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

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ABSTRACT
With the new generation of additive processes introduced by Rapid Prototyping (RP) and their eventual transformation into truly manufacturing systems, appears the necessity to study their implications with 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 during the conceptual product design phase. Such implications are being addressed by the recent Design for Rapid Manufacturing (DFRM) approach.
In order to overcome the geometrical and tooling restrictions imposed by most conventional manufacturing processes, 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 where, through the application of part reduction analysis, detailed geometrical description, simulation, cost approximation and DFRM premises, its possible to consider 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) opens a new range of alternatives for the designer who has the option to replace traditional process-oriented part design with a complete focus and design efforts oriented to the part itself and final user interaction.

Experience has shown that most of the existing design strategies such as Design for Manufacture and Assembly (DFMA), and generally Design for X guidelines between others, 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 result in 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 for manufacturing, assemblability, packaging, and others, represents a limitation of the freedom available to create without regard of feature specifications and constraints. In manufacturing such design constraints are present in every process which in most cases influences directly the way products are designed.

2 RAPID MANUFACTURING DESCRIPTION

Even the denomination “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 series of different processes most of them based on sequential layer deposition of different materials through different means such as sintering, photo polymerization, metal melting, to name a few.

From these already established RP technologies there are a number of processes which, with the proper combination of suitable materials can be considered 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 materials it employs [2].

Although these new manufacturing methods also include constraints and specific parameters that require 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 build 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 they can be produce by a certain process just as the previously mentioned. This is the case of small series or low batches production which within several studies has been identified as the favourite niche market for the technology [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 attitude to be Rapid Manufactured. In the same way it's intended to define the steps of the analysis that can 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.

4 METHODOLOGY

Three products developed by a local Industrial Equipment Design Centre [5], are analyzed which represent some of the most recent and innovative products of the Centre's portfolio, two of them belonging to the small series sector and a third one designed for mass production but included in the study for a 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. If the global result is positive then the study can continue for the product, else it would be worthless to analyze it since possibilities for RM to be applied would be 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 and which resulted as non critical where replaced trough a redesign following common Design for Manufacture (DFM) recommendations regarding current manufacturing process used, part functions, volume and costs where possible.
In the second step, the resulting redesigned parts where 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 a third 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 are 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 [10] 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) information 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 being projected to be an innovative budget option to compete with existing products of the sports and leisure market, two appealing areas for low volumes and 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. 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.

Table 1. DFRM Checklist Tool results 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
The level of confidence that the product will sell well in its marketplace goes from low to intermediate.	✓	✓	X
Will there be an after sales support commitment to supply replacement parts alter production has ceased and stock is depleted?	✓	✓	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			
Would the product benefit from being made available in a range of sizes or shapes to fit different users?	✓	✓	X
During use, will there be a high degree of interaction between the product and its user, such as prolonged or repeated physical contact?	✓	✓	X
Due to opportunities for full customization and the absence of tooling, one-off designs are cost effective when produced by RM. Will the product be used by a single person or uniform group of users?	✓	✓	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 interact with other products or parts? (adapted to electronic components, predefined shapes, etc)	✓	✓	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
Is it required the ability to easily disassembly the product for maintenance and life cycle recovery?	✓	✓	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?	✓	✓	✓
RM has the ability to produce lightweight space frame designs. Is it important for the product to be light weight?	✓	✓	✓
RM enables the merging of a product's assembly components to reduce the number of different construction materials. Is the recovery of construction materials at the end of the products life cycle important?	✓	✓	✓

5.2 DFMA evaluation

After products A and B have been found potentially suitable it's necessary to study their configuration in detail, in order to take advantage of every available opportunity. A DFMA approach was selected to first identify: Product main modules, parts per module, and their complexity implications expressed in time and efficiency indicators. Since some of the main arguments of RM are part consolidation capabilities, free shape and high complexity parts 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.

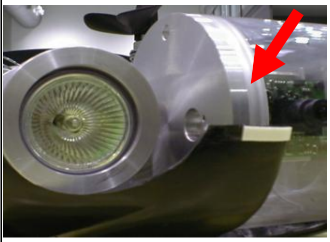
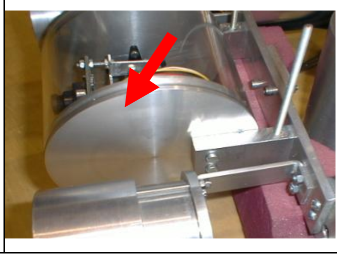
Two main modules of the ROV where analyzed: Vision and Lighting, while for the MRM the transmission module was of interest since it contains most of the machine's functions. The analysis was followed using the DFA tables suggested by Boothroyd [7] on designs documentation and physical parts where available. The final results are shown on Table 2 where the general configuration of the modules can be observed.
The three modules share common design characteristics with 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 which after this analyse were found to be candidates for replacement or elimination by redesign.

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

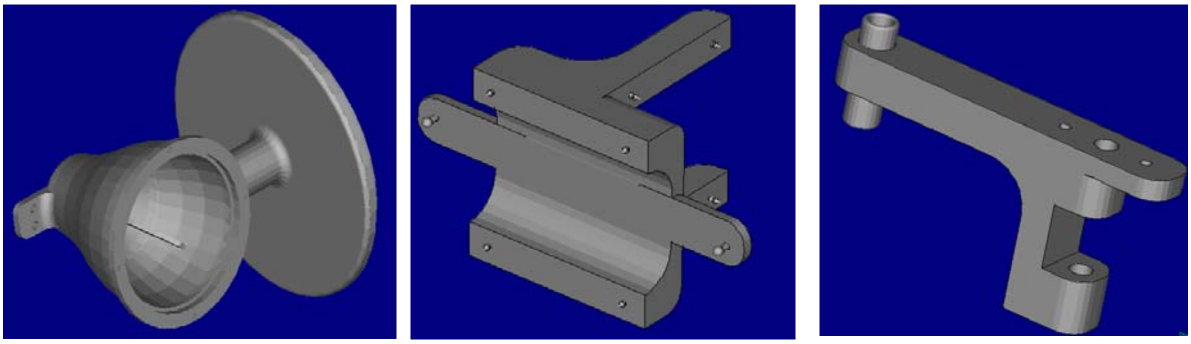
It was detected a tendency on most parts to be projected as machined parts and the use of fastening elements is a common practice. Only the MRM design incorporates special parts designed for casting processes due to the multiple functions carried out by single pieces and the mechanical stresses they undergo.
A brief characterization of key parts is shown on Table 3. This makes an example reference to the lighting module which after the DFMA showed a series of parts that could be replaced or merged in a single piece. The same analysis was made for every non-critical part that resulted from each module. It also includes part functions and current manufacturing method.

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

After the previous characterization, new design concepts 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.
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 to incorporate features which might do it difficult to use the same original machining process. Part 2 can now be hardly manufactured by the original sheet metal process, though 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. Usually geometrical features and shape attributes 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 long as 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 based on Giachetti method [8] is adopted as well as a detailed feature listing as stated by Boothroyd [1] for the three proposed parts in order to find suitable processes. This is shown in Table 4.

Table 4. Geometry Description for the redesigned parts

Basic shape description			
	Part 1	**Part 2**	**Part 3**
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			
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 for sealing components	+ 0,05mm for snap-fits	+/- 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 (annual)	300	300	600
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
No draft	Yes	No	No

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.
Following process-material- geometry compatibility for the parts analyzed is possible to find the recommended 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. • During design must be considered done single partition line • 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	• Draft angles must be projected to remove the part form the mould • Design with constant wall thicknesses in order to avoid different shrinkage

Part 2	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 internal depressions on the part so that expensive mould mechanisms are not necessary • 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. • Machining surfaces must be within easy reach from the tool used. • The L/D relation for holes and boxes must be compatible with tools employed

5.4 Suitability for RM

Once the product has been analyzed and its geometrical implications within conventional processes have been identified, it's possible to search for alternative means to obtain 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.

The included questions about technical requirements of the part 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 [11] 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
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°C	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	Yes	No	No

temperatures			
Undertakes impact forces	Yes	No	No
Critical properties to be observed	Impact strength, stiffness Maximum service temperature Chemical resistance and water abortion Tensile modulus	Tensile module and ageing behaviour	Impact strength, stiffness Tensile modulus
Suitable/ candidate RM processes	SLS,SLM, EBM, FDM	FDM, SLS (Polyamide, Nylon), SLA (Polyurethane like resins)	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 consideration)	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 ones 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 though, while it does not include all the parameters necessary for a accurate estimation, it can be feed with external economic and technical data to model the required scenario for the manufacture of our parts.

Resulting RM costs for three processes selected for each piece are shown in Table 8. It also shows on the first row the estimated cost of sand casting tooling required for each part. Figure 3 shows a screen shoot of the Magics software with Part 1 being analyzed.

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
SLS	42,77	24,25	26,65

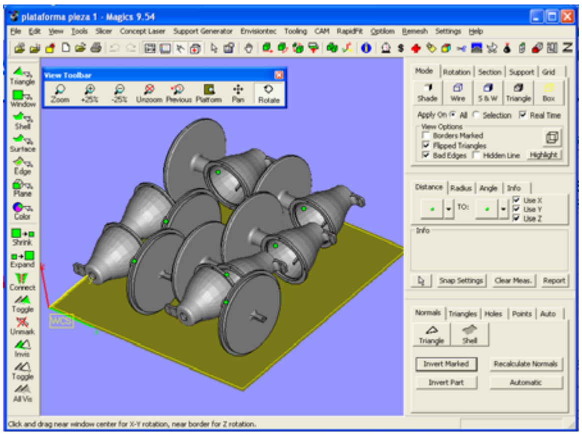


Figure 3. Screenshot of the Magics software analyzing Part 1 placing and build time

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 tend 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.

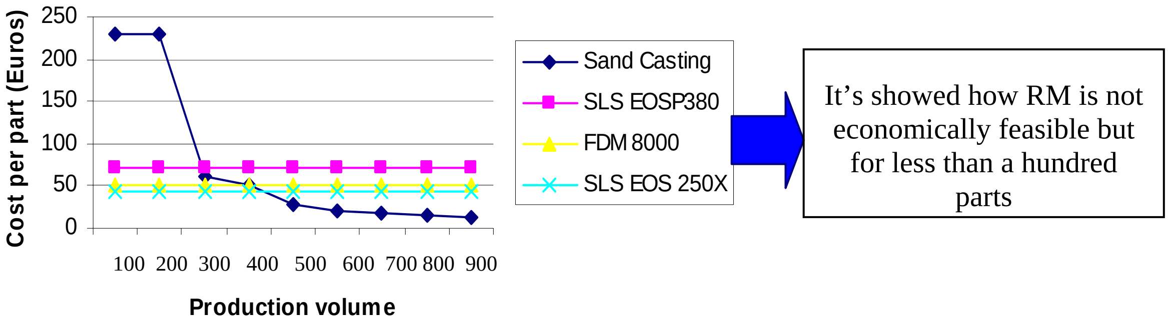


Figure 4. Sample comparative cost graphic RM vs. sand casting for part 1

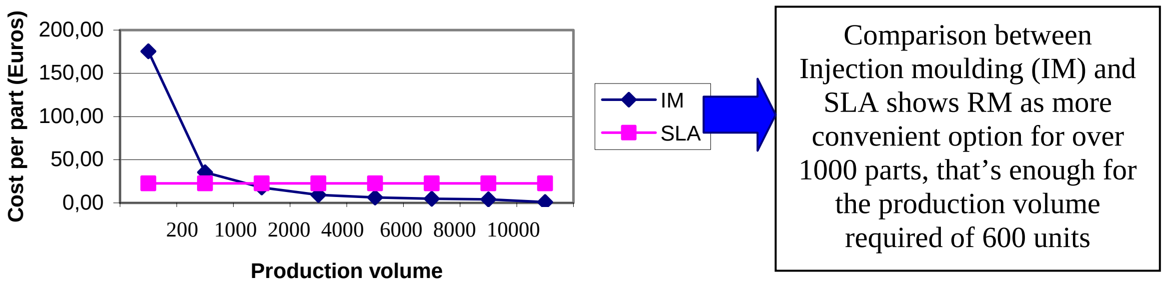


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Figure 5. Sample comparative cost graphic for SLA and IM for Part 2

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 they are the best option for very small volumes, anyway 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 justify the application of RM on conventional products a checklist of design opportunities is developed (Table 9). The tool inspired on the Osborne checklist [10] is a first version which lists current advantages 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.

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
Critical piece	Is the part critical for the function of the product? If not critical, can it be freely modified? Transfer critical functions to other parts in order to modify the current
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?
standard components	Is the piece constrained by standard components? Screws? Tube sections? Fastening devices. Can they be merged within the main part?
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?

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.

It was also seen that even the proposed DFRM tool tends to facilitate the search for suitable parts, materials and processes; much of the decision of choosing a part to be Rapid Manufactured depends on the experience and expertise accumulated by the design team. On the other hand, software simulation helped linking the design analysis with CAD design capabilities which in this study provided a close approximation of the manufacturing incurred cost. This estimation would not be possible to do during the concept design phase with conventional manufacturing routes.

It must be said that even CAD design usually falls outside the conceptual stage, it will be necessary at least to have an approximate sketch in order to apply the proposed strategies. Parametric design might bring closer these two stages, this is why, designers involved along the development cycle should be actually familiarized with these systems. Thus should the new design premises and technology capabilities brought by RM be completely integrated in the designer's repertory so he can make better use of them and effectively translate creative ideas and concepts into constraint-less products.

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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] Osborn, A.F., Applied imagination: principles and procedures of creative problem-solving, ed. p.a.p.o.c. problem-solving. 1963, New York: Scribner.
[11] MatWeb Material property Data www.matweb.com

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