INTRODUCTION OF A DESIGN FOR RAPID MANUFACTURING (DFRM) PERSPECTIVE IN ENGINEERING DESIGN EDUCATION

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ABSTRACT
With the advent of Rapid Manufacturing (RM), substantial changes in the product development cycle are expected but not yet defined. RM is not intended to accelerate the prototyping phases but to improve the global design process as well as the selection of the final manufacturing route, which is enough to change how conventional products are conceived for fabrication. Rapid manufacturing principles have important implications in design, with advantages such as: design freedom, ease of customization, economic low volume- high value products, and so on. In this work is analyzed how engineering design education might play a major role on teaching to the new, and developing designers, how to take profit of the advantages this technologies can offer and how to avoid the incorporation of unnecessary constraints to their designs, which might limit the full potential of RM. At the end a "Free Design" Triz like matrix is introduced as a first step for the contact between RM processes capabilities and students or designers who are struggling with new design proposals and conventional manufacturing restrictions.

Keywords: Rapid Manufacturing, conceptual design, design restrictions

1 INTRODUCTION

Rapid Manufacturing is defined as the production of end use parts, directly or indirectly from a Rapid Prototyping Technology [1]. Whatever the process is, it relays on the direct conversion from 3D modelled data to a real part. Though it seems simple, RM would mean the replacement of moulds, dies, inserts, tooling and any other production means for a single additive process. This is not currently possible due to the lack of materials with stronger properties and the high cost of the RM equipment. However, the first successful applications of RM have emerged in industries such as Aeronautical, Automotive, Medicine, to name a few, and it's been seen how Design Requirements are substantially different for RM compared to those traditionally thought during engineering design education. If those new technologies are expected to change the basic design requirements and process capabilities, then education must also turn and embrace the change with a new perspective, not to replace current design approaches but to enrich them. This is the purpose of Design for Rapid Manufacturing.

2 METHOD

By searching on the contents of leading European Universities with engineering design programs, common design techniques oriented to manufacturing taught during their

courses are identified, such as Design for Manufacturing and Assembly (DFMA), Design for Injection Moulding, Design for X techniques in general. Also it's identified during which design phases the final manufacturing decision is made and how this influences previous steps during the generation of solution concepts of a product.
These design tools are analyzed to show their main implications in the shape, functionality, geometry and aesthetical features of final products. The main process related rules and design recommendations are then confronted trough a comparison matrix with their Rapid Manufacturing rules counterparts to understand how RM concepts relate to this common design restrictions. In the last step, with RM processes and principles in mind, a TRIZ [2] like matrix tool is developed intended to aid the designer during the conceptual design stage, to get rid of common design assumptions that turn later in to design restrictions. Though it does not comprise a contradictions Matrix, the similarity to the TRIZ method consists in how new options are presented to migrate conventional process oriented concepts, to some of the proposed RM Processes

3 STUDY AND RESULTS

The search trough several undergraduate programs [3,4] with engineering design contents has shown a clear difference between the orientations of Mechanical, engineering design, industrial design and product design; with the first one focusing on function, manufacture and fitness for purpose [5]. Though Rapid Manufacturing (RM) Technologies are not yet widely used for final production, they're currently submitted to exhaustive research which tries to find new materials, improved process's parameter manipulation but, overall, the search for new applications and niche markets. The previous tends to reveal every RM process's capabilities and disadvantages which must be addressed by a special approach to overcome process limitations and make a more profitable use of these technologies. Design for RM is a new tendency to address product manufacturing planning, but from a Rapid Manufacturing approach.

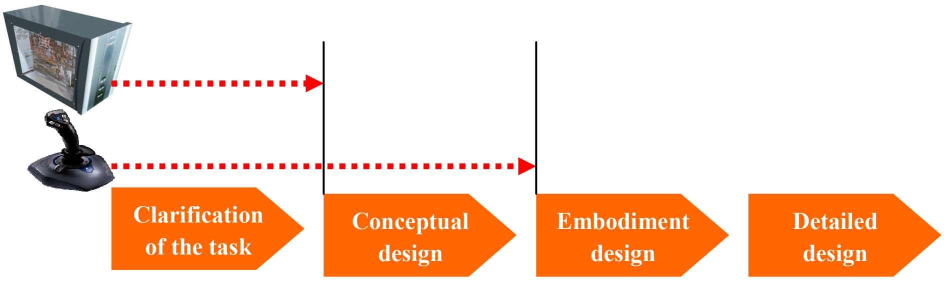

Figure 1 How manufacturing knowledge might influence the design steps

Previous research by Hague [6], Hopkinson and Dickens [7] has shown how RM processes can challenge current DFMA and other specific manufacturing guidelines such as Design for Injection Moulding, which are created to fulfil the essential requirements imposed by the process, having their main impact on the designer's freedom to create. Such restrictions are imposed by every manufacturing process which at the end determine the way products must be designed. Most of this processes' requirements are included as part of undergraduate engineering and design programs in Universities. This manufacturing knowledge defines the border between those designs that can be actually produced and which ones cannot.
A number of undergraduate programs with engineering design content were consulted. From these programs, most of them sharing common subjects, some of the specifically

manufacturing oriented courses were: DFMA, Design for manufacture, Manufacturing systems and Design Innovation. Restrictions imposed by each production process appear early on the design development process. Though there's a debate whether they appear on a conceptual stage, detail or embodiment, it does depend upon the actual design purpose. As in the example shown on Figure 1, if a metal case is needed for a housing element machining operations such as milling, turning and others might be automatically discharged from the very first concept sketches since the basic design knowledge and previous experience would suggest other more suitable processes such as sheet metal forming. However if a not so evident part is to be designed, the first design stages might pass without still regarding the selected manufacturing process influence.

Manufacturing oriented Design guidelines have a direct or indirect impact in a number of product factors that range from geometric, aesthetical, functional, economic and quality aspects between others. Table 1 shows some basic implications of the DFMA methodology that arise when its different design recommendations are followed for a design. For this example the evident economical and time impacts have been discharged.

Table 1 Common DFMA guidelines and their repercussions

	Main repercussion		
Design guideline	**Shape**	**Function**	**Aesthetics**
Design self-referenced parts for the ease of assembly	Surface modification: hole, self aligning feature, cavities, depressions, etc.	More functions are added to the same part giving it more value.	When well solved self alignment does not affect product aesthetics.
Symmetrical surface parts are preferred for easier assembly	Less complex geometry benefits assembly. Original geometry is altered	Functionality is improved. Same functions made by less complex geometry	Symmetry might modify original design appearance, internal or external
Design part features taking into account standard commercial components and tools	Has to meet accurate industry standards for every feature	Savings on time and design effort. Originality might be compromised	Standard elements challenge design when product differentiation is a must
Constantly check compatibility between design intent and manufacturability	Depending on process availability, part shape might be adapted as needed	More flexible Processes might facilitate adding features and functions to the part	The adopted process determines the proper post process, finishing and general properties

Engineering design education usually comprises: knowledge of Materials properties, tolerances, assembly, and manufacturability besides some DFX techniques. Since several design guidelines are based on process limits and constraints, it's usually said that it actually means design for restrictions. It can be said that cost and quality are two of the main parameters to be reached by manufacturing design guidelines, however, when cost is not the major driver and when quality can be accomplished by a careful parameter selection, RM has interesting advantages when compared with common process restrictions. Table 2 shows some of the studied differences between two comparative guidelines: Design for Injection Moulding and Design for Rapid Manufacturing.

Table 2 Design for Injection Moulding and Design for Rapid Manufacturing comparison

Design for Injection Moulding	Design for Rapid Manufacturing
1- Considerations must be taken regarding wall thicknesses. Thinner walls solidify first so uniform walls are preferred.	The use of moulds is discharged so there's no need for uniform walls. Thicknesses may range from 0,001mm and up and can freely change.
2- Avoid sharp corners so there're not stress concentration points during moulding.	No stressed are found in RM processes but some geometries might requires the use of supports
3- Draft angles must be considered for effective part ejection from the mould.	No draft angles required
4- Avoid re entrant shapes and surfaces that make necessary the use of extra ejection mechanisms	Re entrant shapes are possible. Depending on the RM process they might require design of supports.
5- Parting line must be determined on the most uniform side of the part. Special software or skilled labour is needed	No parting line required
6- Always prefer part symmetry. More complex geometries mean higher costs and manufacturing time	More complex geometries require more design time but manufacturing time is not affected

If restrictions comprise an important part of the imparted design education, then there must exist some way to retrieve some of the lost freedom for designing. A DFRM approach is introduced as a concept which might help taking back this freedom. The following matrix is proposed to encourage free design thinking in the cases where: Initial concepts are being generated, selected design is facing modifications due to process limitations or when design concepts or candidate alternatives are evaluated
Though it does not comprise new paradigms, it is based on a compilation of existing current solutions provided by a number of common RM technologies. Since not all RM methods are capable of providing all the possibilities listed, the last column is included to specify key aspects or limitations of the RM processes. Though Rapid Manufacturing systems have also its own restrictions, those usually don't compromise the product's geometry or the original design intent; however they tend to have an influence on product properties, performance, cost and productivity. That's why a comprehensive characterization of RM is needed to be seriously considered for final production.
The shown matrix is intended to encouraging the use and consideration of rapid technologies from the design stage, however even when the result doesn't motivate the "migration to RM" it might be a helpful aid when recognizing design alternatives. Though not yet automated it's the first version of what could become an automated design aid making use of new software applications, which is a recurrent aid for design and creativity [8]. May the designer face the challenge of redesigning, merging multiple parts or adding special features, then he will be able to find new suggested alternatives to enhance the design thus minimising the lost of freedom.

Table 3 Preview of the Free Design Matrix tool

Actions	Opportunity	RM process` limitations / commentaries
Include internal shapes to the design	Embossed features, relief inscriptions different for each unit?	Minimum detail is limited by the machine laser / nozzle
	Internal cooling channels? Hidden electricity cords and connections?	Some processes need powder to be removed from the inside
	Electronic/ commercial factory enclosed elements	In most processes is possible to pause the cycle to introduce external parts.
	Include Nested parts	Support removal might be an issue
Add Undercuts	Don't avoid undercuts, add more	Most RM processes will require supports for free form geometries
	Increase width, height, complexity improves function?	The more complex the undercut the more difficult to remove support material
Add Blind holes	Adding holes improves functions? Aesthetics?	Depending on the orientation they'll use supports or not
	Make Lighter parts, hollow parts	Proper wall thickness might be set to give strength
Non uniform wall thickness	Try changing width of different walls?	Dictated by Layer thickness, laser/nozzle. For powder materials, grain size is a factor
	Interceptions of multiple flow lines are accepted without causing stress	None
Remove Draft angles	Removing draft angles improves performance, time or geometry?	Draft is a non sense feature for final parts made by RM
	Draft whatever geometry without regarding of curved surfaces, sharp edges and corners, captured geometries and thicknesses	Size or build volume is usually limited from 250mm3 to 500mm3. Its possible for some processes to build parts by sections to be subsequently bonded
Free organic geometries	Merge in one single part, pieces of the same material that can be added to only one movable assembly.	Pre-assembled parts are possible with every RM process. Movable parts are separated by supports or feed material
Assembly integration	Mechanisms subjected to low stress and mechanical requirements can be produced already assembled	For demanding mechanical, thermal and other material properties only few processes are suitable. For metallic part processes material properties are better but costs are much higher
	Is the part critical for the function of the product? If not critical can it be freely modified?	Due to reduced range of materials and their properties, RM may not be adequate for critical parts
Design change	New versions: Special editions? Different colours? Adapted for handicapped people? For children? Segment preferences? Evolution?	The direct relation of RM with reverse engineering enables the customization of user oriented products and be produced in small batches
	Changes of design concept? Customized design. Size change. Different versions. Budget version	CAD modification & size scaling is not an issue, making it possible to produce them on the same build

4 CONCLUSIONS

As Rapid Manufacturing evolves from a merely Prototyping tool, into a true manufacturing method, its introduction in engineering design education might make a difference on the way ED programs absorb new emerging technologies. Though the goal is maybe not having future professionals strictly trained for Rapid Technologies but provide them with a wider picture and alternative tools. Usually undergraduate engineering design programmes such as, industrial and product design, except for some exceptions, tend to educate the designer by showing him how to answer to certain restrictive characteristics that existing manufacturing alternatives impose in a given moment. Nevertheless, the current rate of innovation of productive systems makes necessary a certain turn of educational paradigm leading the designer how to be a re-interpreter of the potentials that new technologies give us, taking the maximum advantage of the potential they have to offer us. In this sense, the concept of the expert designer for a specific process has already expired. The speed at which new ways of manufacture appear, having in Rapid Manufacturing just an example, indicate the need of an intensive level of adaptation and adjustment. Though not a generic tool, the intention of this paper is to motivate the migration to new design aids to support this adaptation and help the designer in embracing the new specific characteristics imposed by new processes in the shortest time. However the proposed aid might be improved to be presented as a database or automated software making profit of the advantages of quick processing of comprehensive process related information, thus responding to the fast rate of processes innovation.

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