POSSIBILITIES AND PITFALLS WITH RAPID PROTOTYPING AND RAPID MANUFACTURING ‘THE ROLE OF THESE EMERGING TECHNOLOGIES IN DESIGN EDUCATION’

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ABSTRACT
In the 80’s and 90’s industry needed design graduates with additional computer aided design (CAD) skills to introduce and operate the then emerging, and highly expensive, CAD technology. Now with the cost of CAD tumbling and industry expecting good CAD skills from design graduates, the area of Rapid Prototyping and Rapid Manufacture (RP and RM) is set to replace CAD as the area of expertise/knowledge industry require. Not only is teaching RP and RM a way of differentiating courses from other institutions, and attracting students, but more importantly, it might also provide extra knowledge that will get your graduate the job interview.
The main focus of this paper is to examine the implications of incorporating RP and RM from a curricula perspective, but will also touch on enterprise opportunities, industrial links and research. Major problems examined include managing expectations, staff training, running costs and hands-on student involvement. Bournemouth University has set up the Prototyping and Virtual Manufacturing Centre (PVMC) and this paper will illustrate how we are overcoming the pitfalls of introducing RP and RM teaching and what benefits we are seeing.
The paper concludes by examining the importance of including RP and RM into the curriculum and briefly discusses the future of the RP and RM industry as whole. As with CAD, in the 80’s and 90’s, will the once specialist equipment of RP and RM become common place?

Keywords: CAD, rapid prototyping, additive technology, rapid manufacture

1 INTRODUCTION
The combination of materials and processing developments in additive technology has led to Rapid Prototyping (RP) and Rapid Manufacture (RM) becoming a predominant area of academic interest. RP and RM techniques can now provide far more than a fragile 3D facsimile of an object such as those produced in wax or even via Stereolithography (SLA) or Selective Laser Sintering (SLS) techniques. Thanks to the broad array of additive technologies available, the relationships between these and other aspects of a design course can be greatly extended.
The newly commissioned technologies must be disseminated to a wide academic audience, including management. Staff will quickly identify areas where the additive

fabrication technologies will enhance learning and teaching, especially in the areas of product design and engineering.

The move from RP to RM is being investigated in high value low volume products such as first class seating for airlines [1] and is another reflection that these technologies are being invested in by industry. Griffiths *et al* [2] argued that many design students fail to achieve core competencies and the courses do not always fit industry needs. The introduction of additive technology into the curriculum presents some significant challenges, but the introduction will address an industry need. Such challenges have been identified and discussed below.

2 IMPLEMENTATION OF ADDITIVE TECHNOLOGY IN ACADEMIA

2.1 Define an academic footprint for new and emerging technologies

The first challenge is to identify the emerging technologies which will provide sufficient depth and breadth to be considered for an academic footprint. The establishment of RP and fast expansion of RM clearly identify a need for academic development in these areas. The sustained growth of additive fabrication technologies for the past five years demonstrates the potential for academic research and enterprise activities [3]. University management will often recommend that these additional technologies complement existing academic areas within their institution. The diversity of additive fabrication technologies makes their applications almost limitless. They can be found in areas such as product design, engineering, manufacturing (both in production and tooling), medicine, art and sculpture [3].

2.2 Search for funding

Although the cost of systems and materials in additive fabrication is decreasing year on year, RP and RM systems still use advanced technologies and materials. Therefore, the cost for implementing such systems is still significant. Furthermore, some of the most popular systems, such as SLA, silicon mould and Fused Deposition Modelling (FDM) require dedicated space and auxiliary equipment. Staff training is an additional cost to consider during an initial funding proposal. For example, in 2004 Bournemouth University was awarded a £500k grant from HEFCE to set up a RP and RM centre comprising FDM, vacuum silicone and rapid casting systems. Funding for staff was provided from regional initiatives. High end systems, such as Selective Laser Melting (SLM), are usually funded through research grants and often linked to medical or aerospace research [4].

2.3 Expectations

The acquisition of RP equipment by any organisation, whether academic or industrial is still a significant step, in terms of investment. Such a capital investment within an academic institution brings expectations that would not apply if introduced in industry. The greatest challenge apart from introducing RP and RM into the curriculum is managing the many expectations of staff, students and management:

- *Management expectations*
  Income generation from external sources
  Increased student numbers
  Raising of the Institution’s profile (press releases, launch events, research)
  Industrial links
- *Staff expectations*
  Introduction or increased quality of student prototypes

Exciting new subject to introduce, or, depending on staff member/ implementation, decrease of teaching load (unit given to individual staff member across courses)

- *Student expectations*
  Advanced skills to improve employability
  Easy manufacture of prototypes.

All these expectations need to be appreciated early during the planning of RP facilities so as to be able to allocate resources both of the RP equipment and the staff running it.

2.4 Identification of the most suitable system

Systems for additive fabrication are very diverse. It is critical to identify both the primary and potential secondary areas of application in the academic environment. A thorough investigation of commercial systems should then be carried out by contacting suppliers (or manufacturers) and fellow academic institutions who are already using the technologies. In the UK, the Rapid Prototyping & Manufacturing Association (RPMA) can provide the contact details of key stakeholders and also organise events related to RP and RM. Finally a correlation between existing systems, available funding and academic objectives must be derived.

2.5 Final System Selection

Depending on the system or systems introduced, a thorough understanding of what is involved with regard to pre-processing and post-processing is essential. With all RP and RM equipment there is always a compromise somewhere (see Table 1) so consideration should be given to the specific purpose of the parts, e.g. finished components or parts for functional testing and/or aesthetic analysis. Plus, within academia, RP manufacture often comes in sporadic bursts, such as for assignment hand-ins, which can add operational problems.

	Polyjet	**ZCORP** 3D Printing	**FDM**	**SLA**	**SLS**
	1=Excellent	2=Average	3=Poor		
Accuracy	1.00	1.00	1.60	1.14	2.00
Feature Detail	1.00	2.00	2.40	1.00	3.00
Strength	2.33	3.00	2.33	2.57	1.00
Surface Finish	1.00	2.00	3.00	1.00	3.00
Functionality	1.67	3.00	1.00	1.86	3.00
Semi-Transparent	Yes	No	Yes	Yes	No
Flexible Materials	Yes	Yes	No	Partial	No
Colours	Yes	Yes	Yes	No	No
Multiple colours within part	No	Yes	No	No	No

Table 1 Comparison of commonly available RP systems (adapted from Xpress3D, 2008)

A system with little pre and post processing is preferable if large quantities of parts are required at once. Alternatively if there is a large amount of pre and post processing then staggered submission deadlines or sufficient allocation of staff time should be considered.

Initially many staff may want training in the use of the equipment, but there are many arguments to use dedicated staff for the daily running of the resource. A basic understanding of the RP system can be achieved very quickly, but an in depth knowledge of the subject/system comes with many months or even years of use.

2.6 Purchase and commissioning

The purchase and commissioning of RP and RM systems is not simple. It requires strong project management skills. It is recommended that a champion is identified to lead this process. Firstly, the champion must be fluent with the purchasing processes of the institution and have working knowledge of tendering processes. A mistake at this stage could cause an unsuitable selection both in terms of suppliers and systems. This must be avoided. Prior to the commissioning of the systems, careful consideration regarding estate issues must be undertaken (flooring, power requirements, waste management, health and safety, *etc*). This requires managing efficient communications between the University Estates department and the suppliers. Often RP and RM systems are located in workshops or laboratories. Staff working in these areas should also be consulted in order to gain their support and their expert knowledge of their working environment. For complex and diverse systems it is recommended to plan a schedule of training with a mixture of staff such as technicians, demonstrators and academics. At this stage a strategy must also be developed with regard to the students using the facilities. Finally, due to the potential danger associated with these systems (e.g. lasers, high temperatures, vacuum chambers, and chemicals) a detailed risk assessment must be carried out.

2.7 Maintenance costs

Maintenance costs could be significant and are usually embedded into a yearly service contract equal to 10% of the initial purchase price. Academic institutions have several ways to cover that cost. It could be through research grants, overheads from enterprise activities or annual capital budgets.

2.8 Income generation

As previously described, maintenance costs can be high and academic use of RP is often sporadic. This can leave ideal opportunities (such as non-term time) for income generation. Within Higher Education (HE) there are many issues regarding income generation using RP and RM and a limited amount can only be looked at briefly in this paper:

- The cost of RP and RM systems continue to fall rapidly, making the long term future of ‘bureau type’ services limited
- The administrative costs of raising invoices etc within academia can be prohibitive
- Design and prototype contracts can use excessive staff time.
- Litigation

The development of additive fabrication systems is strongly linked to innovation worldwide, and there are a growing number of patent applications related to these technologies [3]. Academic institutions are therefore taking the risk of distancing themselves from the industrial needs and research excellence if they fail to invest in these emerging technologies. It is consequently very important to keep investing and developing the RP and RM facilities [5]. Research grants and industrial collaboration are the ideal mechanisms to keep up with leading edge additive fabrication technologies.

3 THE ROLE OF RP/RM WITHIN PRODUCT DESIGN EDUCATION

RP resources present college and HE students with significant learning opportunities, and those that are fortunate enough to enhance their knowledge through hands-on application of such equipment find the experience highly rewarding.

As teaching tools, RP and RM resources represent valuable pieces of apparatus that can provide practical demonstrations, prototypes, experiments, case studies and so on. However, these same resources can effectively underpin students' appreciation of the wider context of design and manufacturing. RM effectively bridges the gap between prototyping and production and, by investigating its capabilities in more detail, its associations with related themes such as concurrent engineering, value analysis, bill of materials, design for: environment, least-cost, manufacture, serviceability, reliability, recycling/disassembly, *etc*, become more evident [6]. In contrast, the nature of additive technologies presents arguments that challenge conventional working practices, thus providing the basis of further debate and research. For example, the need for tooling and engineering drawings could essentially be negated if an entire product is generated directly from 3D CAD data.

As RM establishes itself as a genuine choice for manufacturers, the broader contribution that a physical RM resource might make to learning and teaching becomes more appreciable. In terms of design for manufacture for example, students learn to design components suitable for end-use applications by taking into account the specific characteristics of the materials from which the final parts will be produced. Since additive technologies are not subject to traditional manufacturing limitations such as parting line, constant wall thickness, re-entrant features and draft angle, students find themselves presented with a very different set of design constraints. Design for manufacture emphasis therefore shifts from one of constraining geometry to comply with processing limitations to one of optimising geometry to exploit processing capabilities [7]. By providing students with the ability to scrutinise first-hand the results of their endeavours they inevitably become more appreciative of the value such knowledge affords.

By encapsulating the entire manufacturing process within a self-contained unit, the full range of activities associated with production can be simulated at a practical level within an academic environment. Problems that occur in commercial manufacture, such as design and production liaison issues, are also liable to arise here. Similarly, any procedures that would be adopted in a commercial environment to reduce problems and improve administration such as lean manufacturing, production control, inventory control, and quality control will undoubtedly have a positive affect within this simulated environment. Where a faculty is able to combine live projects with commercial activities via a RP/RM facility, the student experience may be further enhanced. These activities subsequently raise additional issues such as confidentiality and product liability. If handled resourcefully, these too can offer practical examples on which to base case studies and other valuable course material.

4 CONCLUSION

The relentless evolution of CAD tools and the increasing use of complex class-A surfaces in consumer products, pose increasing challenges for design undergraduates. Complex surfacing is becoming the norm in product design and traditional prototyping methods are often being ignored in favour of RP technologies. The ease in which complex surfaces can be created virtually, and in rapid prototype form, is allowing student creativity to flourish as RP and RM is becoming more accessible to HE institutions. On the whole, students benefit greatly from gaining practical experience, and through this hands-on experience of RM, students are able to gain a better knowledge and understanding of both the technology itself and of the wider context of design and manufacturing. The introduction of RP and RM into the curriculum is being further extended at Bournemouth University with a recently launched MSc in Rapid Product Development. The rapidly decreasing cost of RP and RM equipment coupled with the increasing use in industry of RP and RM can only be encouraging for job-seeking graduates with an understanding of these emerging processes.

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