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Rapid Manufacturing:
Benefits to Your Business and the Technologies to Consider

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Biography
Neil Hopkinson is a senior lecturer in the department of Mechanical and
Manufacturing Engineering at Loughborough University. He started his involvement
in Rapid technologies undertaking his PhD in 1996. After completing his PhD in 1999
Neil investigated the viability of Rapid Manufacturing. Inspired by his findings Neil
began to investigate low cost, high speed Rapid Manufacturing processes focusing his
research on powder based layer manufacturing. To date Neil has secured over
£2million of research funding and published over 40 journal/conference papers. He
has chaired conference sessions globally and was an invited visiting lecturer at the
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Abstract
Rapid Manufacturing is emerging as a viable “tool in the box” for manufacturing
enterprises and is beginning to open up hitherto impossible opportunities. This paper
introduces the field of Rapid Manufacturing discussing its emergence from Rapid
Prototyping and its recent growth. A number of the generic business benefits of Rapid
Manufacture are described along with examples of existing applications. Rapid
manufacturing technologies are then discussed in terms of current uses and then likely
future developments. The paper concludes with a brief list of the issues that
organisations should consider before adopting Rapid Manufacturing.
1. Introduction
The term “Rapid Manufacturing” has been interpreted in a variety of different ways, so for clarity this article will work to the following definition of Rapid Manufacturing as:

“the use of a CAD based automated additive manufacturing process to construct parts that are used directly as finished products or components”

This is a very precise definition but it does preclude various interpretations such as the manufacture of functional prototypes, wind tunnel models or injection moulding tooling via layer manufacturing processes. Also, it should be observed that various other terms such as freeform fabrication and layer manufacturing have also been synonymous with Rapid Manufacturing.

Rapid Manufacturing (RM) has been born from the group of technologies collectively known as Rapid Prototyping (RP) and this has had a marked impact on the evolution of RM. True to their name, RP technologies have largely made their initial impression on industry by their ability to manufacture objects that “represent” the final product “quickly”. Consequently these processes have been developed predominantly for prototyping purposes where priorities are not the same as those for manufacturing. For example the mechanical integrity of a prototype is often of lower importance than the time required to make a one-off from CAD – thus mechanical properties have not been the focus of development as much as they might have been had the technologies been predominantly used in the field of manufacture. Compounding this issue is the perception of the potential use of the technologies. Experts in RP expect the properties of the parts to “represent” those of the final part implicitly implying that they will not be satisfactory for end use products. Thus RP experts often consider the mechanical properties of parts in terms of “what they can’t do”. Conversely non RP experts often consider the mechanical properties in terms of “what they can do”. This important subtlety was recently shown in the answer to a question asked of a newcomer to the industry about his experiences in applying RM using Selective Laser Sintering (SLS) of nylon for aerospace parts. The question asked how frequently SLS technology had been considered for a new project and then deemed unacceptable because of mechanical properties and/or surface finish. The surprising answer was “never”; by judicious selection of the right technology for each project the company had always found that SLS did the job when called upon. Crucially this company approached the project by asking what the technology could do and started with an open mind.

Roughly five years ago the Rapid X industry started talking about RM and it was initially faced with a high degree of scepticism, not least as a result of its roots in prototyping as described above. This attitude has largely been eroded and case studies involving RM are now accepted as the norm. Industry analyst Terry Wohlers has observed a growth in the percentage of Rapid X technology providers engaging in RM in recent years as shown in Table 1. In the context of the total Rapid X market these figures look small but the 2006 figure is a ~2.5X increase on 2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
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<tr>
<td>% of users</td>
<td>3.9</td>
<td>6.6</td>
<td>8.2</td>
<td>9.6</td>
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An interesting way to look at these figures is to multiply the data in Table 1 with the size of the industry (in dollars), also as published by Terry Wohlers. Figure 1 shows a year on year graph with the Y axis comprising the product of market size and percentage of users applying RM which have been termed “market size indicator”. Once again, despite much initial scepticism the figure for 2006 suggests a 4.5X increase in market size over those for 2003.

Another observation by Wohlers is that for each example of RM that is in the public domain (he recently found over 50 different examples) there are many more that companies are not willing to share as they feel that this may affect any competitive advantage that they have. Therefore the information presented above is really just the tip of a growing iceberg. Given the disruptive nature of RM technology and its tendency to find sector specific non-intuitive benefits (discussed in the next section) this reticence to share industry secrets is not too surprising.

Figure 1. Growth of RM in recent years.

2. Business Benefits
Having considered the early growth years of RM and related issues such as a tendency for companies to keep their RM activity closely guarded, it is worth discussing the business benefits of opting for RM. This section will introduce a selection of the generic benefits afforded by RM but will not attempt to quantify these benefits. In many instances quantification of benefits will be complex and should be a subject of manufacturing management research over the next few years.

RM technology can provide users with a number of unique selling points over other manufacturing technologies, all of which result from the single fact that the process requires zero tooling. The “zero tooling” statement is normally applied when
comparing RM with processes such as injection moulding however it must also be noted that comparisons between RM and CNC machining also result in a unique selling point for RM in terms of the possibility of manufacturing geometries that can not be machined – this is especially important for low production volumes.

2.1 Geometry Freedom
The single biggest advantage of RM, but the one that will probably take the longest to be fully exploited is that of geometry freedom. Although 100% design freedom is not possible, the majority of the rules of design for manufacture need to be re-written or can be ignored when RM is applied (Hopkinson et al 2006). However, today’s designers are often “hard wired” into designing for current manufacturing processes such as avoiding variable wall thickness or re-entrant features and are thus unlikely to unleash the full design potential of RM. The ideal designers for RM are probably those with no industrial experience, who can identify closely with the product that they are designing and without the blinkers of design constraints imposed by current manufacturing technologies. A great opportunity exists for industry to invite young creative minds to put unrestricted ideas forward for products to be made by RM in the future.

2.2 Cash Flow
Given that the majority of companies that go out of business do so because of cash flow problems then a quick return on investment (ROI) is a clear benefit. In this respect RM benefits from its roots in RP where a “can do” culture of quick turnaround exists. Critically the elimination of tooling can shorten the time and cost from initial product concept to initial sale enormously and thus early ROI and increased total ROI by beating the competition to market becomes feasible.

2.3 Supply Chain
The elimination of mould tools in production also opens up possibilities for manufacture at or near the point of sale and also at or near the time of sale. Possibilities such as these will take considerable time to be fully understood and utilised especially by larger organisations. Having said this, RM is currently best suited to small specialist product providers who may be nimble enough to make swift use of this agility.

2.4 Post Sales
Some of the most interesting and least intuitive benefits of RM arise during the product use phase of its life cycle. A clear example of this lies in complex ducting systems used on military aircraft (DeGrange 2003, Hopkinson et al 2005). The obvious benefits at first glance relate to the issues discussed above such as geometry freedom allowing improved functionality through more complex ducting passages. However, these ducts are single piece units that replace multi-component parts that had previously incorporated numerous mating faces. During the life of the aircraft, mating faces need to be inspected at regular intervals and so the elimination of mating faces reduces maintenance costs throughout the life of the aircraft to a significant extent. Numerous similar examples exist in applications as diverse as hearing aids to space shuttles. It is these “system level” benefits that will only be discovered by applying RM to specific applications that will often provide the most significant competitive business advantages over existing manufacturing technologies.
2.5 End of life

Sustainability is a necessary and increasingly important issue for many products and services. It will be prudent for organisations to consider how RM could assist in this respect. A simple example of this can emerge from the geometry freedom afforded by RM whereby multi-component and multi-material assemblies that are difficult to recycle could be replaced by single pieces using RM. A project between Loughborough University and Jaguar Cars (Hopkinson et al 2005) illustrated this point by redesigning a car door handle from an 11 piece assembly comprising eight different materials to a single material, single piece component made by selective laser sintering (see Figure 2).

Figure 2. Jaguar door handle re-designed from 11 components to 1 with the objective of simplifying end of life issues (www.3DSystems.com).

In this section a number of the business benefit issues have been discussed, however numerous studies have investigated these issues in much further depth (Tuck et al 2005, Ruffo et al 2006).

3. Today’s Leading Technologies

SLS is undoubtedly the leading RM process today. The annual Wohlers report presents a range of RM applications and in the last two years 75% of these have utilised SLS with either polymers or metals. Fused deposition modelling (FDM) and stereolithography (SL) provide the majority of the remaining applications from the Wohlers report.

The dominance of SLS is largely based on the range of material types available (polymers, metal and in some instances ceramics) but also the long term performance of SLS parts. SL parts have superior accuracy and resolution than the other RP processes, and these are key for prototyping or creating master patterns for tooling, however the fact that the SL materials rely on a curing reaction leaves parts prone to continued curing and degradation of properties over time. Susceptibility to moisture of SL parts also often inhibits their use for long term application in RM. FDM on the
other hand, has the specific advantage of simplicity for start up with less onerous requirements such as power supply, extraction and other ancillary needs when compared with many other RP processes. However, FDM parts suffer in terms of material properties in the Z direction that often render the process unsuitable for certain end use applications. If SL and FDM can deal with these issues – that is, if SL can produce parts with good mechanical properties that remain stable over time and if FDM can deal with the issue of Z properties then a significantly larger portion of the RM market potentially awaits them.

A number of other (mainly metal based) processes such as Electron Beam Melting and Selective Laser Melting are somewhat conspicuous by their absence in terms of published examples of RM, however these processes are many years less mature than SLS, FDM and SL and examples of RM by these processes are sure to follow in the not too distant future.

4. Tomorrow’s Leading Technologies
As mentioned earlier, today’s RM has largely emerged from RP and this is especially true for the machines used to perform RM. A consequence of this is that machines are designed to make one-off’s of geometries rather than high numbers of the same or similar parts. Thus, the rate at which material is processed is not as high a priority as is the flexibility to produce different geometries, therefore a fast material processing rate is beneficial but not the highest priority. This has manifested itself in terms of machine architectures whereby the majority of the processes are 0D in nature – that is at any instance only a single spot of material is being processed. Figure 3 depicts plan views of different approaches by which layer based processes can process material within a layer. 0D refers to processes such as SLS where a small laser spot traces across the entire surface for each layer. 1D refers to processes such as 3D Printing where an array of print heads allows a 2D area to be processed by scanning in only one axis. 2D refers to processes such as the Perfactory system that uses a digital mirror device to simultaneously process a 2D area with any need for scanning. As the RM industry matures then the prospect of high volume Rapid Manufacture will increase. It is important to recognise that the volume of material processed by RM will dwarf the current volumes of Rapid X technologies and that as this happens then material processing rates will inevitably become more important than is currently the case. A natural, but long term, consequence of this is that 0D processes, such as SLS, FDM and SL that currently dominate RM, will gradually be superseded by 1D and 2D processes.
Another legacy of RP that will need to be addressed by RM is that of repeatability. Repeatability, particularly of mechanical properties/performance, becomes a must.
have for manufacturing whereas this is not the case with prototyping. Consequently repeatability of parts that come from different machines, from different builds made on the same machine and from parts built in different positions within a single build on a machine will need to be improved significantly. Steps are being made in this direction with respect to characterisation of raw materials, improved process control and an increased awareness and implementation of quality control but there is still a lot of room for improvement to satisfy the needs of many applications and hence open up greater opportunities for RM.

5. Conclusions
Despite much early scepticism, RM is maturing into an important part of the Rapid X market and is likely to eventually dwarf the RP and RT markets that preceded it. Numerous potential advantages of RM have been identified and, importantly, new ones are beginning to be discovered — however there are still numerous areas of improvement for the technologies. These improvements will be driven by the end use requirements of various applications; the majority of which will be small volume high added value niche market products in the short term but will gradually expand to larger product volumes over time.

In order for organisations to consider adopting RM they should consider the following:

1. What are current RM process capabilities?

2. Understand the current range of RM uses of the technologies and how they have benefited organisations that have adopted them

3. Attempt to appreciate the broader potentially non-intuitive benefits that RM can bring for their sector/products.

References
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