Rapid Prototyping (through SLS) as Visualisation Aids for Architectural Use.

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Abstract

*The Cambridge International Dictionary of English, explains the word "**Design**" as a "pattern used to decorate something". Whilst this very narrow-minded definition can spark a debate on the meaning of design, it does however imply, that something has to made or manufactured, following a process-chain which started with an idea, followed by the design, and finally, the new product. As **Functional Design** is closely linked to inter alia manufacturing and building, **Designers'** freedom to express themselves, are often limited by the capabilities of craftsmen who have to give physical substance to Designer's ideas.*

The recently completed Manufacturing and Materials national FORESIGHT report [1] from the Department of Arts, Culture, Science and Technology (DACST) of the South African Government shows that manufacturers wishing to compete internationally should focus on integrated product, process and production system design, to speed up production time. This is all encapsulated in Concurrent Engineering, where design and approval are configured into a parallel, iterative process. Whilst it is not only dependent of technologies, technology and enabling tools such as Rapid Prototyping, applied in an integrated process, are crucial in the successful application of Concurrent Engineering. In the past a series of technologies, e.g. CAD, CAM and NC manufacturing was identified to solve these problems. Rapid Prototyping, Solid Freeform Fabrication or Generative Manufacturing - which are all synonyms for new methods of building physical parts directly from CAD data - represent the latest trends in manufacturing technology.

However, all these techniques represent only a **technological view** on how product development can meet the tremendous challenges of the future. In fact, not merely the use of a **single technology** provides better products faster for the market, but the **integration of a large number** of technologies and methodologies. Therefore, aspects of information processing, cost, quality and time management, team work, organisational issues and many other enabling technologies like data highways, multi-media or distributed databases have to be taken into account as well. Rapid Prototyping is being used more and more as a key enabling technology in reducing the time to market for new products, by identifying possible design flaws prior to tooling and manufacturing, and is providing the **common focus** for **multidisciplinary groups**, around which to **resolve design and development questions**. Barkan and Iansti present RP as a means of ***rapid learning*** at **every stage of the design process**. Adopting this view on the whole of the *development process*, one comes to the conclusion that the use of RP to enable Rapid Product Development, is a fundamental challenge that must be addressed by all manufacturers to remain competitive in today's global market place.

In defining manufacturing, one tends to think about plastic products, casting, tooling concerned, and mass production. Whilst this represents the latest trends in manufacturing, one of the oldest methods of manufacturing however, is the conversion of basic raw materials into accommodation, shelters, etc. In adopting Rapid Prototyping and related technologies into the built and architecture environment, numerous new opportunities open up. The paper describes a fresh approach into an age-old industry.

The South African Challenge

The reality in South Africa has a number of implications for initiatives to improve the product development competence in the country. The extent of original design and product development is relatively limited. For many years, South African companies have manufactured to imported designs, supplied by their principals in developed countries. During the sanctions era the local armaments industry developed into a world-class industry, which had a strong positive impact on the establishment of engineering skills in the manufacturing industry. Although some novel product engineering resulted, many of the products were reverse engineered from existing designs in import replacement drives. The original design component of this industry was therefore still limited, but it laid a strong foundation for building the local product design, development and engineering capacity. When the armaments industry was scaled down, many of the skills were transferred to the general manufacturing industry through the migration of staff into these industry sectors. Consequently, pockets of world-class skills are found across South Africa, although the resources and expertise are limited and often located in sub-critical groups [2].

This situation led to the need for South African engineers to participate in teams operating across boundaries of discipline and geographic separation. While an understanding of the full product development process as practised by the global leaders is essential, an ability to adapt to local customer needs that often do not provide much scope for comprehensive developments, should be nurtured. Local product development teams must not only know how to provide input exactly where needed in the development process, but also understand very clearly how to ensure that the essential principles of the concurrent engineering approach are applied to ensure successful and cost-effective delivery.

Modern design requires a holistic approach, which considers issues such as the functionality, user interface, benefit to the customer and design for manufacture. The ability to integrate this knowledge to shorten product development cycles, enables early market entry, which is often key in providing the manufacturer with a global competitive edge through reduced manufacturing costs and shorter time to market. As society moves towards environmental sustainability, there are also specific requirements on materials selection and life cycle management of manufactured products. Designers have to stay abreast of such trends to ensure acceptance in the developed world. These requirements have forced manufacturing companies to resort to quicker and lower risk solutions through computer aided design, analysis and simulation technologies [3].

Apart from applying the various techniques that are available to accelerate the design process, an integrated approach across the whole development cycle is essential for sustainable success. Product development process chains, as well as management models to apply the technology in an integrated approach, is as important as the technology itself. Well-established networks on a national basis can contribute to the solution through simultaneous or concurrent tasking of multidisciplinary teams.

Consequently, the Concurrent Engineering (CE) philosophy offers a major opportunity for the South African industry to improve its competitive position in the global marketplace. The aim of CE is to integrate product design and process planning into an activity, which, if practised correctly, helps to improve the quality of early design decisions and has a tremendous impact on the life-cycle cost of the product.

The Role of RP

Prototypes enable designers to test all kinds of aspects of their ideas, particularly whether they would be technically feasible and commercially viable, before committing themselves to the expense and risks of producing commercial quantities. Rapid Prototyping can be defined as a technique in which physical models are fully created from materials, provided in various forms, completely under the control of model data created within a computer aided design environment. More concisely, the term refers to the transformation of a manufacturer's concept into an object in the shortest possible time [4]. Of course, the term *Rapid* is a relative term. Most prototypes require from one to seventy-two hours to build, excluding clean up and preparation time, depending on the size and complexity of the object. However, it enables designers to see parts of their models within a few hours, opposed to several weeks or months with conventional methods. The ability to quickly create a physical model or prototype for evaluation to assess relative merits or possible design flaws provides the possibility to inspect the object in three-dimensional form.

In their 1998 report, the SME predicts that further growth in RP would be driven by applications that are difficult, time-consuming, costly, or impossible with standard techniques. The authors argue that successful RP applications are those that are driven by users. Many current applications compete in time or cost with standard fabrication methods [5]. Increasingly, future RP applications will be those that are difficult or impossible to achieve with current standard techniques.

Currently, RP processed parts are used as concept models, master patterns, functional prototypes and, in some cases, tooling. Concept models are used for design reviews, form and fit checking, styling, ergonomic evaluations, testing, and CAD-model verification. RP master patterns are used for investment, sand-and ceramic-block casting. Some materials and processes can build RP tooling for urethane casting, plastic injection moulding and limited die-casting. RP technology can also be a cost-effective method for building a large number of functional prototype samples.

RP as Support in the Development Process

Rapid Prototyping can be utilised in the product design process to verify individual phases, or in the product development process as a whole, where it can support verification of development phases and optimisation of development phases. Atkinson [4], distinguishes 4 types of prototypes namely, Design or Aesthetic Prototypes, Geometrical Prototypes, Functional Prototypes and Technological Prototypes. The diagram in Figure 3 illustrates the contribution of RP to the various product development phases.

Communication support

In a concurrent approach to product development, it is advisable that dedicated product development project teams attempt the development, instead of separate functions performing sequential development activities. In such a team approach people with different skills and concerns are involved in the creation of the product. Here prototypes facilitate discussion among team members. Through a prototype, management and marketing can explain their requirements to the design team, while designers can use it to communicate their constraints to management and sales staff. Therefore, prototypes have become the language that a design team can use to discuss requirements of mould makers, production, management and marketing. With a prototype, the job of persuading management to commence or proceed with a project becomes much easier.

Market Testing

Quality Function Deployment (QFD) has become an invaluable part of the Concurrent Engineering process through its support in translating customer requirements into a product specification. Prototyping is equally valuable to the manufacturer as part of the QFD process to ensure that all the customer's requirements have indeed been addressed. It can also be used for market research, to assess how a product would be perceived by the general public.

Platform for Integration

Functional prototypes normally involve individual components in an assembly. Prototypes enable the integration of the components to be assessed, ensuring that the various designs are able to meet the constraints of assembly in the manufacturing process.

Project Evaluation

Prototypes are an extremely useful tool for allowing management and customers to assess the progress of a project at various stages. A model may convince management that a project is indeed progressing towards a marketable product. Since any project has cost implications, prototypes may be vital for ensuring its continuation and sustained funding.

Prototypes should be used in such a fashion that they provide manufacturers with detailed information on the design of new products or parts. A prototype project may be used to verify the integration of different parts in a newly designed product, to confirm the design aesthetics, accuracy thereof, form fit and function testing or even for marketing purposes. In some cases the part may even be used to do mechanical testing, provide a means of thermal testing and enable designers to design for manufacturability.

Form Fit and Function Verification

The Rapid Prototyping Association (RPA) of the Society of Manufacturing Engineers (SME) defines future development of the role of RP as follows [5]:

*"Long-term growth in the RP industry will come from **applications** that are difficult, time-consuming, costly, or impossible with standard techniques. Experts expect the industry to see major breakthroughs in materials over the next five to 10 years. These advanced materials will enable the development of newer technologies that can better satisfy the design requirements of many end products."*

Atkinson distinguishes between 4 types of prototypes, categorised through its end-use:

- ***Design or Aesthetic Prototypes***
- ***Functional Prototypes***
- ***Geometrical Prototypes***
- ***Technological Prototypes***

Shigley defines the design process according to the following six phases:

1. ***Recognition of need***
2. ***Definition of problem***
3. ***Synthesis***
4. ***Analysis and optimisation***
5. ***Evaluation***
6. ***Presentation***

Rapid Prototyping for Architectural use

CAD, CAM and Rapid Prototyping, which can be described as a digitally based convergence of representation and production, represent one of the most important opportunities now facing the architecture and building profession. In a response to industrialization, it became necessary for architects to master ways of production in an attempt to remain engaged in the qualitative aspects of crafting buildings. New means of production have emerged that can enable new aesthetics in post-industrial digital societies.

CAD/CAM technologies may help to avoid traditional manufacturing costs and to design and produce complex freeform components that were previously either impossible or too expensive.

Custom, digitally crafted architectural components can now be directly or indirectly manufactured without expensive reusable tooling, and mass customization is possible because manufacturing efficiencies are no longer driven by variations in what is being produced, or the so-called economies of scale.

Architect Frank Gehry's Guggenheim Museum in Bilbao, one of the finest examples of the use of Solid Free Form Fabrication in the built environment, is a building described as *brilliant innovation and esthetic triumph* by critics. It is said that what Gehry has wrought, is both a cathedral to art, as well as a soaring sculpture functioning as exhibition space and symbol of civic pride for a provincial city reaching for greatness.

Composed of a group of free-flowing volumes that seem to have met in a train crash, the building shows sections of its steel skeleton, but mostly is clothed in tissue-paper thin titanium. Through details generated from computer design, and manufactured by computer commanded robots, panelling of unique sizes and shapes was created. Through the use of three main materials (titanium, limestone and glass), the design and method of construction allowed for the organically irregular and curved shapes [6].

Critic Paul Goldberger noted that changes in architecture have already moved ahead of Gehry;

> "*while Gehry designs in his head and implements with the computer, a new generation has adopted the computer itself as the generator of design*" [7]

However, Gehry's work could not be implemented without the use of Free Form Fabrication [8].

Rapid Prototyping as Visualisation Tool for a Cape Town Homestead

Rapid Prototyping is continuously developing as a very enabling technology in South Africa, with diverse applications in industry. On the educational front, RP is also receiving more attention in conscious development programmes, lead by academia and science councils.

In the Center of the country, the Centre for Rapid Prototyping and Manufacturing (**CRPM**) continues with research into RP applications, backed by their SLS, SLA, Sanders, Vacuum casting, Spin casting and CNC equipment, which, together with CAD and Reverse Engineering, are used in a Concurrent Product Development approach.

An interesting case study was an architectural development, which had the following project requirements: Lead times: 3 weeks for 3D modeling, growing, finishing and painting.

Although RP offered a perfect solution to the architect's needs , a 3 week lead time for 3D modelling, growing, finishing and painting posed a major challenge.

The development (physical construction) was done for a client of a Cape Town Architect, who needed a 3D scale model of the Constantia development in Cape Town. The architect approached a design company in Cape Town (This Way Up) which has a very close working relationship with Technimark, who in turn works closely with CRPM - illustrating the National Network in action!

Due to the short lead time and very fine and specific details on the design, (especially the stair-cases and balconies) Rapid Prototyping became the logical choice in order to produce the various models that made up the entire home. The case study reveals and discusses in depth the process development, prototyping and economical analysis - product development in a concurrent engineering approach, applied on architectural development - a perfect RP application.

Figures 1 and 2 show front and side views of the CAD model, with figures 3 and 4 showing 3D detailed close-up views. Figure 5 shows details of the entrance, which lead to the use of RP in this application study, as conventional means of model building could not reproduce this level of detail, representation of textures, etc.

Figures 6 and 7 shows internal detail of the model, made possible through building with SLS. Figures 8, 9, 10, 11, 12, 13 and 14 indicates the platform separation, as well as the volume and time calculation, based on calculations through MAGICS RP™. Figure 15 shows a detailed photograph of the completed model - a clear prove why anything else but RP would not suffice !

Figure 1 - Front View of CAD Model

Figure 2 - Side View of CAD Model

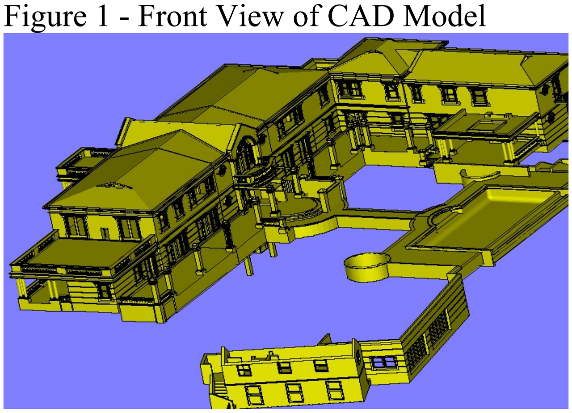

Figure 3- 3D View of CAD Model

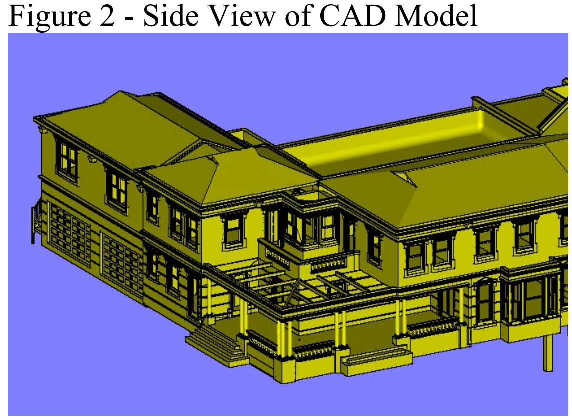

Figure 4 - 3D Close-up View of External Detail

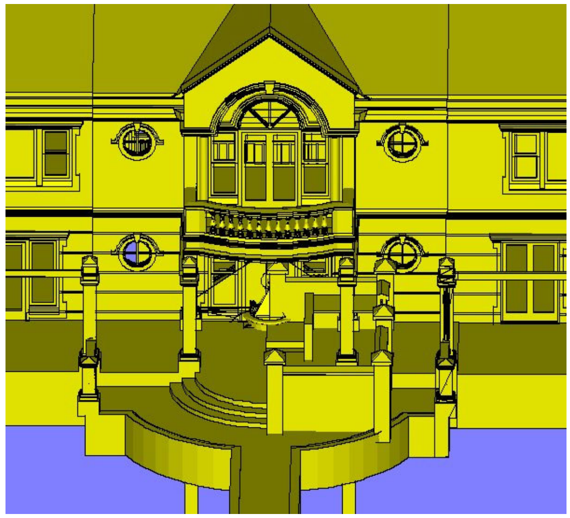

Figure 5 - Close up View of Entrance Details Which Posed a Major Challenge to RP above Conventional Model Building Techniques

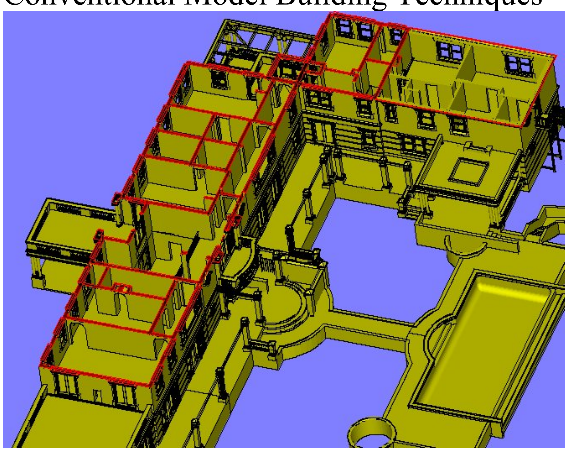

Figure 6 - Internal Room Detail

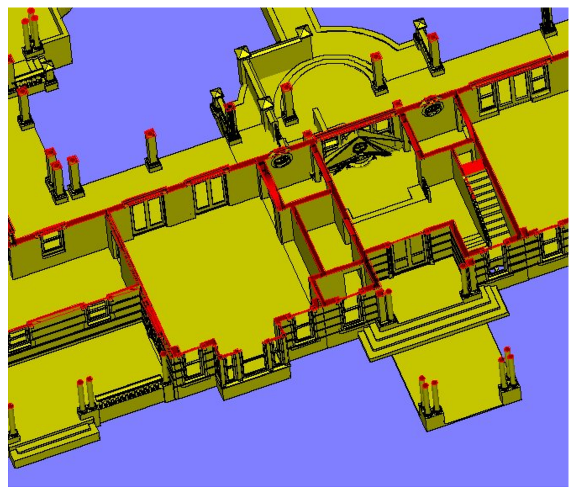

Figure 7 - Close-up of Internal Detail like stairs, steps, etc.

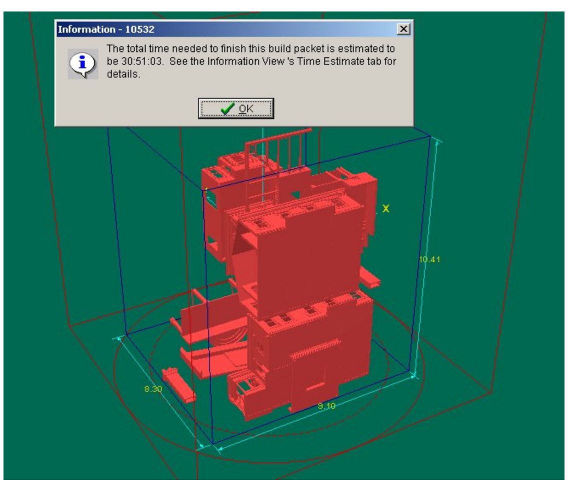

Figure 8 - Time Calculation: Platform 1

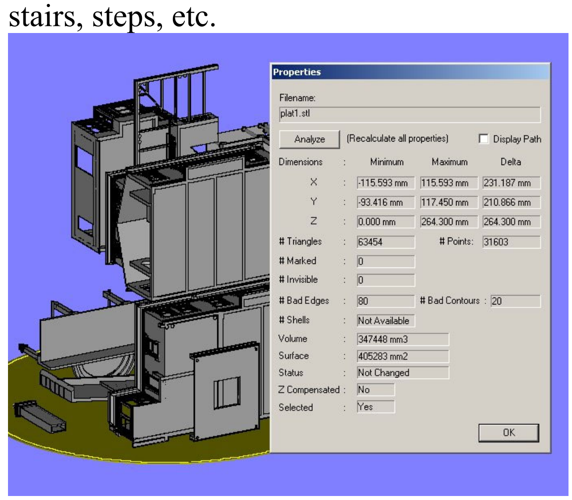

Figure 9 - Volume Calculation of Platform 1

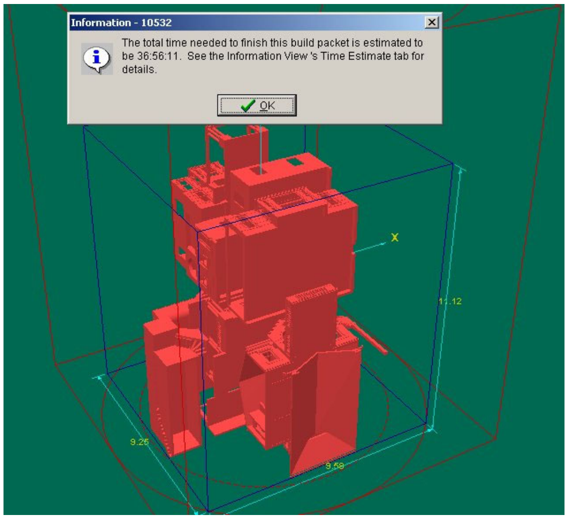

Figure 10 - Time Calculation: Platform 2

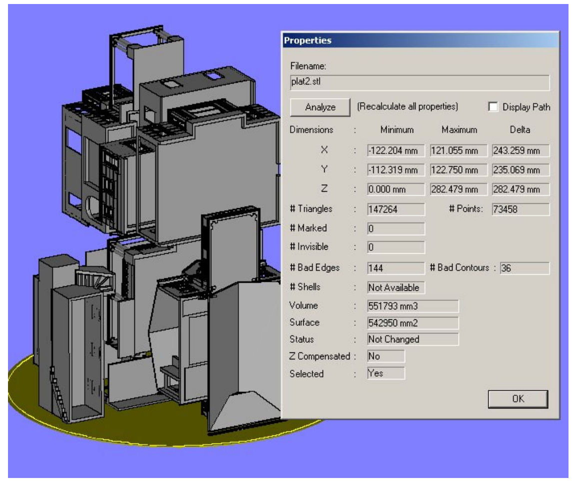

Figure 11 - Volume Calculation of Platform 2

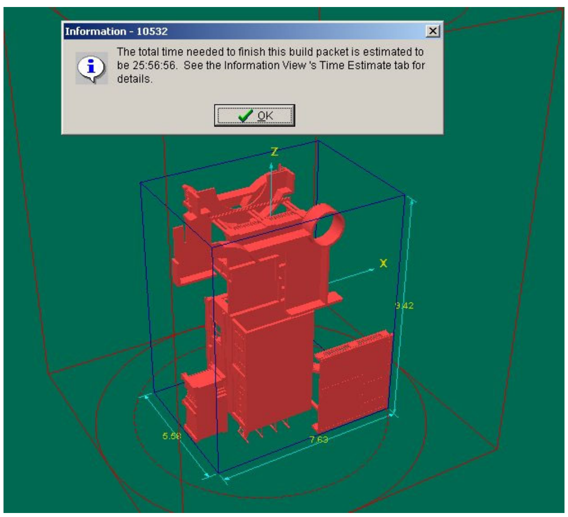

Figure 12 - Time Calculation: Platform 3

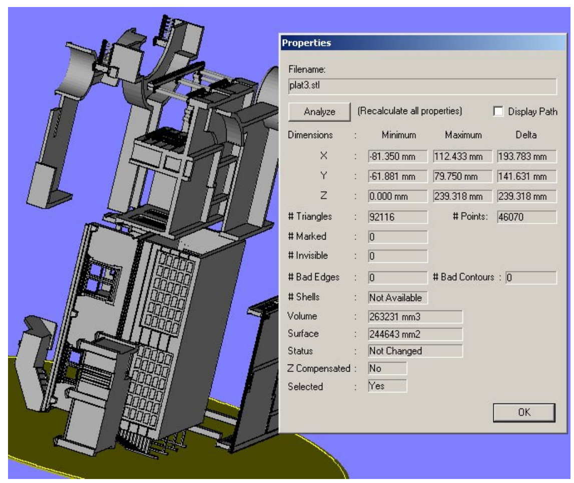

Figure 13 - Volume Calculation of Platform 3

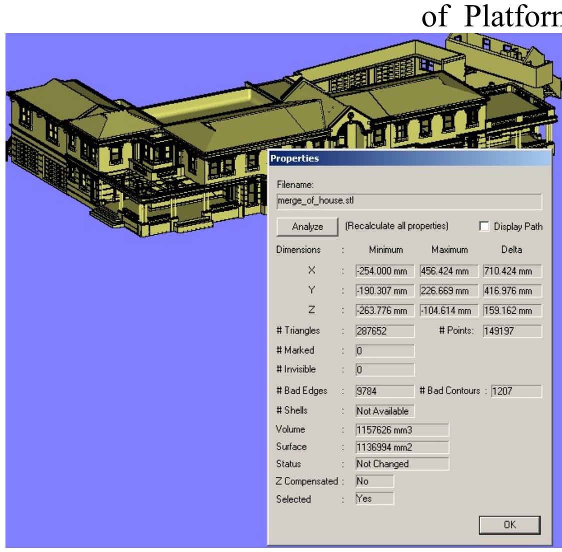

Figure 14 - Time Calculation: Total Volume

Figure 15 shows a picture of the total scale model, developed through SLS

Analysis of the Project:

The SLS growing time was approximately 94 hours, utilising some 6 kg of Duraform, resulting in the following costs (R10: 1 USD):

3D CAD modeling	R 6 500-00	($ 650)
Prototyping	R 22 600-00	($ 2 260)
Finishing/presentation:	R 8 700-00	($ 870)
Total project cost	**R37 800-00**	**($ 3 780)**

Discussion of results

The development was done for a client of a Cape Town Architect, Mr. Hanekom, who needed a 3D scale model of the Constantia development in Cape Town. The architect approached a design company in Cape Town (This Way Up) which has a very close working relationship with Technimark, who in turn works closely with CRPM - illustrating the National Network in action!

Due to the short lead time and very fine and specific details on the design, (especially the stair-cases and balconies) Rapid Prototyping became the logical choice in order to produce the various models that made up the entire home.

2D architectural drawings and plans were supplied which were converted into 3D solid models. The completed CAD models were checked and signed off in order for the models to be grown to allow the appropriate time for finishing and painting. Careful planning went into the 3D modeling of the part with regards to the following aspects:

a) Modeling the parts as various individual part that would allow the architect to present the model to the client in order to create a virtual "walk" through the home or property.

b) Planning splits in the various parts in order to fit the parts on to the RP system in the most effective and economic manner.

c) Modeling to the strength of the RP system in the sense of the fine specific details and the orientation thereof.

During the growing process specific care was taken in the orientation of the various parts to ensure best quality and to minimize finishing time of the models. Although the grown parts was of high quality, a reasonable time was required to work off, finish and paint the parts grown via the SLS RP process. The growing quality, and to ensure that all the specific fine details of the various cad models were grown as crisp and sharp as possible, were the only issues which received attention in selection of growing parameters.

The project was completed within the three weeks, and the final scaled model presented to the client in its completed form. The final results that were achieved were very satisfactory and of very high quality and standards. The architects and client were very impressed with the model as presented to them.

From the case study it was learnt that RP would not be an economic solution to all architectural models, but it does cater for the needs of a specific sector and needs that will make RP a viable solution in order to produce scale models for the architectural industry.

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