Build Time Estimations for Large Scale Modelling

G. Mensing and I. Gibson
University of Hong Kong

Abstract

Achieving speedy results in model making is very much desired if not a necessity in almost any manufacturing industry. There is no doubt that rapid prototyping contributes to this process. It is generally considered that when compared to conventional machining techniques like milling, the current rapid prototyping systems appear to be much faster. This is certainly true for complex, small objects. However, this is not always applicable to simple, large and bulky parts.

There are a number of projects and systems concentrating on the fabrication of large models. Work is being carried out at the University of Hong Kong, using milling along with slicing technology. This report compares some of the rapid prototyping systems with milling. Milling is an established technology and recent developments in materials and machines used in milling make it a good alternative to rapid prototyping when it comes to large scale modelling.

Introduction

Industry has often expressed the need for prototypes larger than current rapid prototyping technology is capable of. A number of approaches [1][2] have been developed to address this. The system at the University of Hong Kong is similar to those developed at Ford Research [3]. This report follows as a result of the proposed system for large scale rapid prototyping [4]. Milling, combined with layer based technology results in faster prototyping for large, bulky objects. Milling is also more appropriate for tooling applications because of the variety of materials that can be used. Some simple objects of variable sizes are discussed with the view to understanding how rapid prototyping systems would deal with making models that are larger than they are currently capable of. Extrapolation is used to calculate the times needed for the largest models since these are too big for the current systems.

The systems are compared using build time. Companies are willing to pay more in the short term as long as there is a considerable saving in time. This makes the company more competitive and can save money in the long run. However rapid prototyping may not save time when building large models compared with conventional technology.

1. The rapid prototyping systems

First some rapid prototyping systems are discussed. These are the systems that were used in the test. Each system displays characteristics that may make it difficult to construct them so they are capable of making larger models.

1.1.1. StereoLithography – 3D-Systems

StereoLithography [5][6] uses photo-reactive polymers, which react to ultraviolet (UV) light. For this, the system utilises a precisely directed laser beam. When resin is struck by sufficient UV light,

it solidifies (polymerises). By scanning UV light onto the surface of the polymer according to the design, a layer (slice) of a model is created.
To make the next and subsequent layers, the object is lowered into the vat filled with resin. This way new resin flows over the object. Next, this new layer of resin is solidified. The process continues until the object is finished.
This process is accurate, but very limited in the variety of materials. It is possible though to use the models to manufacture moulds for casting.

1.1.2. Model Maker – Sanders Prototype

Sanders [7] developed the Model Maker, a plotting system where a liquid-to-solid inkjet plotter with a separate Z-axis input is used. An inkjet subsystem rides on a precision X/Y drive carriage and deposits both thermoplastic and wax materials on the build substrate. The X/Y drive carriage also energises a flatbed milling subsystem for maintaining precise Z-axis dimensioning of the model by milling off the excess vertical height of the current build layer. A support material is used to support overhangs and cavities in the model during the build. Droplets are placed upon the build substrate to within 0.00025 inches (0.007 mm) in the X and Y directions. The droplets stick to each other during the liquid-to-solid phase transition to form a uniform mass. After solidification the milling of the layers immediately follows the deposition cycle. It is a slow but accurate process and only thermoplastic materials can be used.

1.1.3. Fused Deposition Modelling - Stratasys

With Fused Deposition Modelling or FDM [8], a temperature-controlled head extrudes thermoplastic material layer by layer and thus creating a model. The CAD-model is sliced and, if necessary, supports are created similar to the StereoLithography process. Path data is then downloaded to the FDM system. The system operates in the X, Y and Z-axes. In effect, it draws the model one layer at a time.
Thermoplastic modelling material, a wire of 0.070 inches (.178cm) in diameter feeds into the temperature-controlled FDM extrusion head, where it is heated to a semi-liquid state. The head extrudes and deposits the material in ultra-thin layers (0.05 to 0.762 mm) onto a fixtureless base. The head directs the material into place with precision. The material solidifies, laminating to the preceding layer.

1.1.4. Selective Laser Sintering - DTM

The Sinterstation, from DTM [9] works with powder, which is selectively sintered by means of a CO_2 laser. A roller spreads powder on a bed. A laser selectively sinters this layer. The model is indexed down. This process continues until the model is completed. An advantage of this process is that it does not need supports. DTM is in the process of developing a wider variety of materials, and although metal powder can be used it is not quite good enough for long term tooling.

1.1.5. Laminated Object Manufacturing - Kira

The machine from Kira [10], Japan, is a Rapid Prototyping Machine suitable for installation in an office environment. The machine uses paper (wood) as material and the cutting process is not carried out with a laser as used by Helisys [11], but is realised mechanically by means of a cutting plotter. A laser printer is used to print the outline of the model onto a sheet of paper. This paper is then bonded to any previous layers. The Kira then cuts the outline of the shape of this layer. Next a new sheet of paper is added on top of the former, bonded and then cut. This continues until the model is finished.

1.1.6. DeskProto [milling] - Delft Spline Systems

DeskProto [12], a software package, reads the STL-file and displays its contents. Next some milling parameters such as the type of cutting tool, required accuracy, etc. are entered. DeskProto then automatically calculates the milling paths. These milling paths are sent to the desktop NC milling machine, which produces the object. This process can be done with a wide variety of materials.

1.2. Current Rapid Prototyping Systems on a large scale

An obvious technique for producing large scale prototypes would be to increase the size of the current systems. This might not be a trivial process.
Increasing the size of all the systems would be costly, requiring much more attention to system stability and structure. With StereoLithography, for instance, system designers would have to consider the problem of maintaining the stability of the resin over a large surface area.
Laser based systems would require much more powerful lasers and larger surface areas would also result in significant problems with the optics.
A number of the systems use plotting mechanisms (e.g. Sanders, FDM). Large prototypes would require a significant amount of travel for these mechanisms which would result in long build times.
Kira, Helisys and milling rely more on the surface area than the volume of a part. This implies that fabrication of large bulky objects using these techniques would require less energy than purely additive processes.

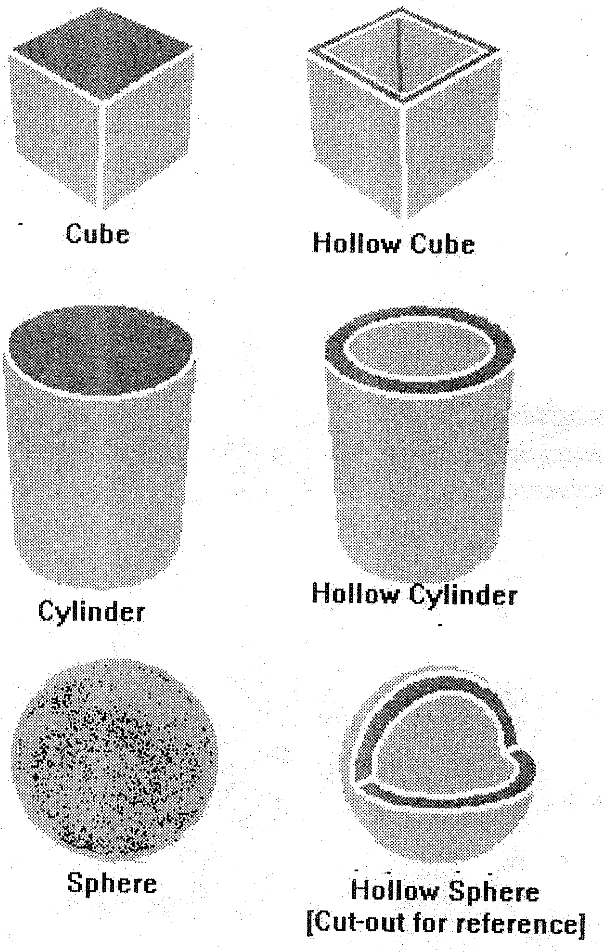


Figure 1

2. The test objects

For this experiment only simple objects are chosen. With basic forms, it is possible to get an idea on how much time a more complex form would need, since most shapes are combinations of the basic forms. The data obtained was primarily from build time estimators, simple geometry therefore makes it easier to produce an estimation without significant amounts of processor, user or actual build time. Users of the different technologies were asked to provide estimations for building the defined geometries, figure 1.
Every object is available in four different sizes, this is to find the relationship between size and speed for the current layer based systems and milling and also to provide a means for extrapolation.

The objects were made in a vertical plane. This set-up is not necessarily the best for optimising the rapid prototyping system parameters.
Some rapid prototyping systems have the option to change solid structures into hollow or honeycomb structures. This has not been done with the models for this report. There is a solid and a hollow version of each model in this report, which may indicate the potential timesaving when using hollow build styles.

3. The experimental build data

3.1.1. 3D-Systems - SLA-500, SLA-250

The build times were calculated with estimation software. While laser scan time depends mostly on the laser power, recoating time goes down significantly with thicker slices and smaller parts. The layer thickness that was used is 0.25 mm and STAR-Weave was used.

3.1.2. Sanders - Model Maker II

In the Model Maker II a 0.052 mm slice thickness was used for all but the largest models used in the experiment, where a 0.13 mm slice thickness was used. The build parameters are set by using what is called a 'Configuration'. This includes not only the slice thickness, but also the thickness of the line, velocities, line spacing, etc. 'Configuration' #470 ("Fast Regular") and #395 ("Concept Model") were used for all the builds. For the cubes and cylinders, an option to generate no support structures was also used, since none is needed. For the other parameters the system defaults were used.

3.1.3. Stratasys - FDM-2000

The FDM-2000 worked with a layer thickness of 0.25 mm. The object was not actually built. The build times were calculated with the build time estimator software that comes with the system, using the default settings.

3.1.4 DTM - Sinterstation 2000

The layer thickness used for the sinterstation was 0.25 mm. For the cubes and the cylinders only a 1 mm layer was made in Trueform and from this the total build time was calculated. Only half of the spheres were built because of symmetry. From this the build times were calculated.

3.1.5. Kira - Laminated Object Manufacturing

The objects were only partly built, for the cylinder and cube only 1mm layers were fabricated. The paper is 0.085 mm. From these times the total build times were calculated. The build times for the hollow objects is on the low side since minimal cross-hatching was used for the calculation. This may result in difficulties during the decubing process.

3.1.6. Delft Spline Systems - DeskProto

The milling estimates are very rough estimates, as the actual build times are very much dependant on the capabilities of the CNC milling machine and material used. For the larger models a lot of practical problems can be expected. For instance the steep vertical walls will need a very long cutter or a five-axis machine. These problems are not taken into account: assuming them to be solved.

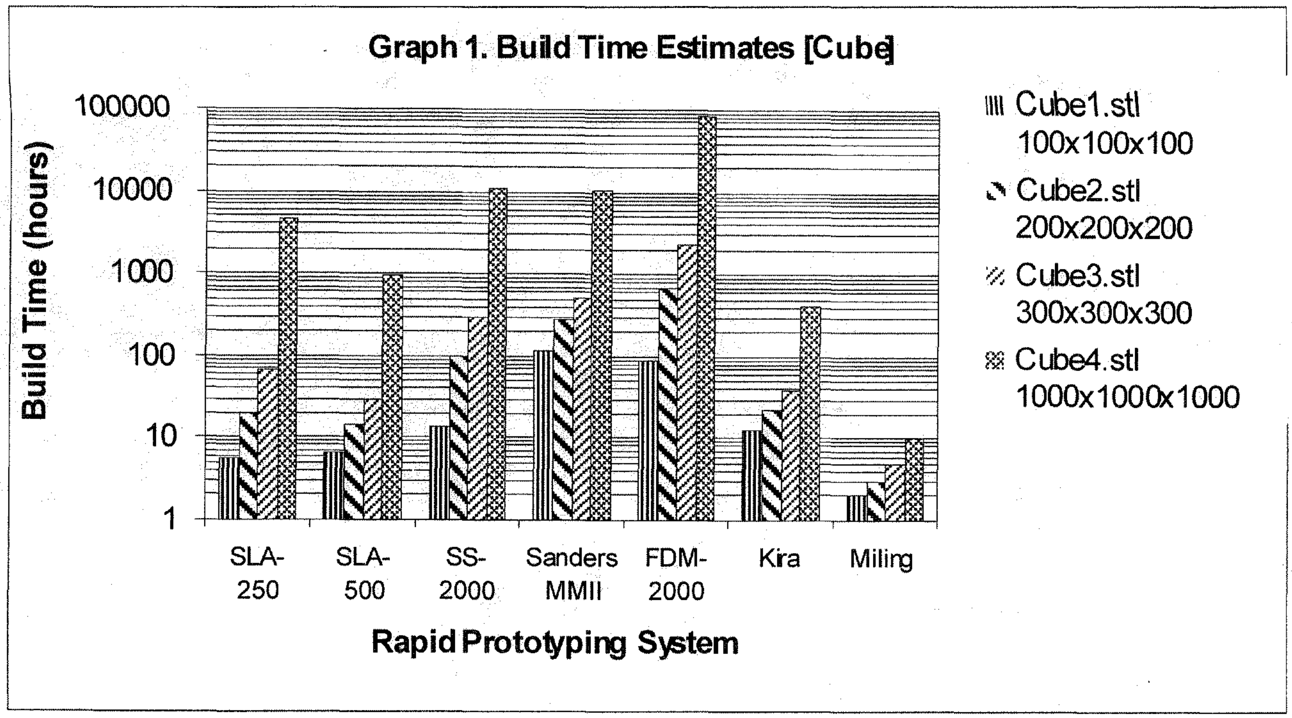
The time mentioned in table 1 is for an accurate model in tooling board (a wood-like material). The build times for a cube (solid and hollow) and a cylinder (solid and hollow) are considered the same. This is done because the travelling time of the mill head is about the same for soft materials. Build times are also very dependent on the level of details: The more complex the model, the smaller the tool required, therefore the longer the build time. For the basic models in this test a large tool is considered: the larger the model, the larger the tool. The hollow sphere is made in two parts and later joined together.

3.2. The Results

Table 1. Estimated times for different prototyping systems

STL-MODEL		Dimensions (mm)	SLA 250	SLA 500	SS 2000	Sanders MMII	FDM 2000	Kira	Milling
Cube1.stl		100x100x100	5.54	6.42	13.58	119.96	87	12.56	2
Cube2.stl		200x200x200	19.91	14.43	96.67	285.99	691	21.78	3
Cube3.stl		300x300x300	68.11	29.34	293.66	531.13	2329.5	39.52	5
Cube4.stl		1000x1000x1000	4432.76	951.68	10767.57	10427.83	86277.78	417.29	10
Hcube1.stl	Hollow	100x100x100x10	5.34	6.38	8.2	64.97	38	12.58	2
Hcube2.stl	Hollow	200x200x200x20	15.6	13.56	50	152.46	296.4	31.67	3
Hcube3.stl	Hollow	300x300x300x30	46.29	24.91	151.95	276.77	994.9	67.32	5
Hcube4.stl	Hollow	1000x1000x1000x100	3287.29	719.06	5065.77	2814.07	36848.15	713.00	10
Cylinder1.stl		80x100	5.34	6.38	7.61	63.45	43.5	10.75	2
Cylinder2.stl		160x200	15.35	13.5	50.44	135.3	343.4	18.33	3
Cylinder3.stl		240x300	44.93	24.51	163.33	240.27	1155.9	33.02	5
Cylinder4.stl		800x1000	2683.18	596.26	5444.25	2960.22	42811.11	347.98	10
Hcylinder1.stl	Hollow	80x100x10	5.13	6.33	5.44	41.41	22.4	n/a	2
Hcylinder2.stl	Hollow	160x200x20	10.52	12.52	31.44	91.87	172	n/a	3
Hcylinder3.stl	Hollow	240x300x30	18.77	19.31	98.33	156.04	575.7	n/a	5
Hcylinder4.stl	Hollow	800x1000x40	742.13	202.08	3277.85	1135.62	21322.22	n/a	10
Sphere1.stl		100	5.27	6.36	8.85	91.64	46.1	n/a	4
Sphere2.stl		200	13.45	13.12	52.21	203.49	361.5	n/a	6
Sphere3.stl		300	37.19	23.06	159.24	340.62	1215.1	n/a	10
Sphere4.stl		1000	3085.15	678.01	5430.10	3087.46	45003.7	n/a	20
Hsphere1.stl	Hollow	100x10	5.14	6.34	5.49	102.41	32.3	n/a	8
Hsphere2.stl	Hollow	200x20	10.22	12.47	32.00	231.77	241.8	n/a	12
Hsphere3.stl	Hollow	300x30	15.37	16.83	100.80	387.18	803.1	n/a	20
Hsphere4.stl	Hollow	1000x100	457.32	144.36	3386.88	3066.61	29744.44	n/a	40

3.3.Discussion



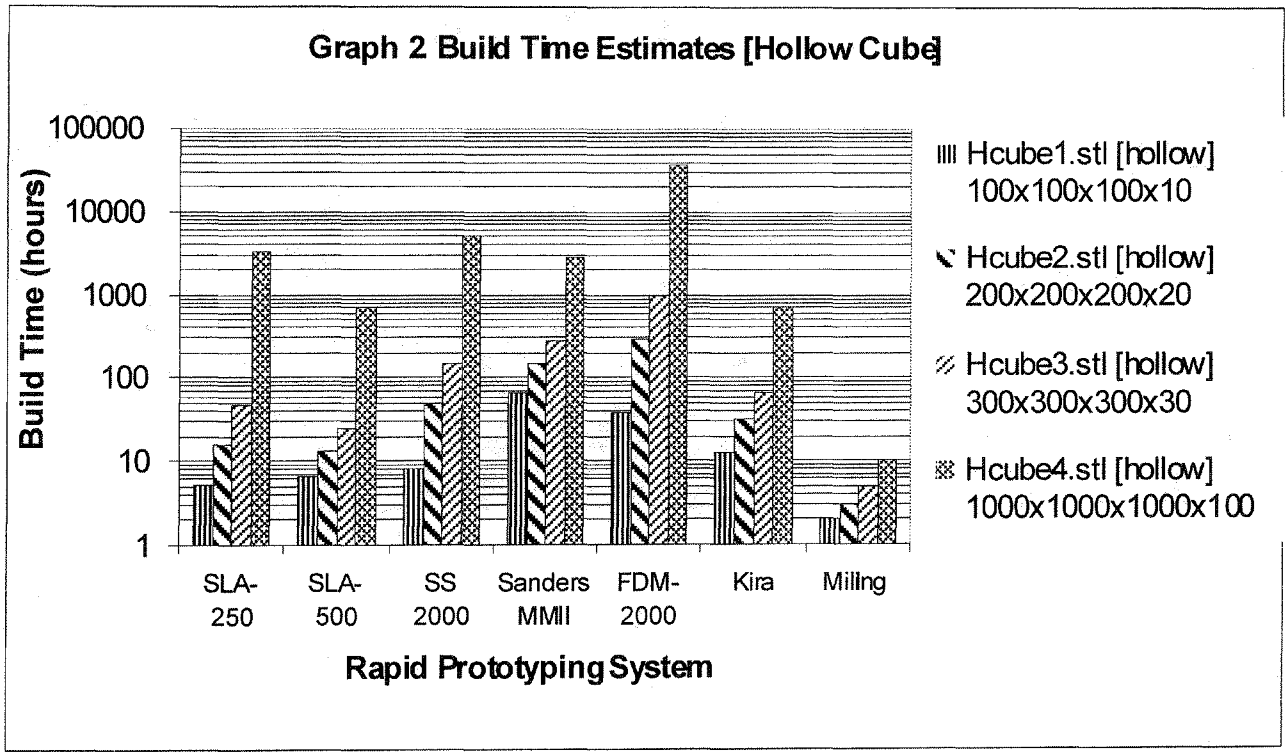
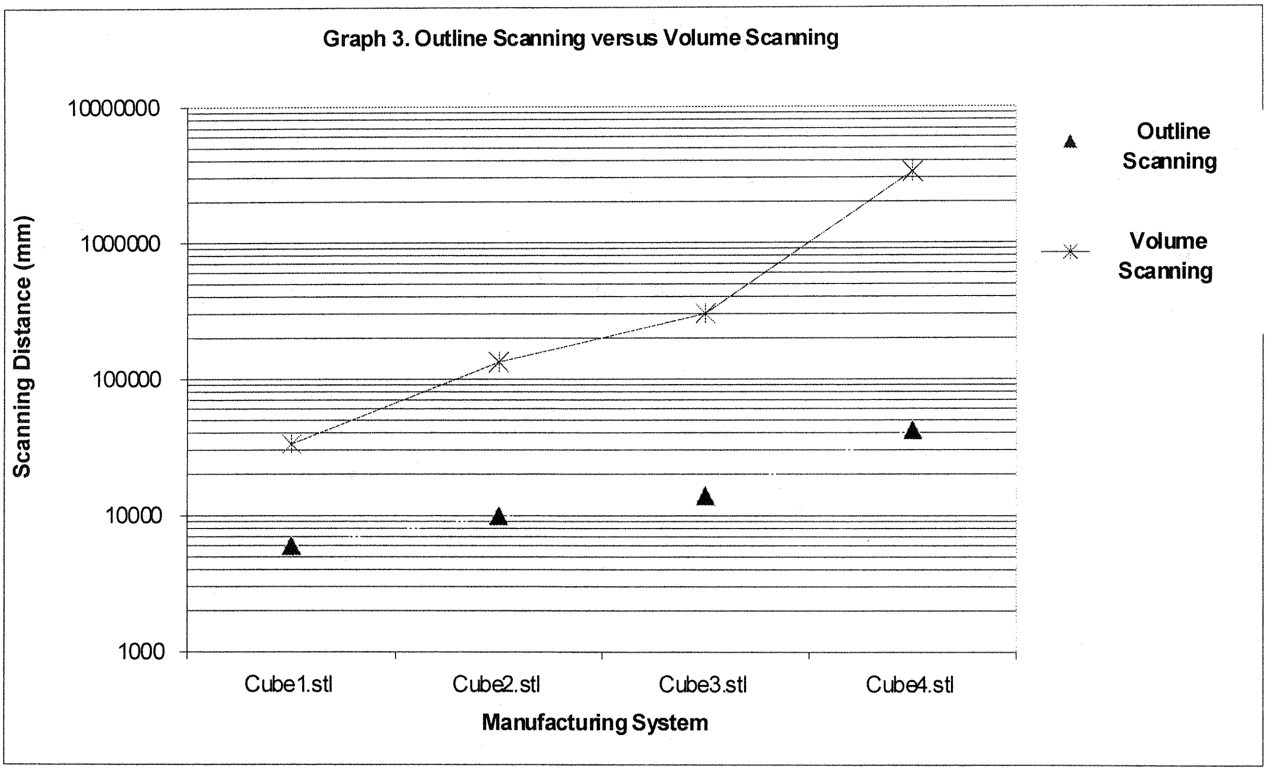


Table 1, graph 1 and graph 2 show that the current rapid prototyping systems do not compare favourably to milling. With the objects being basic shapes, the data for the cube, cylinder and the sphere are relatively the same, which therefore give comparable graphs. That is why only the graphs for the cube and the hollow cube are shown.
Graph 3 shows a comparison between outline scanning (milling, Kira, etc.) and volume scanning (StereoLithography, FDM, SLS. etc.). Volume scanning systems represented in the graph employ a scanning width of 0.3 mm. This figure is quite high for StereoLithography and selective laser sintering. These systems normally use a scanning width of about 0.2 mm. The FDM-2000 uses a scanning width of about 0.3 mm. but can use wider scanning widths.
These results are likely to be prone to error but even considering an error of 20% it is still clear that outline scanning systems are more competitive. A 20% error is acceptable based on the generally considered performance of the build time estimators and the true build time of the Sinterstation and the Kira.
For the smaller objects the time difference between volume scanning systems and outline scanning systems is not that different, however for the larger parts the difference is significant.
Rapid prototyping systems like ZCorp and Stratoconception are not mentioned. This is because data was not available. It is understood that the ZCorp machine in particular would provide a significant reduction in build time and should be the subject of further studies.



4. Conclusion

A number of rapid prototyping systems have been compared with conventional milling for the fabrication of large models. Build time estimations have been made for a range of simple geometry models and sizes.

It can be deduced that for fabrication of large scale models, milling is still a very good option. Its advantage includes speed as well as the variety of materials that can be used. While rapid prototyping remains a very important technology in today's manufacturing industry, milling is no less valuable. A hybrid system combining milling and the layer based technology can produce large models with complex detail and internal structure.

References:

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