Layer Manufacture

A New Form of 3-D Visualization for Artists

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Executive Summary

The author was commissioned by AGOCG to:

(a) report on current technologies for object realisation, with advantages/disadvantages of each

(b) report on facilities currently available in UK HE and UK companies providing a sub-contract service
(c) report on services which could be obtained from those in (b)
(d) preliminary recommendations on what could be done to provide a service for HE

The report review the layer manufacturing equipment (often called Rapid Prototyping) which is currently on the market and which is sited in British Universities. It identifies that layer manufacture is a well established manufacturing process and is well able to offer the artist a new medium in which to work. Of the 5 processes available, 4 are aood candidates for adoption by the art community, namely:

- stereo lithography (acrylic and epoxy models)
- selective laser sintering (nylon or polycarbonate models)
- laminar object manufacture (wooden models)
- fused deposition modelling (plastic or wax models)

In order to employ these processes, a computer-based solid model must be developed and a data file produced in STL (STereo Lithography format, devised by 3D Systems, has become the de facto standard) format. A number of solid modelling systems can produce robust STL files, but few systems which are attuned to the artist are available. Two packages are identified which are

in current use in industry and education and which offer both an intuitive interface to the artist and the facility to generate satisfactory STL data. No doubt further work wiil yield more packages which satisfy the necessary criteria.

This study draws the conclusions that

(a) layer manufacture offers exciting opportunities for the art and design community,
(b) the British HE sector has sufficient facilities and experience to offer bureau services for object manufacture,
(c) a JISC sponsored initiative could enable this technique to become widely available, become a part of the art and design curriculum in HE, and qive UK institutions a world lead in this area.
(d) the surface / object modelling needs of the art community should be examined

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1. Scope

The Engineering profession has been employing Layer Manufacture since 1988 for the production of rapid prototypes. The prototypes are manufactured from data files generated by Computer Aided Solid Modelling systems. Since artists also use such systems, it seemed possible to the author that Layer Manufacture could offer this sector a new medium for the realisation of their creative work.

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During the study, it became clear that there was extensive experience and a wide range of facilities available in the HE sector, and thus industry-based, UK production bureaux have not been considered.

2. Layer Manufacture

2.1 Principles

Layer Manufacture is a process where a solid object is constructed by progressively building up wafer-thin horizontal cross-sections, one on top of another. The slices, and hence the finished objects, can be made of paper, resin, wax, polycarbonate, nylon and (in the near future) metal alloys.

The approach relies on the existence of a data file which describes the geometry of the surfaces of the object. This file is then 'sliced' to produce a large number of cross-sectional data slices. Each 'slice' of data enables the manufacturing device to produce a thin layer of material which is then attached to slices produced earlier.

There are two essential prerequisites for an object to be produced by Layer Manufacture. These are:

(a) a 3-D solid or surface model

(b) a data file from the solid/surface modelling package which can either

(i) be 'sliced' by the manufacturing device's software, or

(ii) be post-processed to render it suitable for 'slicing'.

2.2 History of the process

Layer Manufacturing began in a meaningful way in 1988, when the US company 3D Systems produced their first ***Stereo Lithography*** machine. This device produced thin layers of material by curing a photo-sensitive resin with an ultra-violet laser (further details are provided in section 3). Since that time, over 500 units have been sold world-wide, an additional 5 processes have been invented, and a total of 10 companies are now in the marketplace.

2.3 Manufacturers

There are 5 commercial methods by which layered objects can be manufactured, and the processes are listed in Table 1, along with manufacturers' names and typical costs.

Table 1

Technology	Manufacturer	Approx. units sold	Cost of device
Stereo lithography	3D Systems CEMET (Mitsubishi) EOS	350 50 10	200k (UKP) to 250k (UKP)
Solid Ground Curing	Cubital	15	400k (UKP)
Selective Laser Sintering	DTM	30	250k (UKP)
Fused Deposition Modelling	Stratasys	20	80-120k (UKP)
Laminated Object Manufacture	Helisys	20	80-200k (UKP)

Stereo Lithography holds the major slice of the market, with the original manufacturer, 3D Systems, having the largest portion. The revenue from these machines has grown, on average, by 30% per year since 1988, and is predicted to rise by 35 to 40% each year in the medium term. World-wide revenues in 1993 were over $50m. Costs of machines are decreasing, and computer manufacturers such as IBM and Hewlett Packard are developing desktop devices. It seems likely that in the medium term some devices will be affordable by a wider population of users.

3. Types of Device

This is a manufacturing process which is growing quickly in popularity, and the technology is developing rapidly. Of all the systems which are available, the following technologies are now well proven and mature:

(a) stereo lithography (SLA)
(b) selective lasersintering (SLS)
(c) laminar object manufacture (LOM)
(d) fusion deposition modelling (FDM)

These are discussed in detail below

3.1 Stereo Lithography

In this process, a laser 'draws' a cross-section on to the surface of a bath of photosensitive resin. The laser partially cures the resin and thus produces a thin layer of solid material. The process commences by positioning the support table just below the surface of the resin so that the first layer drawn adheres to the table. After each layer is completed, the table lowers by a small amount, thus exposing another thin layer of resin which can be cured. In this way a solid model slowly builds up in the bath of resin, as shown in Figure 1. In order for the model to be removed from the table, the first layer consists of a fine lattice of resin. As the model develops in the resin bath, overhanging sections can present considerable problems. This is illustrated in Figure 2, where an object with an overhang is being manufactured. To prevent collapse of the structure, supports in the form of a lattice have to be provided for the layers and these too have to be removed from the object after final curing.

Once complete, the model is removed from the bath and the curing is completed by cleaning it to remove excess resin and placing it in an ultra-violet oven.

Following this process, the lattice must be removed and the model finally tidied. Thus the process involves:

(a) a 'drawing' stage
(b) a cleaning and post-curing stage
(c) a final dressing stage

Improvements are constantly being made in the resins available and the structural properties of the final model can vary according to the resin employed.

3.2 Selective Laser Sintering

This process employs a powder which can be fused by heat instead of a resin. Figure 3 illustrates the process. The model is built on a platform which is situated within a horizontal platen. The platform is lowered a small amount so that a very shallow recess is formed between platform and platen. A roller then spreads the powder across the platen, filling the recess left by the lowered platform. A laser directed across the powder by a scanning mirror draws the shape of the cross-section, and thus fuses (i.e. sinters) the powder. The platform is then lowered by a small amount, the roller spreads some more powder, the laser scans the surface, and the process is repeated. There is generally no need, in this process, for additional supports to be provided for overhangs because the unfused powder fulfils this function. No other process is required, and very little dressing of the model is needed. Currently, polycarbonate, nylon and wax powders are available, with metal powders under development. The models can be filed, carved, painted or sprayed.

3.3 Laminar Object Manufacture

In this process, the laser cuts the slices from a sheet of paper which is then attached to previously cut layers. Unlike other processes, only the outline of the shape need be cut, but areas which are to be free space in the final model are finely cross-hatched by the laser, producing a collection of small cubes in the final model. These provide support for material which may come on top, and can normally be removed at the end of the process. Occasionally, the unwanted cubes could become entirely enclosed within the model, and thus the process has to be interrupted so that the extraneous material can be removed before enclosure occurs.

Once lamination is complete, the model feels like (and effectively is) wood. It has to be dressed to remove the support cubes and then polished. It can then be treated like wood, but care must to be taken to avoid delamination.

3.4 Fused Deposition Modelling

In this process, a filament of wax or plastic is supplied to a heated dispensing head. The head moves across the surface, building up the cross-section in molten wax or plastic which quickly solidifies. No further curing is required, and the material is strong enough to not require supports for most overhangs.

Where an in-fill or overhang-support is required, a second head can be employed to lay a plastic or wax lattice which is amenable to easy removal after manufacture.

4. Performance Parameters

Each process has its only particular characteristics. The ones most relevant to artists are tabulated below in Table 3. The cost of manufacturing a small object such as a coffee mug is included in the data, and is approximately the same at 200UKP. The cost quoted is based upon a number of objects being produced at the same time. Just as in the fashion industry where minimum material wastage is attempted by good nesting of patterns, a manufacturing run can be made most productive if as many objects as possible are packed into the manufacturing volume. This is achieved by good software on the manufacturing device, and even involves packing objects inside others to minimise waste.

Table 3: Process Characteristics

Characteristic		**PROCESS**		
	SLA	**SLS**	**LOM**	**FDM**
Data Preparation time	high	low	none	low
Manufacturing time	same	same	same	same
Post Processing time	high	low	medium	low
Material Cost	high	medium	low	high
Vertical Resolution	75-100 m	75-100 m	250 m	125 m
Typical Cost of Object	200 UKP	200 UKP	200 UKP	200 UKP

5. Software Issues

5.1 Modelling Software

Layer Manufacture is a computer-controlled engineering production process which requires detailed manufacturing data (an STL file), just as numerical controlled machine tools need precisely defined paths for the cutting tools to follow.

Computer aided engineering design packages define 3-D models in a rigorous fashion and can be employed to generate sound data for Layer Manufacture. However, the interface of an enqineering CAD packaqe is not generally suitable for artists. This group prefers a Free Form Surface Modelling package whose main objective is to produce visually acceptable screen images. Such systems are designed principally to produce visually acceptable 2-D pictures of 3-D objects. When used in Layer Manufacture, they will often produce models whose surfaces may not be fully closed (i.e. the facets of the surface may not meet), whose facets overlap, or which have walls of zero thickness.

Software is required, therefore, which has a suitable interface for the artist, but which has rigorous geometric data underlying it so that it can produce good models via layer manufacture. The author has been introduced to 2 packages which would seem to provide these facilities and which will also produce STL files. These are listed below in Table 4. No doubt other packages exist which fulfil both the desian and the manufacturinq requirements.

Table 4

Package	Supplier	Platforms	Cost
DeskArtes	Bite Design, 178 Huntingdon St Nottingham NG1 3NE. Tel: 0115 9503504 Fax: 0115 9472002	Silicon Graphics (preferred),HP, Sun, IBM PowerPC (just launched)	5K UKP for single license
Alias	Alias Research Inc Richmond Street East Toronto Canada M5C 1P1 Tel: 1-800-	Silicon Graphics	approx 25k UKP

	267-8692		

5.2 Pre-Processing

(a) An STL file must be checked to detect if the object exhibits non-closed surfaces or there are places where surface facets overlap. Software is available for this, and this is best done by the manufacturer.

(b) In the SLA process significant overhangs cannot be supported, and software is required to identify these and insert the necessary supports. This is sometimes available in the desian software.

(c) In order to reduce costs, a number of objects should be manufactured simultaneously, and appropriate nesting software is required by the manufacturer.

5.3 Scanning Systems

Systems and software are also available which can scan an existing 3-D object, transform the scan into data for a 3-D model, and then produce an STL file. Thus an existing object can be digitised, manipulated in a CAD system, and then realised by Layer Manufacture.

6. The British University Scene

The Universities listed in Table 5 have the Layer Manufacturing equipment indicated .

Table 5

University	S LA	S L S	LO M	F D M
Leeds		X		
Sunderland		X		
Warwick	X		X	
Coventry				X
Nottingham	X			
Belfast	X			
Liverpool	X			

Visits have been made to the Keyworth Institute at Leeds University, the Advanced Manufacturing Centre at Warwick University (operated in conjunction with Rover Group), and Coventry University. It is clear from the discussions held that there is a wealth of experience in the University sector, and all offer well developed production services to external clients. It seems likely that their costs will be less than those quoted by specialist non-education production bureaux. They are all connected, of course, to SuperJanet and thus data transfer between originator and manufacturer should be swift and straightforward.

7. From Design to Manufacture

The process illustrated in Figure 6 is necessary to take a product from design through to successful manufacture. In order to minimise failures, reduce costs, and produce objects which the designer requires, a number of necessary points must be noted.

These are

7.1 Training

Designers require training so that they fully understand the manufacturing process and they can

(a) not oroduce failures. and

(b) take advantage of the medium

7.2 STL File Generation

Once the object is designed and a data file is stored on the host computer, an STL file must be generated. Whilst these are available for many engineering packages, the situation in the art / sculpture field is less clear. It is known that DeskArtes and Alias are currently in use by designers and can produce robust STL files. However, users will always have a preference for a specific package, so further investigation will be required to identify suitable systems, and perhaps some post-processing software will have to be written.

7.3 Data Transfer and Verification

The originating site can send its data via floppy disc, but transfer via JANET or SUPERJANET is more efficient. Once at the manufacturing site, the data can be checked to ensure that the surface is closed etc. At this stage, if errors are found, feedback to the designer is necessary. It is essential that the designer understands the issues raised by the manufacturer so that the designer's true requirements are satisfied. This emphasises the need for adequate training of the designer, and also an understanding by the manufacturer of the designer's unique requirements (which will often be different from those of an engineer!).

8. Recommendations

8.1 Suitable Processes

From the above discussion, there are 4 possible manufacturing processes which would produce models acceptable to the art and design community, namely:

< stereolithography (SLA)
< selective laser sintering (SLS)
< laminar object modelling (LOM)
< fused deposition manufacture (FDM)

The first process (SLA) can produce models in resin or epoxy. Warwick University has considerable experience with this equipment. The second (SLS) produces models in nylon or polycarbonate. Leeds University has had the equipment installed long enough for it to have become well understood and robust. The third (LOM) will provide wooden models and is available only at Warwick University. The last (FDM) can manufacture wax and plastic models, and Coventry University is the only current HE site.

8.2 Integrating Layer Manufacture into Art & Design Departments

In order to explore how the process of layer manufacture could be integrated into teaching, it would be attractive if art and design departments had the facilities on site so that students, teachers and support staff could become very familiar with the technology, logistics, quirks etc. This is an unreasonable expectation because of the current expense of equipment. However, there is a lot of experience of using Layer Manufacture in British Higher Education, and at least 3 sites have indicated their willingness to act as production bureaux and to provide training to artists. A project could be envisaged whereby a small number of Art & Design Departments would undertake to employ Layer Manufacture in teaching and research. The Departments would involve students, tutors, researchers and technicians in the activity, and would explore the educational, research, logistic, and financial issues involved in employing the technology. Dissemination of the findings will enable the community to assess the impact of such innovative high-technology manufacturing on the teaching curriculum and in research.

8.3 Modelling Software for the Pilot Project

Modelling software is required which has an intuitive interface for the artist, but which has rigorous geometric data underlying it so that good models can be produced via layer manufacture. The author has been introduced to 2 packages which provides these facilities and which will also produce STL files without the requirement for separate post-processing software.

8.4 Needs Analysis for Software

Further work is required to identify other useful packages which offer the appropriate facilities, or whose output files can be appropriately post- processed.

9. Acknowledgements

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