temperature can act on the different phases of the material.
- ✓ There is material limitations, for example, the wood and the glass can't be implemented in AM.
- ✓ When producing an assembly with multi materials, there is a compatibility constraint that must be studied, such as post process heat treatments.
- ✓ Fabrication strategy and the positioning of the part are important to ensure the specified surface condition and the mechanical response [6][7]. The staircase effect (figure 5) and the integration of supports are determined by this fabrication orientation [8].
- ✓ Because of the gravity and the cases of hollow or curved shapes (figure 5), support must be integrated to en-sure the fabrication. On the other hand, the removal of the added material must be anticipated.

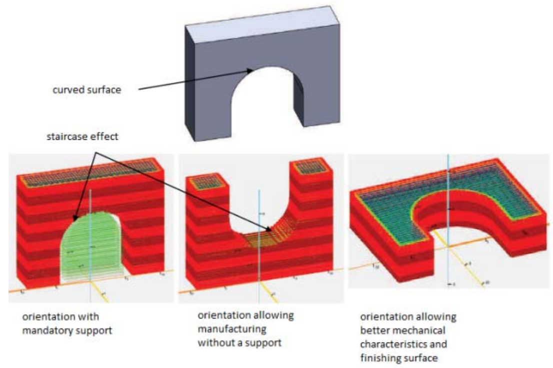

Figure5: Staircase effect [4]

2.5 Importance of the Design Process

The possibilities offered by AM in the design area make the need of a DFAM methodology obvious. The products are getting more complex, which impose a change of paradigm on their design phase. The market competition is rapidly growing and the end users have different expectations, thus, the prototypes must be modular. Finally, the clients have high quality expectations, then, the manufacturing sequence must be well studied to respond to their expectations.

Since 1983 with Reinertsen [9], followed by Ciavaldini 1996 [10], the importance of the design phase has been shown as predominant for the profit of the manufacturing projects. Here are the factors that influence the profit with their impact:

Table 1: Impact according to factors

Factors	Profit impact
Six months delay in launching phase	-31.5 %
Quality problem requiring a 10% discount	-14.9 %
Volume reduction	-3.8 %
Exceeded product cost	-3.8 %
Exceeded development budget	-2.3 %

The launching phase or the designing phase is the cost that penalizes the most the budget. The development speed allows many advantages, such as the increase in the sales lifetime and the market share. On the other hand, a slow design phase makes a lost in the market share, the profitability and the commercial image.

2.6 Influencing Factors

According to [11], the creativity is influenced by the following resources:

- ✓ Cognitive factors: intelligence and knowledge
- ✓ Conative factors: personality and motivation

- ✓ Emotional factors
- ✓ Environment

The factors that impact the most AM are the cognitive factors (intelligence and knowledge); because the added value here is the innovation and the new paradigm involved by these AM processes.

The information that must be integrated on the DFAM methodology is [12]:

- ✓ Material knowledge:
  - o Integrate material shrinkage into the 3D design
  - o Limit oxidation, water uptake or aging of the material during storage
  - o Minimize the impact of anisotropy on part behavior with an adapted orientation during manufacturing
  - o Minimize the impact of the position during manufacturing on the thermal cycle of the prototype, to ensure the adequate crystalline phase of the material
  - o Identify material equivalents between prototype and serial parts
  - o Reduce the internal constraints and porosities when choosing the manufacturing strategies
  - o Know the "approved" materials for a specific machine
  - o Remove geometries that can lead to deformations
- ✓ Process knowledge
  - o Adapt the geometries to the characteristics of the selected machine (thickness, height, dimensions…)
  - o Make the voids for the removal of any residual material
  - o Place the parts according to the axis accuracy
  - o Limit the dispersion between batches by assigning the same machine to a series
  - o Reduce the staircase effect by choosing a layer thickness adequate to the maximum resolution of the machine
  - o Choose the most suitable orientation to minimize the support
- ✓ Product knowledge
  - o Add the functional play in the numerical model to guarantee the functioning of the assemblies
  - o Merge multi-solid files
  - o Transform the client file into a compliant faceted file
  - o Use TO (Topological optimization) to guarantee an optimized compromise between mass and performance
- ✓ Procedural knowledge
  - o Dedicate a machine to a material to simplify the series change
  - o Avoid full shapes
  - o Optimize the production density by mixing several product for a same production
  - o Perform the tradeoffs quality/manufacturing time by fixing the play of the settings
  - o Reduce material costs by modulating the purity of materials
  - o Ensure compliance with ISO 9001 and ISO EN 9100

The result is a realistic optimized part that can surely be manufactured on a specific machine following an appropriate machining procedure.

2.7 Conclusion

Many interconnected parameters must be managed to achieve an optimized product using AM, such as the geometry, the material or the orientation during the fabrication. This orientation must be validated with the expected roughness of the surfaces, but also with the volume of the machine. On the other hand, the machine choice depends on the material that can be fabricated on it. All these variables form a complex matrix that must be studied to determine the best case scenario for the product.

3 DESIGN FOR X

3.1 Sequential Methodologies

Researchers have been working on design methodologies since the beginning of the industrial revolution and the machining processes. The difference between the methods is in the goals. Some try to optimize the cost, others the mechanical properties and some methodologies are specified for a particular process.

The traditional methodologies used in most factories are sequential; with an "over the wall" principle (figure 6); each step must be completed before moving on to the next [13]. Generally, the first step is the client specifications, it comes after the marketing to detail the different tasks that must be achieved with the product, and it also contains the geometry data. Secondly, according to the performance and nature of the manufacturing process, the different functional surfaces are detailed and conceptualized. The final step is the implementation of the design on the machines, and the optimization of the fabrication.

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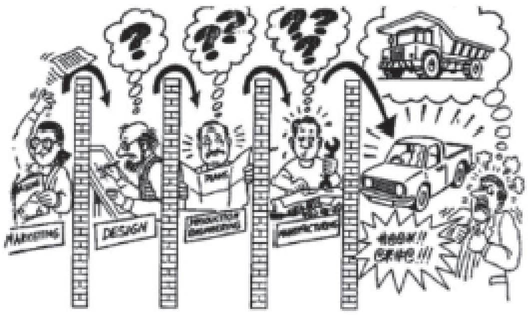

Figure6: Over the wall effect [14]

Howard [13] made a design study of the sequential methodologies (figure 7), and came with the conclusion that all of them have the same structure; it starts with the client specification to end with the final prototype, in a sequential manner. After analyzing the client needs, the tasks are dispatched between the different offices. The first office works on the concept and how the prototype can do what is expected from it, the second works on the architecture of the different parts that are going to make the assembly, then comes the detailed design involving the precise dimensions and their tolerances, also the material and all the physical and mechanical data of the prototype. Finally, this information is used to manufacture the desired assembly.

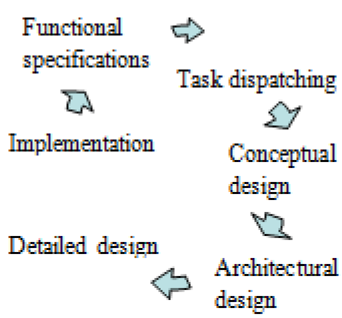

Figure7: Howard et al [13] sequential methodology

Following the sequential methodologies, the optimization will be time consuming, because each step must be revalidated before moving on to the next. The added value of AM is the possibility to design innovative proto-type, the methodology must then be flexible, and therefore, the designer must use a new methodology for AM.

3.2 Integrated Methodologies

The second type is the integrated methodologies; they are widely used in architecture of buildings, it can then easily be interpolated to the engineering of products. They consist on teamwork during all the design phases. They allow the interdependence of the design choices. To be validated, each design choice must be approved by all the services (marketing, design, methods, quality, and sales). Thus, the modification and the optimization of the product are easier and guaranteed [15].

The integrated methodologies are based on the design for X [16], the goal is to optimize the design for a specific life cycle phase of the product, such as:

- ✓ Design for assembly: the goal is to optimize the cost and production time of the assemblies, and ease the junction between the different parts of the product. AM allows the fabrication of non-removable assemblies, this design is then obsolete, especially if it is possible to manufacture high precision mechanical connections.
- ✓ DFM (Design for manufacturing) [17]. The goal is to optimize the fabrication time and the manufacturability for a specific process. The defining parameters are the cutting tools and there trajectories. To assure the manufacturability, this methodology takes into account the business rules and the design indicators [18].
- ✓ Design for additive manufacturing, it is the same principle as the DFM, the limitations of the process are discussed in 2.4. This type of methodology has three determinant aspects :
  - o Approach: if the 3D model exists, there are two different approaches. The first is the direct approach, the design is based on the zones hard to manufacture by the process. It's generally used when reengineering an existing prototype, because it's dependent on the pre-established geometry. The second approach is the indirect one; it is based on the modification of an existing manufacturing sequence to decrease the cost and production time.
  - o Manufacturability: it's measured in four different manners:
    - ▪ Binary: it is based on the dimension or the quality to determine with a yes or no if the manufacturing is achievable.
    - ▪ Qualitative: this qualification is subjective, it qualifies the manufacturability with adjectives (very easy, easy, normal, hard, very hard)
    - ▪ Quantitative: it's based on the comparison of the manufacturability following different strategies. This allows classifying

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the strategies with a common scale, which is often a numerical index.
- Direct: this measure is objective, it evaluates simply the cost and production time.

o Interaction: the interaction corresponds to the input and output of the methodology, the input is generally the 3D parts not the client specifications. The output is the evaluation of the manufacturability of the product.

✓ Design for cost or environment or any other goal

4 DESIGN FOR ADDITIVE MANUFACTURING

4.1 Introduction

Since the raising interest of different fields for AM, some design methodologies have been developed to benefit from the adding value of these processes. However, the knowledge around the manufacturability of these processes is still limited; thus, the design methodologies are still maturing.

New limitations must be integrated when thinking the fabrication of the product, such as the adequate orientation that will ensure the respect of the client specifications [19][20], the integration of supports, or many other limitations discussed above (2.4).

There are two types of methodologies for additive manufacturing. The first is based on a process choice. In this case, the goal of the methodology is to determine the adequate process to develop the product, and it's based on the cost and the mechanical response of the manufactured material [21], and also the performance and the machines volume. However, some important details are not taken into account, such as the orientation of the product on the manufacturing phase. Therefore, these methodologies don't guarantee the manufacturability of the part.

The second type is based on the opportunity [22]. There is no limitation on the part design shape or complexity; the only constraints are the ones from the client specifications. Each volume is functional, obligatory and minimum. The topology of the product is optimized for the selected process (figure 8), to gain weight, time and cost.

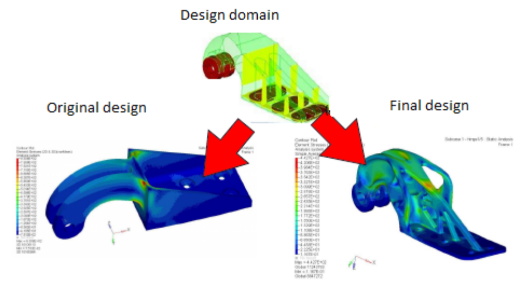

Figure8: Illustration of the opportunity methodologies using the topological optimization [23], here the first design is made to be manufactured by a three axe milling machine; the second is made for AM.

The manufacturing methodology in AM is the same for all the processes (figure 9). It starts with a computer assisted design using 3D software in case of an innovative product, or a 3D scanner if the aim is to re-engineer an existing part. The model is then trenched in a way that can be integrated to the machine (figure 10), with a commonly used ".stl format". The path of the nozzle during the fabrication is generated with adequate soft-ware in G-code format that correspond to the machine input format. Afterwards, the machining begins. Finally, the post process of the prototype is operated to remove any residual stress or eventual support. A checking phase close the process, it aims to test of the mechanical performance of the prototype, if all the conditions are met, the chain is over, if not, the designer modify the CAD (computer aided design) model and redo the process.

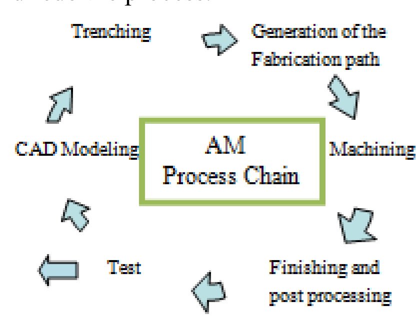

Figure9: Classical process for AM

Figure10: A trenched 3D part [3] [5]

4.2 Ponche Methodology

Some researchers developed their own methods, such as R. Ponche [24] who developed in

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2013 a methodology specified for the CLAD (direct additive laser construction), it is based on the SLS (selective laser sintering) process; the difference between the two processes is that the powder is melted in the nozzle, not in the powder bed, the second difference is the material. This design methodology takes the functional specifications and the machine parameters as an input. The designer needs to follow the steps and choose between different designs solutions that respond to the constraints of the client, and are achievable by the machine. However, the part orientation during the fabrication is not taken into account efficiently.

The methodology is conceived around four steps, the first is the definition of the design domain. Here the de-signer enters the geometry and the functional surfaces, including the finishing surface achievable by the ma-chine and the one desired by the client. This first step gives a 3D part. The second step is the theoretical geometry definition. The designer includes the load constraints that are going to be applied to the prototype, and then a topological optimization is carried out to obtain an ideal model at the cost viewpoint. Thirdly comes the realistic geometry, here the physical parameters of the manufacturing process and machine are taken into account (temperature, speed, materials that can be implemented …), the designer simulates different fabrication strategies to find the exact parameters. Finally, the different solutions are indexed and detailed to facilitate the choice of the most suitable solution.

This methodology is interesting because it takes into account the client specifications, the process and the machine specificity. The designer role is simplified, he just have to choose the most suitable solution between all the realizable simulations done at the third step.

On the other hand, some issues are not considered by this methodology, such as the result of the topological optimization that is fixed. The authors think that the design must be modified to have appealing designs. To conclude, Ponche methodology is highly oriented toward the CLAD process and can be enhanced at the shapes validation step.

The authors' methodology is inspired from Ponche work, but has some added value. First, the suggested methodology considers the parameters that can influence any AM process; it is not personalized for only one process. Secondly, to better the shapes and the overall design of the product, one can modify the result of the "TO". More importantly, the cognitive factors that influence the way of thinking of the designer are integrated in the decision making at each step.

5 NEW METHODOLOGY FOR ADDITIVE MANUFACTURING

After analyzing the previous design methodologies, with their advantages and their drawbacks, the authors developed their own. The objective is to start with the client specifications, without a fixed idea about the part that the designer is working on. Then, following the methodology step by step, he obtains a realistic, optimized prototype that can surely be implemented on a specific machine.

The authors' methodology takes the client specifications, the process knowledge and the business rules as an input (surface finish, layer thickness, compatible materials, minimum angle, speed …). These data is taken from the machines documentation or their associated software. On the other hand, the output is a 3D numerical part with an optimized topology, trenched and ready to be manufactured on a specific machine.

The methodology that the authors developed has 5 big steps (figure 11); it must be followed in a sequential manner to guarantee the manufacturability of the designed prototype. Beginning with the client specifications, the data must be understood and translated into a set of information according to the loads, the dimensions and the assembly constraints that must be respected by the product. Then the designer looks for the conception domain, which is the intersection of the process domain and the functional domain. Any data integrated into the 3D part must be in the range of both the functional and the process domain. Afterward, he optimizes the resulted volume to gain weight and cost, and then the designer validates the

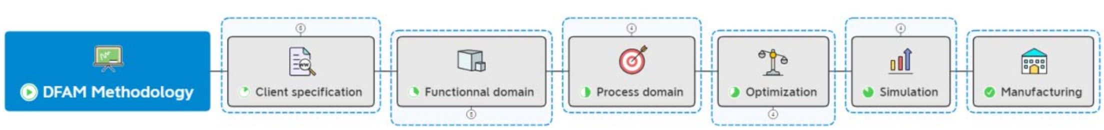

Figure11: New DFAM Methodology

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prototype by simulations. Once it is validated, the manufacturing process can begin.

5.1 Client Specifications

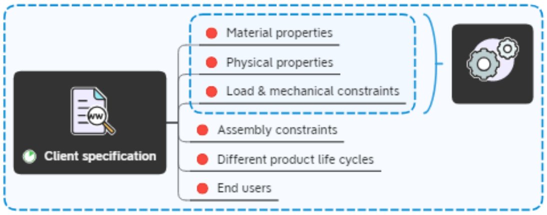

Figure12: DFAM Client specifications

The methodology starts with the translation of the client specifications into concrete data that can be implemented into the 3D prototype, these data include material properties (physical, chemical, thermal, electrical, magnetic, acoustical and optical properties) that are related to the application of the conceived part. The client specifications also include the assembly constraints, such as the movement freedom of a part according to the others, or the distance between them, or the constraints that must be respected to achieve the desired application.

The aim of any manufacturing operation is to satisfy a client order. So the first step is to understand the demand, by detailing every aspect of the client specification. The information that must be extracted is the following:

- ✓ Functional surfaces
- ✓ Functional volumes
- ✓ Dimensions
- ✓ Tolerances
- ✓ Assembly constraints
- ✓ Material information and physical constraints
- ✓ Load and mechanical constraints

5.2 Functional Domain

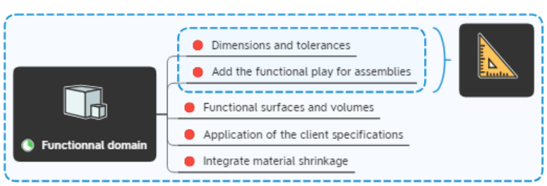

Figure13: DFAM functional domain

The second step is the definition of the functional domain, in response to the client specifications. The de-signer starts with the functionality of the product, and the tasks that must be achieved by it. This gives the functional surfaces that represent the basis of the 3D part. Then, he creates the functional entities that will achieve the different tasks. To do so, he must integrate the minimum thickness to ensure the manufacturing of the volumes. After that, he has to add the assembly constraints of these entities, and verify if the movement freedom between the entities is respected.

The functional surfaces are all the contact surfaces issued from the client specification analysis (figure 12), which integrate the surface finish and the geometric tolerances. These surfaces can be normalized (bearing, screw, nut…) or designed manually.

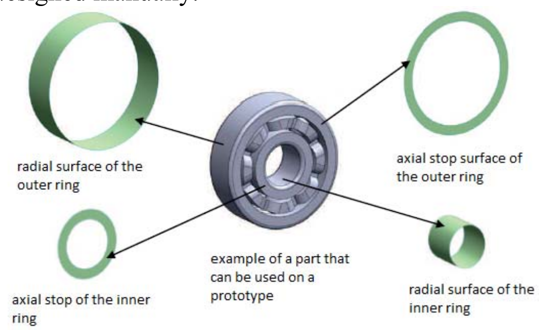

Figure14: Mandatory functional surfaces (bearing case) [4]

Depending on the process, the material and the part orientation, some functional surfaces need an oversize thickness to assure their manufacturability (figure 13).

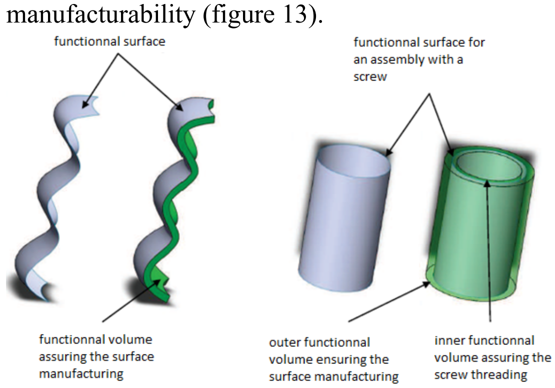

Figure15: Functional volume [4]

From the client specification, he determines the minimum volume that responds to all the criteria (figure 13). To do so, he assembles the constraints one by one until he obtains a closed volume. Then he adds the material type and other physical properties. Afterwards, he incorporates the dimensional tolerances. At the end, he has a designed part with a minimum volume that respond to the client specifications.

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5.3 Process Domain

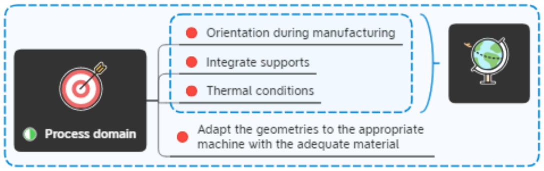

Figure16: DFAM process domain

To gain time and avoid complex modifications, the methodology integrates the process characteristics at an early step to guarantee the manufacturability, and help the designer choose the most adequate surface and functional volumes. The authors base their methodology on an indirect approach.

The third step is the process domain, in this part the designer integrates the process details and the machine constraints, to find a suitable environment that guarantee the manufacturing of the product. Depending on the client specifications related to the material and the dimensions, also to the availability of the machines and the operative cost of the processes, he chooses the adequate process. Then according to the operative volume of the machine, he determines the one that allows him to manufacture the product in an orientation that will respect the desired dimensions.

This part is about the process that is going to be used. Each process has its own application domain, with specific advantages and drawbacks. The first limiting constraint is the material. For example, there are only three processes capable to manufacture metals in additive manufacturing. Then these processes must be validated according to the thermal aspects. The second limiting constraint is the resolution and the minimum wall thicknesses that assure the product manufacturability.

The design domain is the intersection of the functional and the process domain (figure 14). The process do-main contains the minimum thickness "em" achievable by the machine and the finishing thickness "ep" that guarantee the desired finishing surface. The functional domain contain the functional surfaces (in green), and the volume where the volume where the material can be integrated.

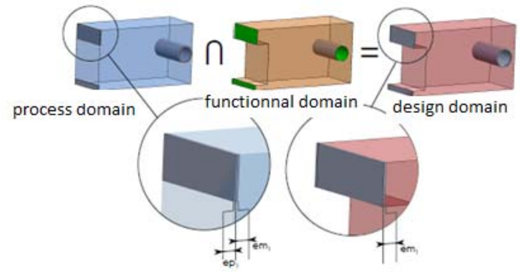

Figure17: Illustration of the design domain [24]

After choosing the adequate process, an appropriate machine must be used, according to the manufacturing volume and the acceptable operative production time.

At the end of this step, the machine in which the designed part can be manufactured is determined.

5.4 Optimization

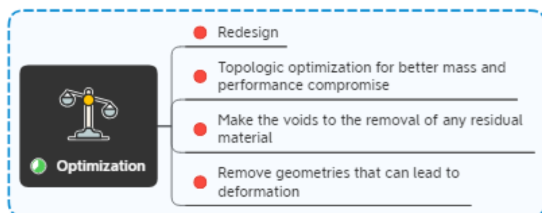

Figure18: DFAM Optimization

The next step is the optimization of the actual volume (figure 15 and 16). The authors start with the TO (Topology optimization) [25] [26], it is a finite element method that defines the minimum volume in a given space, and guarantees the mechanical response to a given set of constraints and boundary conditions. Some 3D soft-ware integrate this function, there is also specific TO software dedicated to it, such as "Inspire". To do so, a specific TO software must be used, where the client specifications and the actual volume are entered, and then the mathematical method is lunched. The resulted design is often unthinkable and not attractive; however, it guarantees the mechanical response of the product to the constraints that it will endure during its life cycle. The shapes can then be rounded to have an acceptable design.

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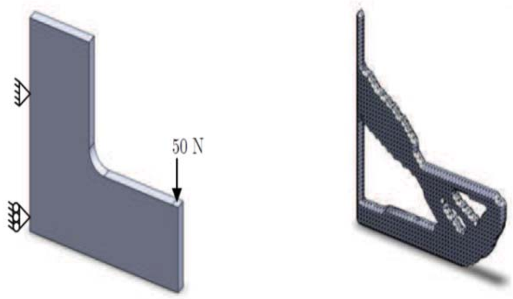

Figure19: Topology optimization example [4]

Figure20: example of TO [27]

Ullman (2009) [28] has stated that: ‘‘it has been estimated that fewer than 20% of the dimensions on most components in a device are critical to performance. This is because most of the material in a component is there to connect the functional interfaces and therefore is not dimensionally critical. Once the functional interfaces between components have been determined, designing the body of the component is often a sophisticated connect-the-dots problem.”

This step is about the optimization of the manufacturing phase. At first, the topology optimization is done to gain weight, cost and production time, and then the design is modified to make the product appealing. Then the most suitable orientation for manufacturing is determined. For some processes, the integration of supports must also be anticipated.

At the end of this part, the decomposition of the designed part into successive layers can be lunched.

5.5 Simulation

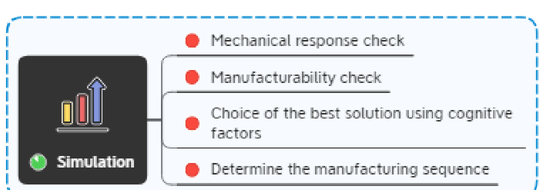

Figure21: New DFAM Methodology

Finally, the simulations are lunched to verify the manufacturability of the product using the selected process, and the selected machine. Then the mechanical response of the resulted 3D part is checked according to the constraints issued from the client specifications. The feasibility of the different tasks that must be achieved by the product is also verified.

Based on the manufacturing simulation, the designer determines the manufacturing sequence that guarantee the feasibility of the prototype. The simulation result must validate the client specifications with binary and quantitative measures.

This step is about the simulation of the manufacturing process to ensure the feasibility of the prototype. The mechanical response is also simulated according to the client specifications.

5.6 Synthesis

After analyzing the simulations results, the designer must choose the adequate solution. Here, the creativity plays a predominant role, because there is no geometry limitation, the only limitation is from the imagination of the designer.

The added values to the existing methodologies are in the decision making, the cognitive factors (intelligence and knowledge) are taken into account to decide about the most suitable solution. The proposed methodology also affords a better product design by modifying the result of the TO. Finally, it is a generalized methodology that can be transposed to any AM process.

6 CONCLUSION

AM processes allow the design of complex parts. The process parameters are all interconnected; the mechanical performance depends on the geometry and the material, but also the orientation during the fabrication. On the other hand, this orientation influences the surface roughness and depends on the machines volume. The machine choice limits the material that can be used. The connections between these parameters impose a flexible integrated design methodology, to allow the optimization and the modification of the prototype easily. The sequential methodologies that distribute the task in a step by step way are not efficient for AM processes.

Because of new process limitations such as the orientation during the fabrication and support integration that are not manageable by the traditional methodologies, a specific AM designs methodologies must be developed.

Ponche methodology is interesting for AM; it takes into account the machines parameters, and the specification of the client, to develop an

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optimized design for the product, without being limited by the complexity of the shapes. It has served as base for the authors work, however, it can be improved on the manufacturability step, especially because of the importance of the orientation during the fabrication; it must take into account the volume of the machine, but also the resulted surface roughness and mechanical performance of each positioning. Moreover, it should be generalized to any AM process, and the resulted product is more appealing.

This paper gives a feedback about existing design methodologies; it shows the specificities of AM processes. It also outlines the need for personalized methodologies to benefit from the advantages of these technologies, such as high product design complexity and possibility to make a multi material assembly in one go. Finally, it presents a methodology that affords a new way of design thinking, with respect to the client specifications and the machines achievable performance, also with added value compared to the existing DFAM methods.

The next step is to do a proof of concept to emphasize the adding value of the methodology. And to compare a prototype designed with different methodologies. On the other hand, one can think of specific methodologies for each AM process.

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