DEVELOPMENT OF AN ADDITIVE LAYER MANUFACTURING (ALM) SELECTION TOOL FOR DIRECT MANUFACTURE OF PRODUCTS

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Reviewed, accepted September 10, 2008

ABSTRACT

Advancements in Additive Layer Manufacturing (ALM) technology and a broader knowledge base of process and material capabilities make ALM increasingly, a more valid manufacturing option.

Small creative industry and industrial designers in the UK, as well as experienced engineers, can benefit from the freedom from design, manufacture and distribution constraints that ALM technology offers, yet they are unaware of the opportunities available.

This paper present a method for selecting an ALM technology as a manufacturing method, based on a part specification, as an ALM selection tool. Selecting appropriate processes, materials and giving design for rapid manufacture advice are part of the recommendations offered from this ALM selection tool.

KEYWORDS

Additive Layer Manufacturing, Design for Rapid Manufacture, Selection Tool, Creative Industry

INTRODUCTION

Rapid Manufacturing (RM) using ALM technologies, also known as tool less manufacturing, has the potential to allow small companies to manufacture products on very low scales, possible at a production scale of one, thus opening up the opportunity to compete with bigger companies for whom amortising the cost of a tool over a large production run is not problematic.

RM with ALM technologies can produce high value products, where value is added through the design of the product, either through innovation or customisation. Other advantages of RM with ALM technologies are that designers can adopt new design methodologies to improve their products, such as design for assembly and design for service (Ulrich & Eppinger, 2006).

Adding functionality to designs to aid assembly, maintenance and disassembly at the end of the products lifecycle theoretically adds little extra cost to its manufacture using ALM. In fact, the potential for radically different design methodologies is one of the major drivers for the development of rapid manufacturing systems and materials (Hopkinson et al. 2006)

However, lack of knowledge concerning ALM technologies is slowing the adoption of RM into current design methodologies and so is having little impact on design cycles and is yet to impart any change in the small business sector in the UK for design, despite its potential for change. So far, in terms of RM, we do not yet have a full understanding of all the features that may be required for a typical part (Hopkinson et al. 2006). On top of the lack of understanding of RM parts, the market is flooded with technology and materials that are not yet fully understood and so selection of suitable technologies is a laborious task even for expert users of ALM. For small businesses and non-experts, the task can be impossible, so RM using ALM remains underutilised.

Cost of RM using ALM is another inhibiting factor for its adoption. Yet, in order for the cost of ALM technologies to come down, there needs to be an increase in their use, and an increase in demand can drive the growth of the ALM market bringing in new machine and material options for designers to utilise. Conversely, in order for companies, especially small to medium sized companies, to start exploiting the advantages of ALM, they first need to be made aware of what is possible now and what is available. This paper presents a potential solution to these problems as an ALM selection advisor tool.

The research presented in this paper is a review of previous research regarding selection of an ALM technology as a method for producing a rapid prototype as opposed to selection of a RM method. The paper then describes the building of a relationship database of available ALM technologies based on what is currently available in the UK market through service providers and bureaux. The paper then goes on to present a tool which can be queried by a user to recommend suitable technologies to manufacture any given product. The final part of the paper describes further work to be undertaken.

EXISTING SELECTION TOOLS

Intelligent RP System Selector

The Industrial Research Institute Swinburne (IRIS), based at Swinburne University in Australia, was developing a system named the Intelligent RP System Selector in 2001. It is an expert rule based system that assists a user wanting to purchase a rapid prototyping technology. This is done by asking the user a series of questions relating to their machine specification. The main criteria for selection are price, dimensional accuracy, surface finish, maximum build volume, range of materials, range of layer thickness and speed of build (Masood & Soo, 2002)

The system is aimed at both experienced and novice rapid prototype users in manufacturing. It includes rapid prototype systems from the USA, Japan, Germany, and Israel and includes 39 rapid prototype machines available before 1998. The selection criterion for the system was based on results of a questionnaire that was given to groups of vendors and users.

The program has four main choices for the user to make: Quick Selection, Detailed Selection, Build Technology, and Machine Style. An illustration of the system user interface (UI) is given below in Figure 1. The selector is programmed with a series of ‘IF’ and ‘THEN’ rules based on the knowledge input into the system. The system checks user input against the rules and generates recommendations based on that input.

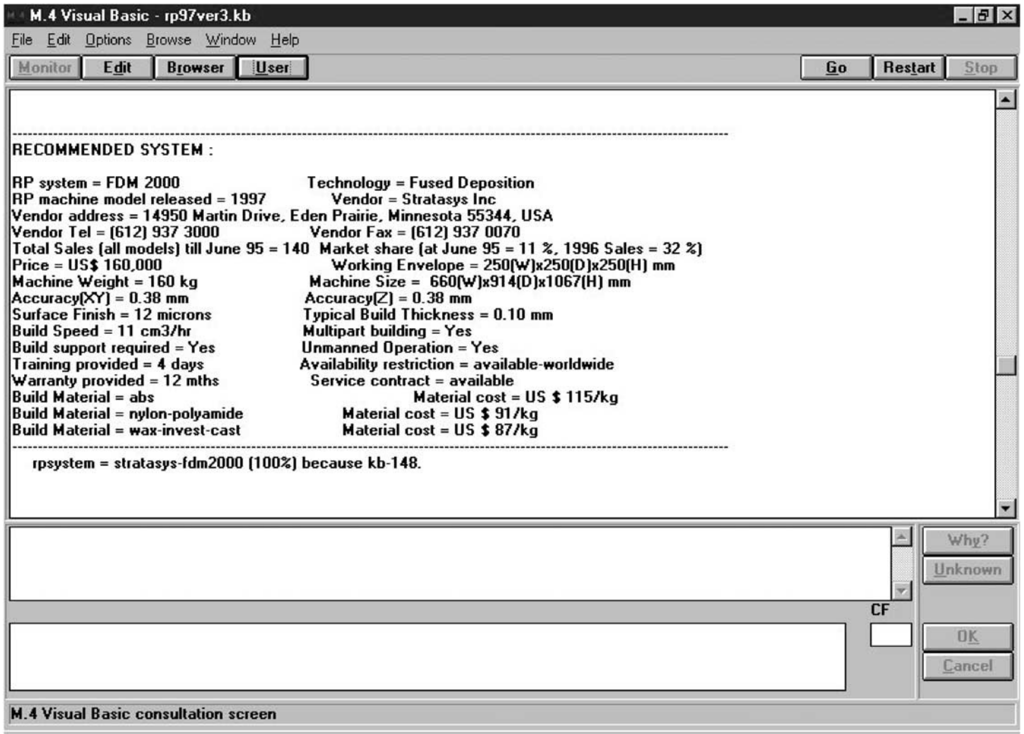

Figure 1: Intelligent RP Selector User Interface (UI)

Data for the selector system was gathered from original equipment manufacturers and verified through vendors and users of the technology. For each of the four major selection options, a different basis is used to generate the recommendation:

- Quick Selection: Price, XY accuracy, build volume and material.
- Detailed Selection: Price, XY accuracy, Z accuracy, surface finish, build volume, build thickness and build speed.
- Building Technology: Laser or non-laser system, building process, price, XY accuracy and build volume.
- Machine Style: Office environment, desktop, normal commercial type, price, XY accuracy and build volume.

The selector asks questions of the user giving them options to choose from. The process continues and an appropriate technology is recommended. Along with the technology description, other information is displayed including vendor details. Multiple recommendations can be made by the selector and displayed as a list for the user to choose from.

The creators of the IRIS rapid prototype selector suggest that improvements could be made with the addition of images of the machines and graphs displaying any technical data.

Computer based rapid prototyping design advice system

In 1999, the Design Engineering Research Centre at the University of Wales Institute (Cardiff) developed a computer based rapid prototyping design advice system. The system operates on a similar basis to the IRIS system which works using a knowledge base and some sort of inference engine, using rules often expressed as 'IF', 'THEN' and 'ELSE' statements organised as a pattern. However, this system works by breaking tasks down into subroutines, some of which make decisions based on input data and others contain rules for checking and either implementing or rejecting the decision (Bibb *et al*, 1999). This system gives priority to certain input criteria and other input is checked against this initial selection.

This particular system also incorporated the use of Computer Aided Design (CAD) data in the selection process, primarily because the overall design of the system was to be user friendly and so user input was kept to a minimum. The CAD data was interpreted and values inferred from it through calculations from a second program. The resulting values were then used as input data for the main system. Having the ability to call secondary programs from the main program allowed for less time to be spent coding the system and more time to be spent on the content (Bibb *et al*, 1999).

Rapid prototype process selection using graph theory and matrix approach

Rao and Padmanabhan of the National Institute of Technology, Gujarat, India and the SNG College of Engineering, Kerala, India, discussed rapid prototype process selection using graph theory and matrix approach (Rao & Padmanabhan, 2007).

Their logical system, like other technology selectors, defines desirable attributes of a rapid prototyping system as process selection criteria. The interrelations between the selection criteria in terms of their relative importance are modelled in a diagraph and matrix style.

The selection criteria they impose are similar to other rapid prototype selectors and include dimensional accuracy, surface roughness, tensile strength, elongation, part cost and build time. In the system, all attributes with the exception of part cost and build time, are given real values. Part cost and build time are expressed as a fuzzy value, for example, very high, medium, low, very low. These fuzzy values are quantified through a conversion table that assign an attribute: a value based on a relative scale that starts at exceptionally low (0.045) and ends with exceptionally high (0.995).

A user then defines what the most important attributes are that they require for a model produced using a rapid prototype technology. The system calculates a value for each technology in the program in relation to the attributes defined by the user, ranking the technologies in order of suitability for the users' purpose and thus making a recommendation.

Rapid prototype system selection system using a TOPSIS method

Byun and Lee (2005) describe a rapid prototype technology selection system using a modified technique of order preference by a similarity to ideal solution (TOPSIS) method. Like in other systems, the authors define attributes a user will input to determine the suitability of a rapid prototype technology for production of an end use model. They use both crisp and fuzzy data related to the defining attributes to rank individual rapid prototype technologies. The crisp data they use includes values for accuracy, surface roughness, tensile strength and elongation. These values were obtained via benchmarking of each rapid prototype technology by designing a test part to be produced using each of the rapid prototype technologies. Values for the crisp data attributes were taken from these test parts. Fuzzy data which includes model price and build time, have values determined from linguistic terms such as very very low to very very high.

The attributes used to generate recommendations for a rapid prototype technology for a user are the same as those used by Rao and Padmanabhan in their selector system using graph theory and matrix approach. In fact, Rao and Padmanabhan borrowed theses attributes from work carried out by Byun and Lee, who determined these attributes through questionnaires with vendors, institutions and bureaus.

Once the rapid prototype technologies have been ranked according to their attributes, the user can generate recommendations on which system to choose by giving weighting factors to the various attributes in terms of the most desirable for a particular model. This presents an easy to use system which can handle both crisp and non crisp data. However, no UI has been presented by the authors where it is offered as a system where data can be organised and analysed to generate an outcome.

Summary

One of the problems with the aforementioned selector tool concepts is that the user needs to have some specific input data about their product before they can make any recommendations using the system. For some designers with very detailed design specifications, this would not be an inhibiting factor. However, for an industrial designer or small creative industry business, the input data required as logical values such as surface roughness, could be off-putting and to omit it could cause the system to fail. For a system utilised for selecting an ALM technology for rapid manufacturing, the input data needs to be easily understood by the majority of designers, such as using text to describe attributes a product might need as apposed to a numerical value.

SELECTION SYSTEM DATABASE

In order for a system to be developed to aid designers in choosing an ALM technology route for manufacturing, firstly a database needed to be built containing all current rapid manufacturing technologies. For this selector, a relationship database was constructed detailing the types of machines available from various producers, the different types of technologies each machine used, the available materials for each machine and technology, and the characteristics of a part created with a combination of machine and material. Figure 2 below illustrates the construction of the database and the relationships between each category. Constructing the database this way makes it easier later to programme a selector tool to make recommendations based on user input. Each relationship shown here, such as the relationship between one manufacturer who can produce many products, is a database of information relating to that particular category. Figure 3 below illustrates the materials database. Each material in Figure 3 has an identification number so that it can be referenced quickly and easily throughout the other relevant databases, and a category identification which puts it into a material category of either polymer, metal or ceramic. The categorisation of attributes in the system, which includes material type, technology type, manufacturer, products, etc, means that building of relationship databases can be done quickly and easily. It also allows the system to be easily queried to generate recommendations and allows it to be easily updated.

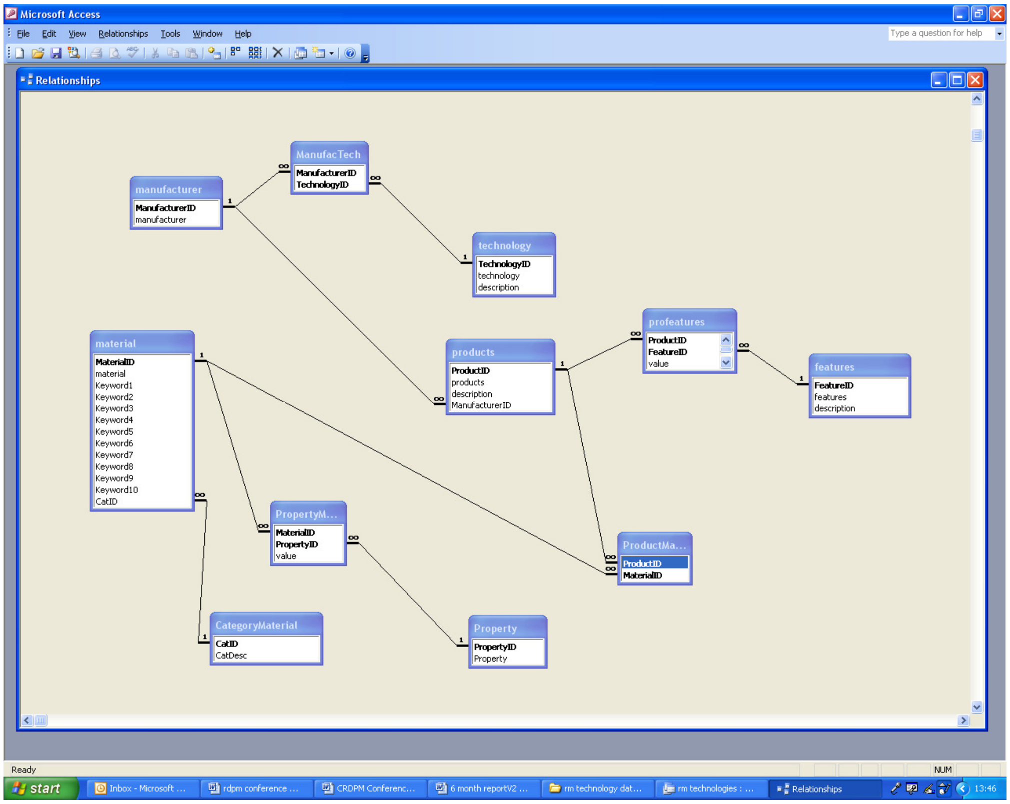

Figure 2: Relationship database construction for RM selector

The database contains 40 ALM technologies/machines from seven different manufacturers (see Figure 4 below). Although there are many more manufacturers of ALM technologies available, the technologies included in this database are based on information gathered by the authors in relation to the most suitable technologies for rapid manufacture of parts and the availability of technologies in the UK market.

MaterialID	material	Keyword1	Keyword2	Keyword3	Keyword4	Keyword5	Keyword6	Keyword7	Keyword8	Keyword9	Keyword10	CatID
1	Duraform PA	Durable	Fine detail	Chemical resist	Thin walls	Snap fit	White	Accurate				1
2	Duraform GF	Stiff	High temperatu	Machinable	Smooth surface	Accurate						1
3	Alumide	Stiff	Metallic grey	High temperatu	Accurate	Machinable						1
4	Carbomide	Stiff	Strong	Durable	Black	Long term stabi	High temperatu	Impact resistan	Conductive			1
6	AccuraXtreme	Durable	Impact resistan	Snap Fit	Grey							1
7	Accura10											1
8	Accura 25	Flexible	White	Accurate	Fine detail	Snap fit						1
9	Accura 40	High temperatu	Fine detail	Tough	Snap fit	Accurate	Amber	Stiff				1
10	Accura 50	Durable	Accurate	Snap Fit	Stiff	Grey	White					1
11	Accura 55	Tough	Durable	Accurate	White	Snap Fit						1
12	Accura 60	Tough	Stiff	Clear	Accurate							1
13	Accura Amethy	Jewellery patter	Master models									1
14	Accura Bluesto	Accurate	Long term stabi	Water resistant	High temperatu	Stiff						1
15	Accura Accuge											1
16	Accura 45HC	High temperatu	Stiff	Clear	Amber							1
17	AccuDur 100											1
18	RenShape SL 7	Strong	White	Durable								1
19	RenShape SL Y	General purpos										1
20	RenShape SL 7	General Purpos	Clear	Amber								1
21	RenShape SL Y	Medical	Hearing aid	Pink								1
22	RenShape SL Y	Clear	Custom colorec	Medical	Hearing aid							1
23	RenShape SL H											1
24	Somos 7110 Ep	Clear amber	Rigid	Accurate	High temperatu	Thin walls						1
25	ULM 17220 Bla	Rubber	Flexible	Black	Tough							1
26	ProtoTherm	High temperatu	Water resistant	Red	Strong							1
27	Somos 9420 EF	Durable	White	Accurate	Snap fit							1
28	Somos NanoTo	Strong	Stiff	High temperatu	Fine detail	White	Smooth surface					1
29	WaterShed 111	Durable	Water resistant	Accurate	Strong	Clear	Thin walls					1
30	WaterShed 111	Durable	Water resistant	Accurate	Strong	Clear	Thin walls					1
31	ProtoTherm 121	Water resistant	Strong	High temperatu	Red							1
32	14120 White	Durable	White	Water resistant	Tough							1
33	Somos 9120 Ep	Accurate	Durable	Chemical resist	Snap fit	Clear amber						1
34	Somos ProtoGe	General purpos	Clear									1
35	Somos 9110 Ep	Durable	Accurate	Chemical resist	Snap fit	Clear amber						1
36	WaterShed XC	Durable	Clear	Water resistant	Strong							1
37	Somos ProtoGe	General purpos	White									1
38	DMX-SL 100	Very tough	Durable	Very fine detail	Very accurate	Impact resistan	Smooth surface	Snap fit	White			1
39	Somos 9920	Durable	Accurate	Clear amber	Snap fit	Chemical resist						1
40	WaterClear 101	Stiff	Durable	Strong	Clear							1
41	Somos ProtoCa	Investment cast										1
42	WaterClear 101	Clear	Stiff	Durable	Strong							1
43	NanoForm 1512	Strong	Stiff	High temperatu	Grey							1
44	Somos 7120 Ep	Very accurate	Clear amber	High temperatu	Thin walls							1
45	Somos 8120 Ep	Flexible	Clear amber	Impact resistan	Accurate	Snap fit						1
46	Somos 8110 Ep	Flexible	Accurate	Impact resistan	Clear amber	Snap fit						1
47	DuraForm Ex	Impact resistan	Tough	Durable	Black	White	Accurate	Thin walls	Snap fit			1
48	CastForm PS	Investment cast										1
49	DuraForm Flex	Durable	Smooth surface	Flexible	Fine detail							1

Record: 1 of 79

Figure 3: Materials database part of RM selector database

ProductID	products	description	ManufacturerID
1	Sinterstation Pr		1
2	Sinterstation Pr		1
3	Sinterstation Hi		1
4	Sinterstation Hi		1
5	Vanguard		1
6	Vanguard HS		1
7	Sinterstation 25		1
8	Sinterstation 25		1
9	Sinterstation 20		1
10	Viper Pro		1
11	Viper		1
12	SLA 5000		1
13	SLA 7000		1
14	SLA 3500		1
15	Formiga P 100		2
16	Eosint P 390		2
17	Eosint P 700		2
18	Eosint P 730		2
19	EosintS 750		2
20	Eosint M 270		2
21	Eden 250		4
22	Eden 260		4
23	Eden 350		4
24	Eden 350V		4
25	Eden 500V		4
26	FDM 200mc		6
27	FDM 360mc		6
28	FDM 400mc		6
29	FDM 900mc		6
30	Dimension 768		6
31	Dimension 120(		6
32	Dimension Elite		6
33	Dimension 768		6
34	Dimension 120(		6
35	M1		7
36	M2		7
37	ZPrinter 310 Plu		5
38	Zprinter 450		5
39	Spectrum Z510		5
40	A2		3
(AutoNumber)			0

Figure 4: ALM technologies contained in the database

UK AVAILABILITY

The content for the database is related to what is available currently in the UK market through service providers. This is because the RM selector tool which uses the database is aimed at UK creative industry businesses and so it was deemed appropriate to design the system in the context of what was available in the UK.

Figure 5 illustrates the availability of technologies in the UK's service providers and universities. By technologies, the authors refer to ALM hardware capable of rapidly manufacturing products.

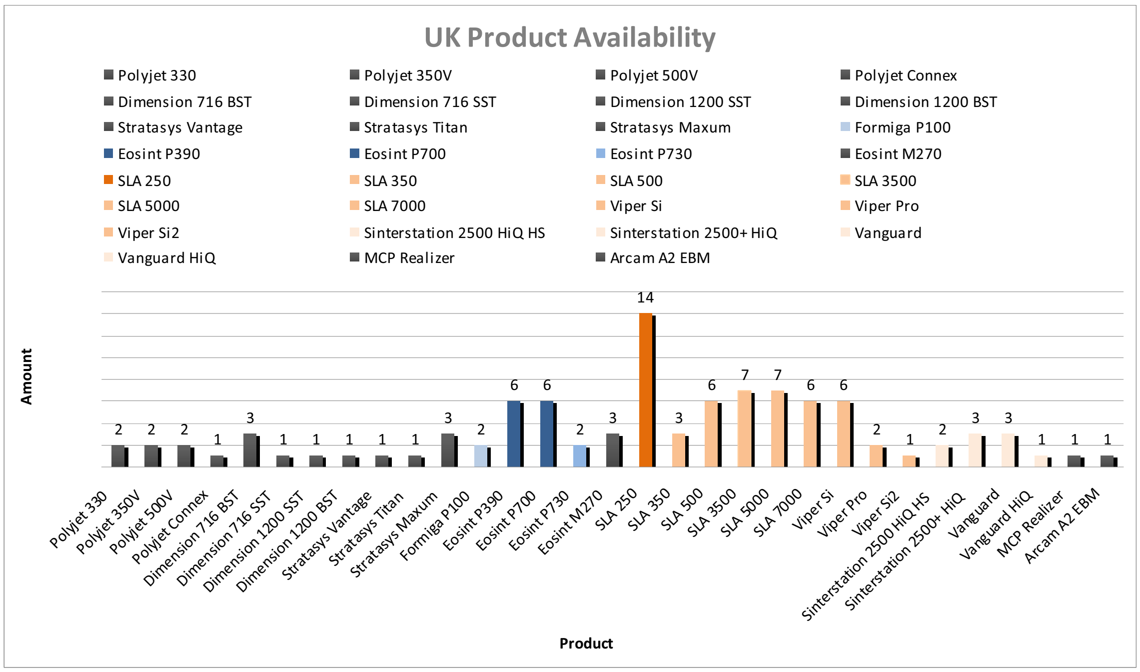

Figure 5: ALM technologies available in UK

Within the UK market, there is a lean towards two types of technology that are more readily available than others. Figure 6 shows how Stereolithography (SLA) and Selective Laser Sintering are the dominant technology platforms and most widely available to rapidly manufacture products, with a heavy weighting of polymer based systems over metallic systems (Figure 7).

The same can be said for the availability of materials for RM in the UK, with SLA resins dominating the material availability (Figure 8).

RAPID MANUFACTURING SELECTION TOOL

Whereas previous attempts at a rapid prototype selection system have required some level of user input knowledge about either ALM technologies or specific product data, like surface roughness, build orientation etc., this selector uses input data that does not discriminate against lack of knowledge. It was decided that initially, the use of keywords relating to the required characteristics of any given technology would be used to search the database and generate a list of recommendations that the user could then use to make their final decision on a suitable ALM technology for manufacture. On a user entering certain keywords into the selector tool, it would search for materials that concur to the entered data until it finds a match, or in most cases, many matches. The construction of the relationship databases allows the system to relate each material to a technology, manufacturer and product which will stand as the information generated for the user to view.

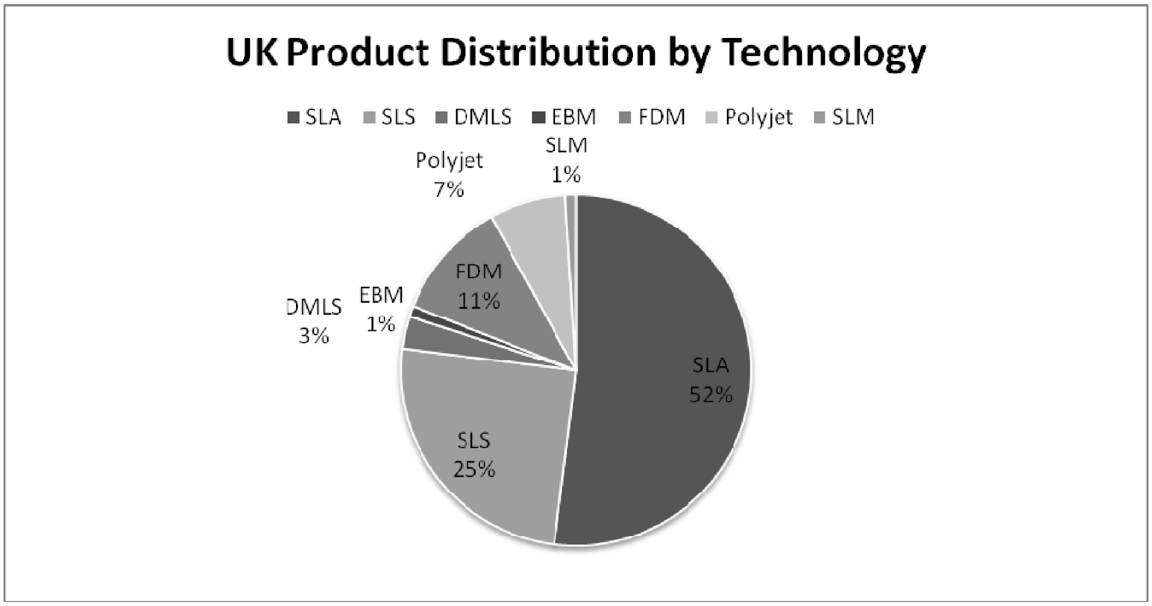

Figure 6: Percentage of technology platforms in the UK

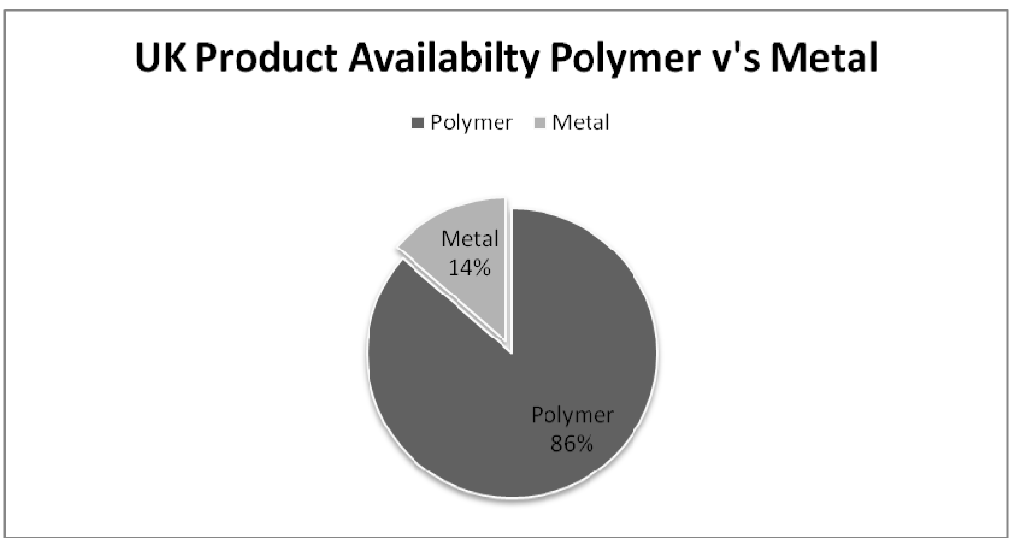

Figure 7: Percentage of polymer systems to metallic systems

Figure 9 below shows the UI for the RM selection advisor programme. It is a web based programme that has been designed to be easy to use. Once the user has entered a keyword into the selector advisor or answered some product profiling questions, the programme searches the database for any relating keywords or materials that match the profile of the product.

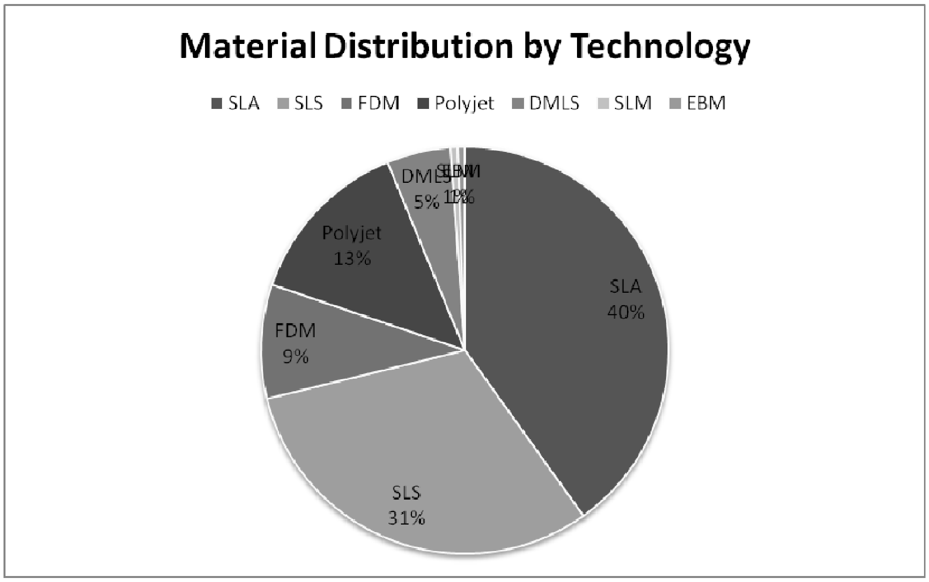

Figure 8: Availability of materials in the UK by percentage

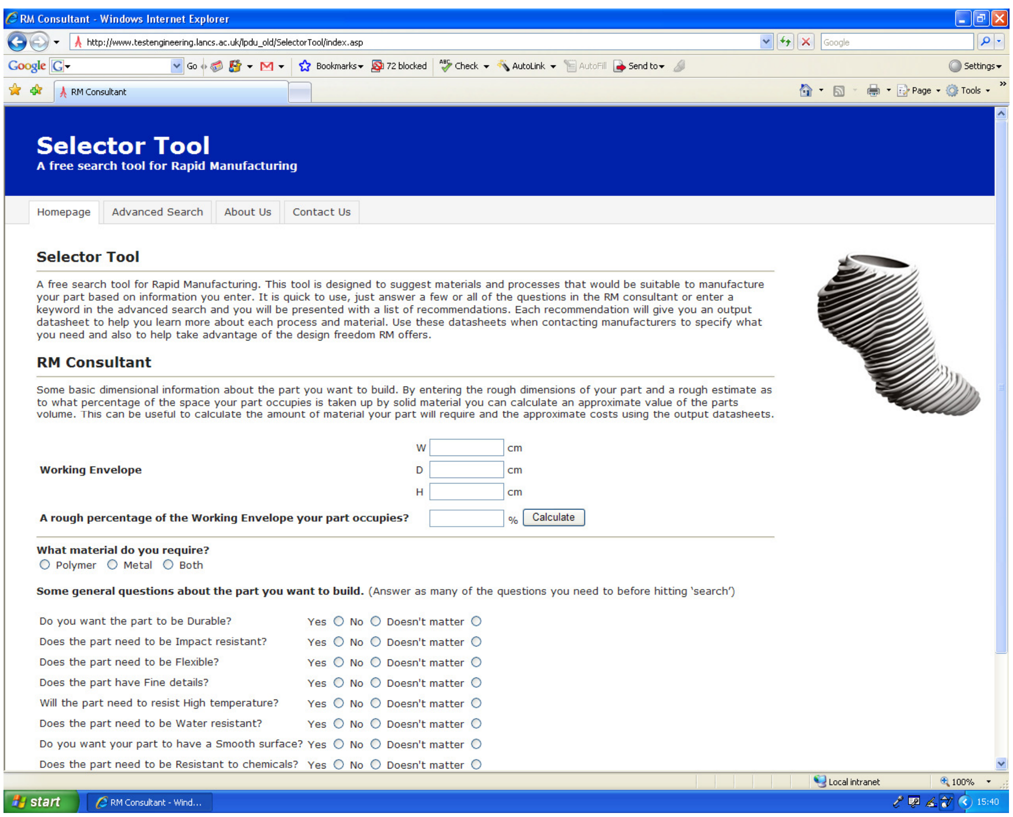

Figure 9: RM selection advisor UI

When the search is complete, the user is presented with a number of suitable RM materials that relate to a particular technology which can then be used to specify a rapid manufacturing process for manufacture of their product. Included with the recommendations are a series of technical data sheets that relate to each of the materials featured in the database. These sheets are included as support for designers. They give information about each particular material, its corresponding technology platform and advice on how to redesign parts specifically for the recommended material and process. The sheet is available as a PDF document which can be accessed by clicking the document link next to the corresponding recommendation (Figure 10).

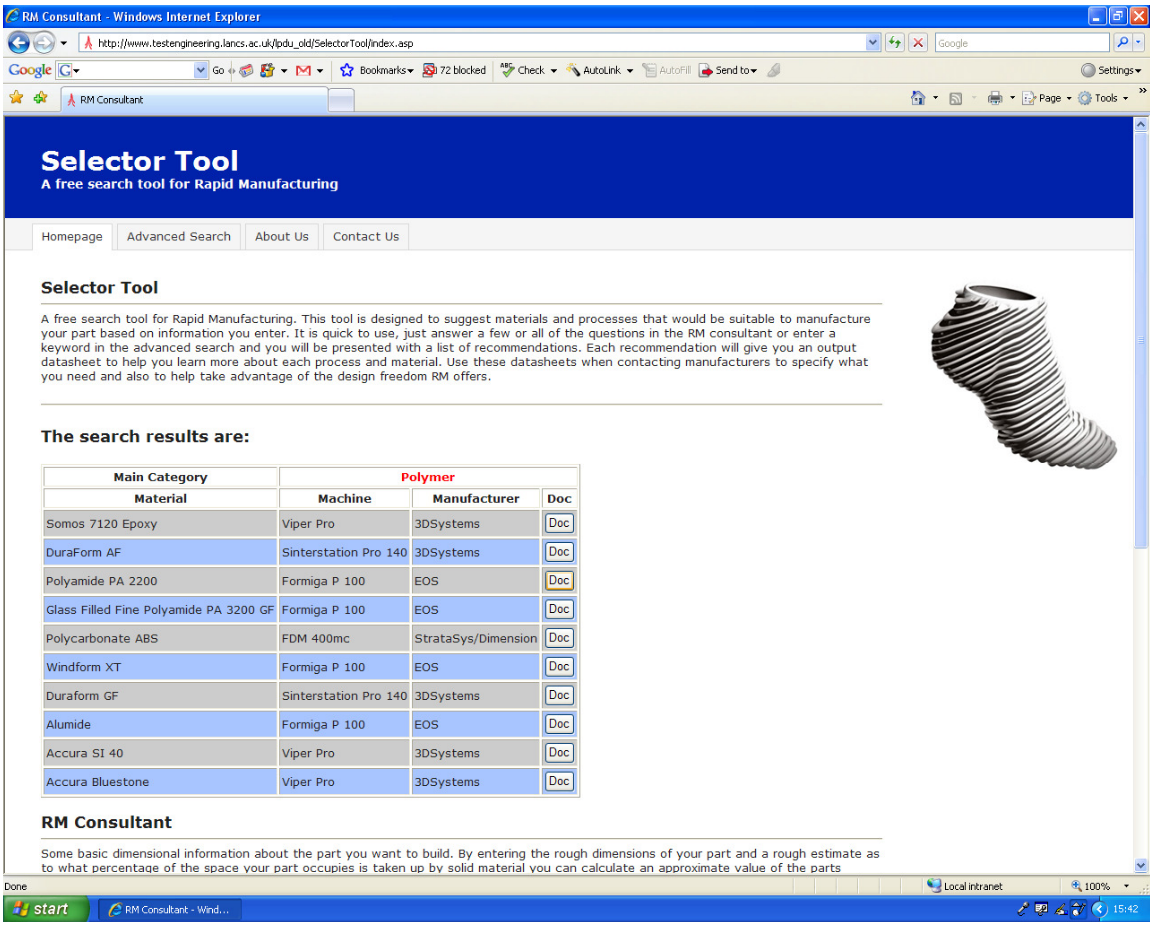

Figure 10: Recommendations made by the tool and corresponding technical document

The resulting information is intended to be enough so that a designer could research suitable service bureaus and use it to specify to the bureau what they require. It is not the intention of the selector tool to give definitive information on one recommendation, mainly because there is, for most products, more than one rapid manufactured solution, but also because what is achievable by one bureau service provider with a certain material and technology may not be achievable with another due to experience or conditions. For these reasons consulting with a service provider would be necessary before a final decision is made.

CONCLUSIONS AND FURTHER WORK

To increase the use of ALM technologies as a direct manufacturing method, relevant information needs to be made available to designers of all abilities. The selector tool presented in this paper allows basic specifications to be made for individual products which can then be used to provide recommendations of suitable materials and technologies that can manufacture that product.

There are improvements that could be made to the selector tool. As well as improving the overall aesthetic view of the UI, the intention is to include approximate weight or cost values for any given product, the data of which will be input into the system in a future version, and allow the user to select a material category before querying the system. Other further work can be summarised as:

- Make the selector more intelligent:
    - Add more countries;
    - Allow country selection;
    - Refine keyword search to respond to product application.
- Integrate with other applications:
    - CAD;
    - Quotation tools;
    - Order and Purchasing system.

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