INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

IN THE SEARCH OF DESIGN FOR RAPID MANUFACTURING STRATEGIES TO SOLVE FUNCTIONAL AND GEOMETRICAL ISSUES FOR SMALL SERIES PRODUCTION

Javier Munguia[1], Carles Riba[2] and Joaquim Lloveras[1]
[1]Technical University of Catalonia, Spain (UPC)
[2] Industrial Equipment Design Centre (CDEI-UPC)

ABSTRACT
The new generation of additive processes introduced by Rapid Prototyping Technologies (RP) and their eventual transformation into truly manufacturing systems, shows the necessity of studying their implications towards conventional design practices such as Design for Manufacturing and Assembly (DFMA), Functional and Cost Analysis, as well as to search for design strategies to be used mainly during the conceptual design phase. These implications have started to be addressed by the recent Design for Rapid Manufacturing (DFRM) approach.
In order to overcome the geometrical and economical restrictions imposed by most conventional manufacturing processes, usually regarding the need for production tooling, and to search for alternative means to turn into realizable products those usually constrained by common manufacturing oriented design guidelines, a set of strategies is proposed, which through the application of part reduction principles, geometrical description, simulation and DFRM premises, show the feasibility of considering Rapid Manufacturing (RM) as an alternative route for production.

Keywords: Rapid Manufacturing, DFMA, manufacturing design restrictions, small series

1 INTRODUCTION
The possibility to assess aesthetical and functional features of consumer products through different perspectives such as Design for Rapid Manufacturing (DFRM) gives the designer a new range of alternatives to replace traditional process-oriented part design, with different approaches such as product, performance or end user –oriented design, moving the focus of the design efforts from process to the product and its user interaction.
Experience has shown that design strategies such as DFMA and the general Design for X guidelines are a valuable aid during product design and its specific activities such as parts reduction, redesign, manufacturability analysis, cost estimations, and so on, which usually lead to significant savings for the company if they are correctly applied [1]. On the other hand, the tendency to design for the fulfilment of specific guidelines whether it is for manufacturing, assemblability, packaging, and others, represents itself a limitation of the freedom available to create due to the specifications and constraints included which in most cases influences directly the way products are designed.

2 RAPID MANUFACTURING DESCRIPTION
Although the name "Rapid" doesn't exactly make reference to a faster production method, Rapid Manufacturing Technologies introduced during the last years, comprise an interesting alternative to the way everyday products are manufactured. Derived from the existing Rapid Prototyping technologies, RM includes a set of different processes most of them based on sequential layer deposition of different materials through different means such as laser sintering, photo polymerization, metal laser melting, or liquid binder deposition to name a few.
From those already established technologies there are a number of alternative processes which, with the proper combination of suitable materials and processing parameters can be considered as truly manufacturing methods. This is the case of Selective Laser Sintering (SLS), Selective Laser Melting

(SLM), Electro Beam Melting (EBM), Fused Deposition Modelling (FDM) and to a lesser extent other ones like Stereolithography which is usually limited to prototype testing due to the low properties of the photopolymers used [2].
Although these new manufacturing methods also include constraints and specific parameters to be fulfilled, their ability to translate any CAD modelled entity into a physical part without the need of tooling, moulds and process adjustments, represents an important advantage which can be profited in the search of new ways to generate innovative products.

2.1 RM and small series production

Rapid Manufacturing's implications on design, product costs, production technologies, and materials are studied by the Design for RM approach which tries to identify new potential applications, suitable products and the best way to produce them by any "Rapid" method. This is the case of small series or low batches production which within several studies has been identified as the favourite niche market for RM technologies [3].
The main characteristics that make small series production the best target for RM are namely: usually high production costs, high added value, specialized products and low number of parts produced which also encourages a full customization potential for every single unit. [4]
In addition, most metal and plastic parts produced for small series are designed so as to meet the capacity offered by processes such as injection moulding, investment casting, machining, and some others which are not always the most convenient alternative for low quantities or short runs, so this makes it necessary to find new alternatives for production.

3 OBJECTIVES

Through the analysis of different products in the field of small series production, this study tries to establish a sequential series of strategies which tend to reveal a product's aptitude to be Rapid Manufactured. In the same way it's intended to define a series of steps that could be followed by the designer to show the potential opportunities of improvement and lead to a free and creative product conception mainly during the conceptual design phase.
Although the objective is not to establish a fixed procedure for applying RM, but to show how different strategies might help when it's necessary to verify alternatives for applying RM from aesthetical, functional and economical approaches.

4 METHODOLOGY

Three products developed by a local Industrial Equipment Design Centre [5], which represent some of the most recent and innovative products of the Centre's portfolio, are analyzed. Two of them belong to the small series sector and a third one is clearly designed for mass production but thought it's included in the study for feasibility verification.
The method used to analyze the products and their key components is divided in four steps: First a questionnaire based on the Design for Rapid Manufacturing tool (DFRM tool) [6] is applied to rapidly check the product's suitability to be rapid manufactured. It's been found convenient that at least 50 percent of the responses for each analyzed product must be positive, else it would indicate that the advantages of applying RM to the product are minimal. Then the DFMA methodology [7] is applied to have an approximation of the different modules and parts that comprise each product and measure their individual complexity in terms of part fabrication and assembly times.
The indicators of interest to be obtained by the DFMA method are: Maximum assembly time per part, design efficiency and minimal part count. Parts with the highest assembly times are classified in: critical and non-critical for the product's overall performance. Non-critical parts with high assembly times were subjected to redesign following common Design for Manufacture (DFM) guidelines.
As a third step, the resulting redesigned parts were analyzed based on their geometrical characteristics. This is achieved by a characterization using two main methods: basic shape definition and specific geometrical features [8]. Following this classifications and rules, common manufacturing processes are proposed for each new part.

As fourth step, the second part of the DFRM questionnaire is applied which was modified so as to include economic and technical feasibility issues to assume the RM suitability of complex parts. The responses of this questionnaire were fed in the software Magics v10 [9] in order to get time, maximum build size and cost approximations to find the break even point between the compared processes. In the last step a checklist of design opportunities is developed with a number of suggestions on geometrical freedom gains, liberated process- compromised features as well as the potential for customization.

5 ANALYSIS AND RESULTS

5.1 Product selection and analysis

The three analyzed products are shown below in Figure 1. These were chosen based on their Product Deign Specifications (PDS) as well as on the availability of physical models, documents and drawings that allowed further analysis of each one. During the selection of products, data about their intended function, geometrical features, processes used and cost was compiled.

A ***B*** ***C***

Figure 1. Three analyzed products: A) ROV, B) MRM, C) Pen corrector

Two of them, the Remote Operated Vehicle (ROV) and the Muscular Relaxation Machine (MRM) share the common principle of having been projected as innovative budget options to compete with existing products of the sports and leisure market, two appealing areas for low volume personalized products. Other features are common such as low annual volumes (300 to 600 units), modular architecture and low initial investment required. On the other hand the pen corrector was intentionally included in the analysis since it can be seen beforehand that its characteristics differ much from the other products. However it's considered an exercise to try the effectiveness of method used.

As a first analysis strategy the DFRM Tool is used [6]. This checklist utility rapidly identifies suitable prospect products for RM regarding opportunities on production volumes, shape, geometry, assembly and process. Though it only indicates product opportunities potentially gained from a Rapid Manufacturing approach and doesn't go further into technical and costs analysis for comparisons, it's a valid start point when a number of products are to be evaluated in the search of alternative design and manufacturing options.

The checklist results are presented in Table 1 where for the first two products ROV and MRM clear advantages of using RP can be envisioned, while for the third one, there are not really encouraging factors that show potential benefits. Therefore, since product C is ruled out as a potential beneficiary of RM, the next phases of the analysis will focus on products A and B in order to find more specific RM possibilities for the global product or single pieces.

5.2 DFMA evaluation

After products A and B have been found potentially suitable to be Rapid manufactured, it's necessary to study their configuration in detail, in order to take advantage of each available opportunity. A DFMA approach was selected to identify: the product's main modules, parts per module, and their complexity implications expressed in time and efficiency indicators. Since some of the main advantages of RM are the possibilities for part consolidation as well as free shape- high complexity part generation, DFMA was selected as an enabling tool due to its tendency to end up in parts redesign which usually incorporates more complex geometries and challenges for the design team.

Two main modules of the ROV were analyzed: Vision and Lighting, while for the MRM the Transmission module was of interest since it contains most of the machine's main functional parts. The analysis was followed using the DFA tables suggested by Boothroyd [7] to evaluate designs documentation and physical parts when available. The final results are shown in Table 2 where radiography of the assembly's time and complexity can be envisioned.

Table 1.Synthesys of the DFRM Checklist Tool applied for the three products

Answer: Affirmative ✓ Negative X	**A**	**B**	**C**
Regarding production volumes and product lifecycle			
Target production volumes for the product are between one and several hundreds units	✓	✓	X
Life expectancy of the product in the market place before it comes obsolete and requires change is located between 1 and 7 years?	✓	✓	X
. Is the product a fashion item or is having up to date aesthetic styling, an important factor in maintaining market popularity?	✓	✓	✓
Regarding form and geometry			
During use, will there be a high degree of interaction between the product and its user, such as prolonged or repeated physical contact?	✓	✓	X
Will the product be used by a single person or uniform group of users that require economical low volumes or one-off products?	✓	✓	X
Is the product modular or does it uses trim features and extra components to define levels within a product range? (budget, exclusive versions)	✓	✓	X
Regarding function and product assembly			
Is the product comprised of more than one non moving component that is or could be made from the same material?	✓	✓	X
Does the product use mechanical fasteners or chemical bonding agents to join material component parts?	✓	✓	X
Will the product's intended user have any suggestive or creative input during design or development?	✓	✓	X
Regarding fabrication			
Is the product's shape or geometry compromised in any way for conventional manufacturing methods?	✓	✓	X
Does the product need to house any specific bought in components or accommodate non-standard mixtures or fittings?	✓	✓	✓
Is the recovery of construction materials at the end of the products life cycle important?	✓	✓	✓

The three studied modules share common design characteristics, for instance, an important amount of commercial standard parts (screws, nuts, connectors, tube sections, etc.) most of them used as fastening means for small machined components. MRM also incorporates standard elements like pulleys, cords and rails which after this analysis were considered good candidates for replacement or elimination by redesign.

It was detected a tendency on most parts to be projected mainly with machining processes in mind, and the use of fastening elements is a common practice. Only the MRM design incorporates special parts designed for casting processes due to the multiple functions carried out by single pieces and the mechanical stresses they bear.

A brief description of one studied module is shown in Table 3. It refers to the lighting module and its non- critical parts which were identified during the DFMA analysis. The volume, functions, and processes employed for those parts are analyzed for each module of both, the ROV and the MRM, so redesign strategies such as part merging or replacement can be envisioned.

Table 2. DFMA analysis results for three modules

DFMA analysis			
Parameters	**ROV**		**MRM**
	Vision Module	lighting Module	Transmission Module
Total assembly time (s)	270, 3	183,15	577,31
Assembly efficiency	8,87%	13,1	31,17
complexity factor	2775	1288	12936
Total parts	37	23	66
Different parts	15	14	30
Non critical parts	8	6	3
Parts with longer times	screws, nuts and fastening elements	screws, nuts and fastening elements	Fastening and standard parts

After the parts characterization, new design alternatives were generated based on the premises established by the method used such as: elimination of non- critical parts, design for commercial essential elements (lamp, camera, cords, etc), reduction of high assembly time parts and reduction of different manufacturing processes.

Table 3 Sample characterization of non- critical parts for the lighting module of Product A (doesn't include fastening elements)

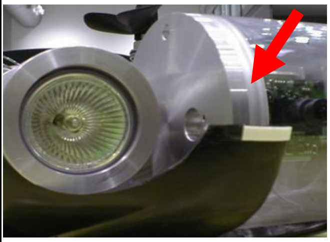
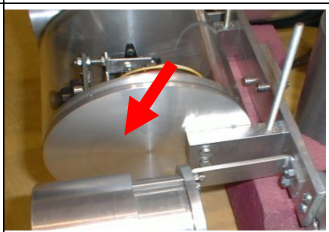
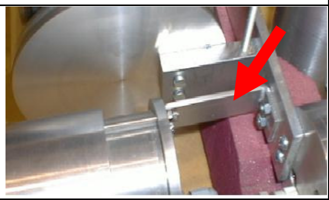
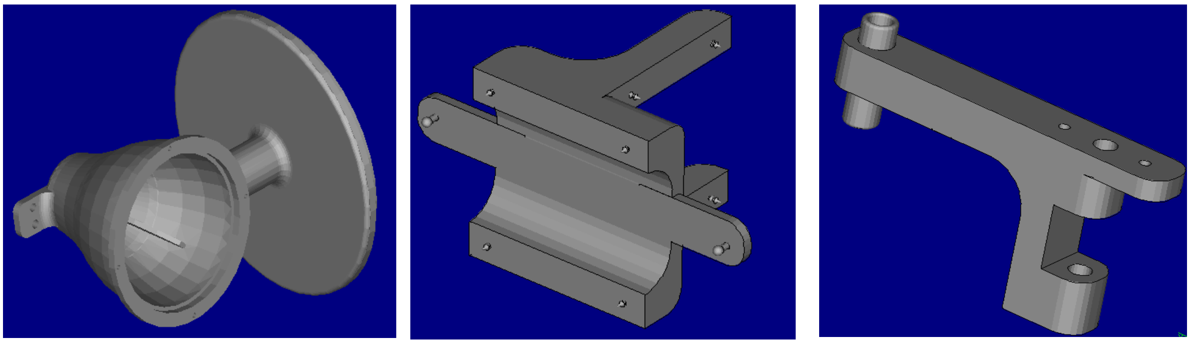
Part name	Location	Volume box mm	Process/ material	Main Functions
Right cover		D120x10	Machining on Standard Al round bar sections	• Keeps union of camera module and main chassis • Seals the camera module on the right side
Left cover		D120x10	Machining on Standard Al round bar sections	• Keeps union of camera module and main chassis • Seals camera module on the left side • Supports camera and controller
Fastenin g angle		25x40x 12	Drilling , cutting Al profile	• Joins camera module with the main body chassis

Figure 2 shows three proposed part redesigns as alternatives to the already existing ones. This new parts follow the previously mentioned criteria. Part 1 is an alternative that merges elements from two modules incorporating the functions of holding lighting elements, self fastening interface and integration with the camera module. Part 2 it's a small camera holder incorporating snap fits for the assembly of electronic parts, and part 3 is the alternative to the current transmission mechanism of the MRM machine which replaces six of the most expensive parts. All the proposed parts replace the use of common commercial fastening elements.



a) Part 1 **b)Part 2** **c) Part 3**

Figure 2. Proposed redesigns for three parts. a)Part 1(Lighting chassis of ROV), b) Part 2 (camera support of ROV), c) Part 3(Transmission for MRM))

It can be noticed that the main design criteria for the proposal of the new parts is not the correct fulfilment of certain production process rules, but the incorporation of as many functions as possible regardless of geometrical complexity implications, material or process availability.
However since these are mechanical internal parts, there is some degree of pre conceived assumptions towards their final shape and how it must be produced.
For instance, part 1 has been conceived with features that might do it difficult to adopt the same original machining process. Part 2 can now be hardly manufactured with the sheet metal process, originally intended, though it now it incorporates typical characteristics of injection moulded parts. On the other hand Part 3 which was conceived to replace other existing sand casted parts was also conceived with the same casting process in mind.

5.3 Geometrical analysis

In order to find prospect manufacturing routes for the shown parts a geometrical analysis is undertaken. Geometrical features and shape attributes usually indicate which processes would be suitable and which ones should be ruled out. However it's a common practice to adapt and modify parts attributes so that available processes or materials can be profited. This is a usual example of how parts geometries become compromised by the selected production means.

A basic geometry description for the three proposed parts is adopted in order to find suitable processes. The Giachetti method [8] is taken as a reference as well as a detailed feature listing as stated by Boothroyd [1]. This is shown in Table 4.
By means of conventional process datasheets or automated systems for process and material selection (MAMPS, COMPASS, CP/MS) is possible to find the most suitable alternative for a certain part with a given geometry as stated before. For this study the approach adopted by Giachetti and Boothroyd [1], [8] to relate geometric characteristics with typical process capabilities is applied.

Table 4. Geometry Description for the redesigned parts

Basic shape description				
		Part 1	**Part 2**	**Part 3**
Guiachetti`s criteria	Configuration	Prismatic. Positive & negative features. Cylindrical block and boxes Partly axial	Prismatic. Positive and negative extruded shapes. n Thin walled	Prismatic. Positive surfaces, holes and extruded features

Detailed features listing				
Boothroyd`s feature definition	Part No.	**Part 1**	**Part 2**	**Part 3**
	Volume (cm3)	317	49,3	113,34
	Bounding box (mm)	120x 120x120	60x60x50	135x100x38
	Weight (gr)	855	133,11	306
	Tolerances max/min	+ 0,2mm	+ 0,05mm	+/- 0,5mm
	Finishing	Standard/ smooth	smooth	Standard
	Wall thickness	3mm (min) 20mm(max)	5mm (min) 7mm (max)	18 mm (min) 38 mm (max)
	Production rate	300 annual	300 annual	600 annual
	Undercuts	No	Yes	No
	Depressions	Yes	Yes	Yes
	Uniform walls	No	Yes	No
	Cross section	No	No	Yes
	Axis of rotation	No	No	No
	Regular cross section	No	No	No
	Captured cavity	Yes	No	No
	Enclosed cavity	No	No	No

For the previously redesigned parts, three main processes were found as suitable, and therefore as candidates to be implemented: Injection moulding, Sand casting and machining. It was possible by following process-material- geometry compatibility for the parts analyzed is possible to find the proper manufacturing route. However every single processing option carries associated guidelines, rules and limitations which tend to reduce the freedom of the design.
The typical geometrical constraints imposed by three of the recommended processes are shown in table 5

Table 5.Proceses suitable for parts 1, 2 and 3 and their geometrical implications

Process	Usual geometrical constraints regarding part and design considerations
Sand Casting **Parts 1, 3**	• Requires projection of draft angles and Radius similar to wall thickness • Non difficult bodies are preferred in order to avoid the use of internal nucleus • Firmly hold the nucleus so to avoid unwanted displacements and the formation of walls with different thickness • Doesn't accept hidden or captured cavities. • Avoid sharp corners and angles as well as multiple union points • Consideration of metal shrinkage is necessary • Partition line must be projected on the most regular geometry section
Injection Moulding **Part 2**	• Draft angles must be projected to remove the part form the mould • Design with constant wall thicknesses in order to avoid different shrinkage during part cooling • Thin wall parts are preferred to optimize material costs • Part projections must be aligned in order to avoid the use of ejection pins, runners and other mould elements • Avoid re-entrant shapes that require mould modifications • Prefer rounded corner and junctions instead of sharp ones • Snap fit direction should be oriented outwards to avoid extra components in the mould

Machining **Part 1, 3**	• Requires preferably rotational parts, symmetrical in one axis or non rotational parts whose features are parallel and oriented don the same direction. • Machining surfaces should be perpendicular to the tool direction • Avoid slots and internal shapes specially if these must have tight tolerances • Holding zones must be projected on the part • Radius of the tool must be the referent for round corners, boxes, chamfers and most rounded features. • The L/D relation for holes and boxes must be compatible with tools employed

5.4 Suitability for RM

Once the three parts have been analyzed and their geometrical implications within conventional processes have been identified, it's possible to search for alternative RM processes which might be capable of generating the same geometry without regarding shape restrictions and possibly compromised features. The strategy applied in this stage is also based on the Nobel DFRM tool [6], which has been modified to include specific questions on technical and economic issues to assure the feasibility of Rapid Manufacturing the studied product.

Questions about the part's technical requirements tend to clarify the product's final use and operating conditions; this is important when identifying which of the existing RM materials posses the required properties for the intended use. To achieve this it's necessary to compare available Rapid Manufacturing material databases [10] or search trough manufacturer's datasheets. Functional requirements for parts 1, 2 and 3 are shown on Table 6.

Once the operating conditions and mechanical requirements are fulfilled by certain material, the process associated is then evaluated on its key parameters for construction such as available build volume, surface finish, tolerances as shown also in Table 6. While RM has the main disadvantage of having a reduced range of materials compared with conventional processes like injection moulding, it on the other hand, facilitates the search for compatible RM equipment since they operate typically in a range of one to three different materials.

Table 6. Rapid Manufacturing suitability questionnaire

	Individual part requirements	**Part 1**	**Part 2**	**Part 3**
Regarding the part	Part weight	Lightweight	Lightweight	Medium
	In contact with solvents, chemical substances and aggressive environment?	Yes, Clorox, seawater, etc	No	No
	Requires sealing or low water absorption and humidity levels?	Yes, direct contact with water	No	No
	Maximum temperature of exposure or contact	45℃	Room temperature	Room temperature
	Rated load	No	No	Yes
	Requires displacement or flexion due to external forces	No	Yes, for snap fit assembly	Yes
	Operates under extreme temperatures	Yes	No	No
	Undertakes impact forces	Yes	No	No
	Critical properties to be observed	Impact strength, stiffness Chemical resistance and water abortion Tensile modulus	Tensile module and ageing behaviour	Impact strength, stiffness Tensile modulus

Regarding the process	Suitable/ candidate RM processes	SLS,SLM, EBM, FDM	FDM, SLS (Polyamide, Nylon), SLA(PU)	SLS, SLM, EBM, FDM
	Is available build volume enough for the intended part?	Yes	Yes	Yes
	Is the part: visible-external Non visible-internal	External	Internal	Internal
	Is the process` surface finishing and texture suitable for the final use	No (requires sealing, and plating)	Yes	Yes
	Layer thicknesses offered are enough for the part geometry finest features	Yes	Yes (snap fit are the top consideratio n)	Yes
	Minimum tolerance offered by the process enough for the application	Yes	Yes	Yes

Since the proposed strategy tries to evaluate RM feasibility early in the design concept phase, economical implications should not be fully comprehensive, taking into account that in this step not all of the final product implications have been defined. It is possible however to state a reduced number of parameters which might facilitate the search of economical combination of parts volumes and processes. From the method developed by Hopkinson [3] for a RM cost estimation is possible to extract the basic necessary parameters as shown in Table 7 to get rough estimates for the desired parts.

Table 7. Basic parameters for cost estimation

Parameters	Process	Material	Labour
• Parts per platform • Time per platform • Production rate • Machine hours per year • Total annual production	• Total annual machine cost • Machine power consumption -kW/hr • Annual depreciation • Machine cost	• Material cost per x kg, or Litters • Part volume cm3 • Part weight gr • Material density g/cm3	• Cost op/hr • Set-up time • Post process time • Labour cost per batch • Total labour cost per part

For a more agile estimate for RM costs, the software Magics v10 [9] is used, which, while does not include as an input all the mentioned parameters it can however be fed with a minimum number of known parameters acquired from experience, observation or previous records so that acceptable rough estimates are obtained for comparison purposes.

In Table 8 cost estimations obtained from the Magics software simulation are shown for each part. Due to the convenience of the simulation it is possible to set different scenarios, this way, cost estimation for three processes: SLS, FDM and DMLS were considered.

Table 8. Price per part for sand casting and three different RM processes

Process	Part 1	Part 2	Part 3
	Cost per part		
Sand casting	4500 (tooling)	NA	1800 (tooling)
SLS PA	72,56	21,27	46,41
FDM	50,34	29,79	53,28
DMLS (metal)	42,77	24,25	26,65

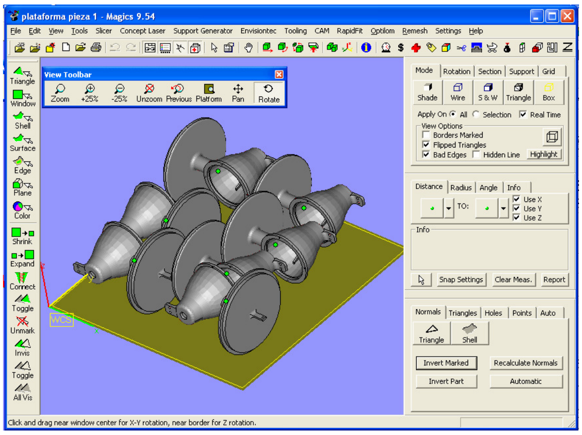


Figure 3. Screenshot of the Magics software analyzing Part 1 placing and build time

Two example graphics are shown in Figures 4 and 5. Built from the data obtained by the Magics software and compared with typical cost of conventional processes, they show how the cost of the RM route tends to be higher after a few hundreds of parts, however in the case of Figure 5, the camera support built by SLA process it's a more economical option for manufacture than injection moulding of the same part.

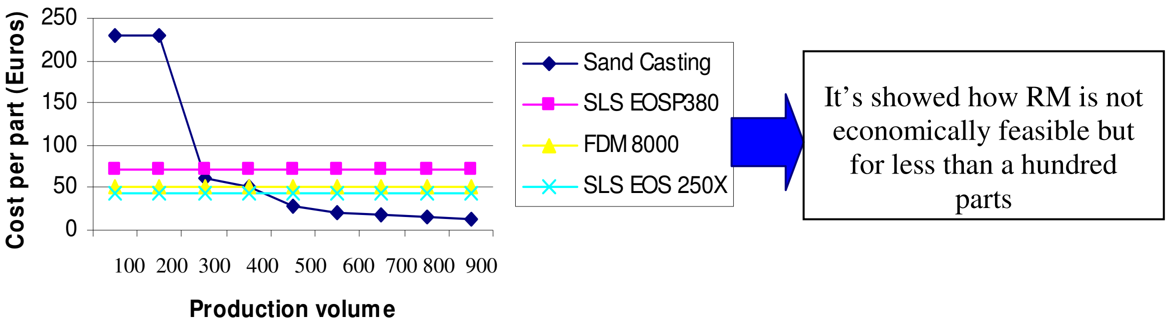
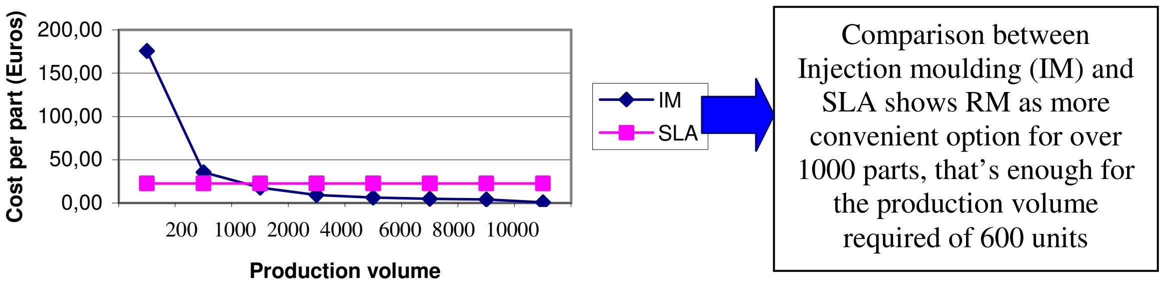


Figure 4. Sample comparative cost graphic RM vs. sand casting for part 1



.

Figure 5. Sample comparative cost graphic for SLA and IM for Part 2

5.5 RM checklist

Since the economical factor is not the main advantage of RM technologies it's necessary to find alternative advantages than can confirm the route of RM as the most suitable technology. It has been shown that RM is the best option for very small volumes, however it's possible to appeal to strategic factors such as: customization capabilities, free form and rapid design changes allowance during production, between some others.

In order to show the designer possible factors that would justify the application of RM on conventional products a checklist of design opportunities is developed (Table 9). The tool lists current properties of existing RM processes that can be exploited in the search of competitive advantages versus conventional design approaches making an emphasis on the part's customization capabilities. Though it does not intend to change the designer's mind by suggesting new feasible geometrical features it does try to go further into exploring the processes capabilities once they've been shown as technically and economically feasible.

Table 9.Rapid Manufacturing concept checklist

Internal shapes	Which functions could they do? Internal cooling channels? Functional captured cavities? Hidden electricity cords and connections?
Undercuts	Don't avoid undercuts. Increase width, height, pull? Increasing complexity improves function?
Blind holes	Adding holes improves functions? Aesthetics? Lighter parts
Re-entrant features	Adding snap-fits helps? Cantilever snaps? Opposite side? Increase length of re-entrant features, turn them. Add more
Non uniform wall thickness	Try changing width of different walls? Interceptions of multiple flow lines are accepted without causing stress in the piece. Changing width improves aesthetics?
Draft angles	Removing draft angles improves performance? Cost? Development time? Functions? Geometry optimization?
Commercial components	Design for commercial items and just their geometric features and user interaction in mind
Assembly integration	Are there pieces of the same material that can be merged in only one movable assembly? Mechanisms that withstand small stresses and mechanical requirements can be produced already assembled
Parting line	Is product configuration affected by partying line? Eliminate line distribution. Analyze part geometry and performance without parting line necessity. Add complex functional features on both sides. In the middle. Along the current parting line
Symmetrical parts	Are parts symmetrical due to moulding economics? Because ease of handling and insertion? Eliminate simetricity. Improves that performance? Part count? Final cost?
Product replacement	How long is the expected product's life cycle? Are new versions required? Special editions? Different colours? Adapted for handicapped people? For children? Segment preferences? Evolution? Commercial variety?
Design change	Probable changes in de design concept? Customized design. Size change. Different versions. Smaller, big, micro, jumbo. Budget version
Ergonomics	Piece in direct contact with final user? Body geometry acquisition possible? Adapt geometry to specific user?

On the other hand, RM does not lack of restrictions. Tough RM constraints are not of a geometrical type, they do appear in the form of process parameters affecting precision and final part properties: layer thicknesses, minimum air gaps between each deposition, hatching patterns, orientation and support structures to hold overhanging features, to name a few. However the expertise on each method can minimize their impact and generate any shape regardless the limitations imposed by the RM process.

6 Conclusions

The factors included in this study, namely: part complexity, technical, time and cost feasibility can trace the way to propose new free-design premises to make possible for a part conceived by standard processes to be optimized and profit the current advantages of RM technologies.

During the study it was shown how the DFMA approach shows a systematic way to translate complex geometry features to cost, which is not a real indicator of complexity for the DFRM approach whose

cost depends on more operational factors such as orientation of parts, volumes, materials, and other parameters which are independent form geometrical complexity.
During the application of the different strategies it was possible to envision how their individual results, actually shape the final decision for product manufacture. This is, the DFRM tool rapidly rules out non-suitable parts and products for Rapid Manufacturing. Then Geometric analysis suggest possible manufacturing routes, but it also raises evident process restrictions and requirements which are systematically confronted to RM alternatives trough the questionnaire and simulation introduced.
Once technically and economically accepted it is proper to explore further RM capabilities regarding design freedom. This is the main intent of the proposed checklist.
In order to move current design focuses from process to the product itself it is necessary to convince the principal actors through both: already proved methods and techniques as well as with new aids, so that the advantages of trying new technologies are promoted, as in this case, Rapid Manufacturing. Thus might the new design premises and technology capabilities brought by RM be completely integrated in the designer’s repertory, then he will be enabled to make better use of them and effectively translate creative ideas and concepts into constraint-less products.

ACKNOWLEDGEMENTS

We are indebted with the CDEI-UPC centre for providing the design cases for this study as well with Materialise for facilitating the software licence during the project’s development time.

REFERENCES

[1] Boothroyd, G.D.P. Knight W, Product design for manufacture and assembly. 1994, New York: Marcel Dekker.
[2] Hague, R, S.Mansour, (2003). "Design opportunities with rapid manufacturing." Assembly Automation 23(4): 346-356
[3] Hopkinson, N.D., P. Analysis of Rapid manufacturing using Layer Manufacturing processes for production. in Proceedings of the Institution of Mechanical Engineers. 2003. Wales, UK: Mechanical Engineering Science.
[4] Grimm, T., User´s Guide to Rapid Prototyping. 2004: Society of Manufacturing Engineers (SME). 404.
[5] Centre de Disseny de Equips Industrials (CDEI-UPC) Memorias de Diseños Industriales 2000-2006
[6] Burton, M., Design for Rapid Manufacturing (DFRM) questionnaire, SME, Editor. 2006, Loughborough University.
[7] Boothroyd, G.P.D., Design for assembly: a designer's handbook, ed. c. Amherst: University of Massachusetts. 1883, University of Massachusetts at Amherst.
[8] Giachetti, R.E., A decision support system for material and manufacturing process selection. Journal of Intelligent Manufacturing, 2004. Volume 9, Number 3 / May, 1998: p. 265-276.
[9] Software Magics v10. by Materialise, Belgium. 2006 www.materialise.at
[10] MatWeb Material property Data www.matweb.com

Contact: Javier Munguía
Technical University of Catalonia
Department: Engineering Projects
Diagonal 647 Planta 10 CP 08026 Barcelona, Spain
Phone: 93 401 66 47 / 17 50 Fax: 93 334 02 55
e-mail: Javier.munguia@upc.edu
URL: www.rpd-project.ne1.net