From "Soft" to "Hard" Prototyping: A Unique Combination of VR and RP for Design

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Abstract

This paper will highlight innovative approaches to the building design process made possible by the application of two of the most sophisticated technologies currently available: Virtual Reality (VR) and Rapid Prototyping (RP). These will be discussed by drawing examples from recent case studies.

Keywords: Virtual Reality, Rapid Prototyping, 3D Modelling, design process.

1. Introduction

Abstraction is a skill usually developed by design practitioners through experience: cultural background is used to encode ideas and then to decode sketches and technical drawings in order to understand how building will look once constructed.

Traditional visualisation techniques, such as sketches, plans, sections, elevations, isometric view and perspectives, also require encoding and decoding in order that technical information may be draw from their symbolism.

Generally speaking traditional media give only a limited representation of building design and their use is no longer suitable for controlling some of the complexity of modern architectures.

Critically their use often leads to loss of information and frequently "the designer must wait for the actual construction of the object before perceiving design errors"[1].

Modern CAAD systems allow architects and engineers to easily handle 3D models of structures or entire buildings but they are still unable to provide both professionals and users/clients with the option of *navigating* freely inside and outside the building.

Virtual Reality (VR) in architecture provides a natural and easy to understand interface between practitioners and clients. It enables them to test the functionality of the design and to see whether the design reaches the clients expectations.
First of all "the three-dimensional representation becomes a tool to investigate the space"[2] and secondly it acts as a vehicle for experiencing the design prior to construction.

If VR is already an effective means of solving some of the design issues, what about the possibility of creating a physical duplicate of the computer-aided design thus creating a link between the virtual model and the physical world?

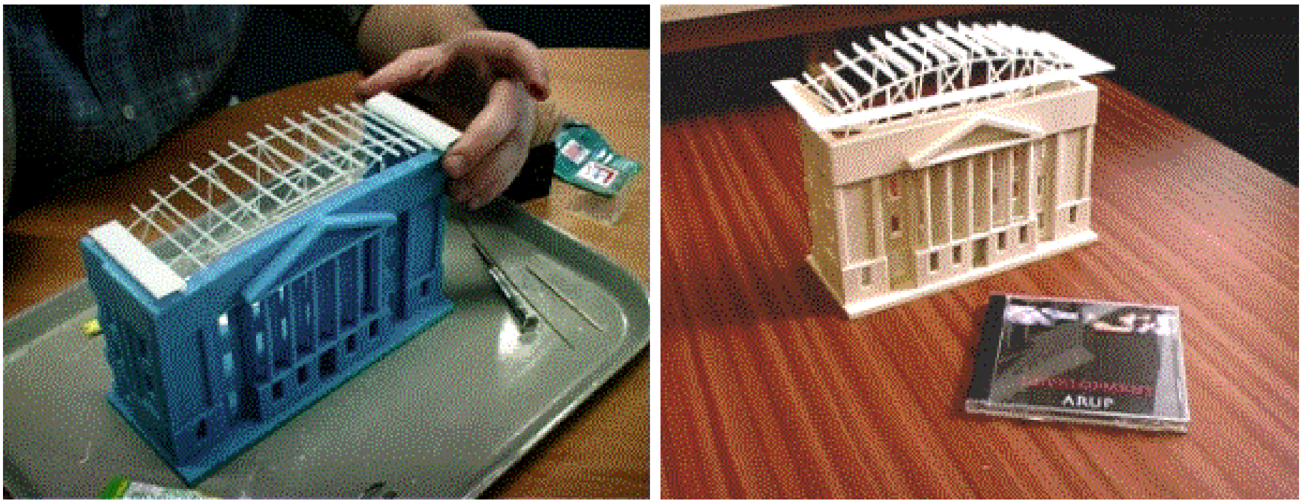


Fig. 1: two models made with RP technology: the first design solution (left) of the truss was changed and in the second project (right) a new different material was also used for the walls.

The answer to this question came with the introduction to the market of Rapid Prototyping (RP) technology. This refers to the group of technologies that create 3D physical models from 3D computer models using a variety of materials including paper, polymers and resins (See Fig. 1).
The first example of RP was commercially introduced in 1987 with the presentation of StereoLithography, a process developed in 1984 by Charles Hull. Nowadays modern rapid

prototyping systems are relatively fast and precise devices capable of building models from 3D CAD packages such as Pro Engineer, Unigraphics, CATIA etc.

The number of applications for RP is growing rapidly thanks to the enormous benefits in terms of visualisation capability, the decrease in cost and cycle time associated with fabrication of prototype parts and the optimisation/development prior to prototyping. The most common applications are in concept models and investment casting but generally speaking all the industrial sectors, from the construction to the medical industries[3], rely on the use of prototypes.

2. Methodology

In this research it was possible to combine both VR and RP technologies to investigate the decision-making phase of the design process.

With the use of VR and RP architects and engineers were able to elaborate, visualise, refine and then handle their design ideas.

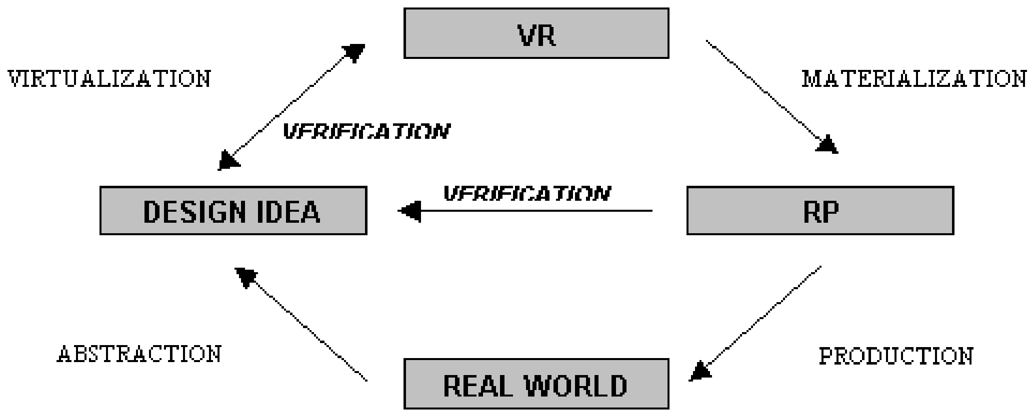


Fig. 2: the design process after the adoption of VR and RP technique

The resulting design process can be divided in four main steps:

- **Abstraction**: from the real world elaboration of the design solution.

- **Virtualisation**: from sketches and design ideas creation of virtual models for visualisation in the Virtual Environment Lab.
- **Materialisation**: from the virtual environment back to the real world via the Rapid Prototyping machines.
- **Production**: check of the design solutions from a technical and aesthetic point of view.

After the idea is evaluated, during the **verification** phase, changes are made and the design idea is again reviewed by repeating the process.

3. Virtual Environment And Rapid Prototyping Laboratories

Research made use of advanced laboratories both available at the University of Strathclyde, Glasgow: the *Virtual Environmental Laboratory* (VEL) and *the Rapid Design and Manufacture Centre* (RDM).

3.1 Virtual Environment Laboratory

(VEL) is a so-called *Reality Centre*: it is similar to a small 15-seat theatre with a 5 metre wide, 2 metre high, 160 degree curved screen. One of the most powerful graphic engines in the world, a 12 processors Silicon Graphics Onyx2 system fitted with 4 Gb RAM, projects high resolution images through three Barco projectors at the frame rate of 25 fps.

The three images are merged together to form a single 5X2 meter image which corresponds to the viewers cone of vision. The system enables a small group of people to share the experiences of navigating an environment in real time. This giving a fully immersive experience to the viewers and creates the sensation that the participants are 'within' the projected environment.

3.2 The Rapid Design And Manufacture Centre

(RDM) is provided of two conceptually different technologies: the Z Corporation 3D Printer and the Fused Deposition Modeller, Stratasys FDM 3000.

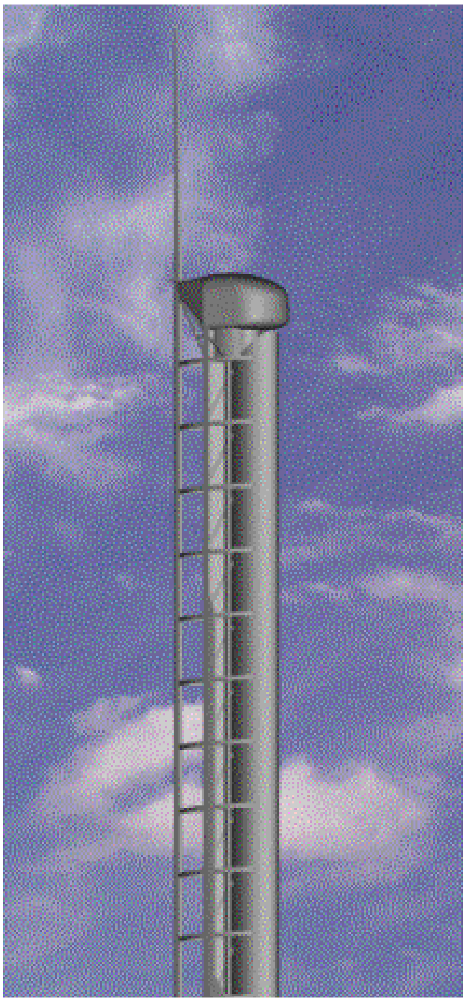
The Z Corporation 3D Printer was developed from commercialised research at Massachusetts Institute of Technology, Boston, and it evolved from standard inkjet printer technology. Layers are deposited by printing a water-based binder onto successive layers of cellulose and starch powder. It is the fastest 3D Printer in its class offering a build rate of up to 1 vertical inch per hour. Parts can be finished in either wax or acrylate resin for increased functionality.

Specifications: Build Volume: 203 x 254 x 203 mm
Layer Thickness: 0.076 - 0.254 mm
Build Materials: Starch/Cellulose powder with water based binder
Accuracy: 0.4 - 0.5 mm

The FDM 3000 is the latest in its class from Stratasys offering a larger build volume and soluble support structures. The system deposits layers of ABS plastic to create functional parts to within 0.2 - 0.3 mm accuracy that behave in a similar fashion to injection moulded plastics.

Specifications: Build Volume: 254 x 254 x 450 mm
Layer Thickness: 0.1 - 0.2 mm
Build Materials: ABS Plastic
Accuracy: 0.2 - 0.3 mm

4. Case Studies



Two major projects both related to Glasgow were chosen as case studies: the redevelopment of the **Old Sheriff Court** building and the construction of the **Millennium Tower**.

The *Old Sheriff Court*: dates back to 1842 as a town hall and merchants house extended to form Law Courts, it is situated in the city centre. The building has a rectangular footprint and has been unoccupied for some years. Glasgow Development Agency (GDA), being keen to preserve this historic significance, has commissioned Page & Park architects and Ove Arup & Partners Scotland Consulting Engineers to propose a redevelopment project.

The *Millennium Tower*: dates back to 1992 when architect Richard Horden designed a new tower as a landmark for Glasgow. The tower was originally intended for the city's St Enoch Square as the highest freestanding structure in Scotland. It was eventually located in one of the biggest Millennium Projects in the UK and, when open in spring 2001, the biggest new attraction in Scotland, the Glasgow Science Centre on the River Clyde at Pacific Quay in Govan. Building Design Partnership (BDP) is the architect for the entire centre.

The Glasgow Tower will be 100 metres high (328 feet) to the viewing cabin and a further 25 metres to the very top of the structure. It is the only tower in the world designed to rotate 360 degrees and when operational will turn into the prevailing wind.

During the creation of 3D models the research team worked closely with both architects and engineers and had continuos access to all the information regarding the design progress and changing priorities.

For both projects the models were also put in their urban context using part of the 3D model of Glasgow[4] in order to simulate the impact of the new constructions in the urban environment. Furthermore the areas surrounding the new constructions were modelled using photo-realistic textures in order to achieve a more natural and realistic environment.

In the case of the Old Sheriff Court the 3D models were constructed from design sketches and the model itself became a vehicle for arriving at a design solution (See Fig. 1, 4 and 5).

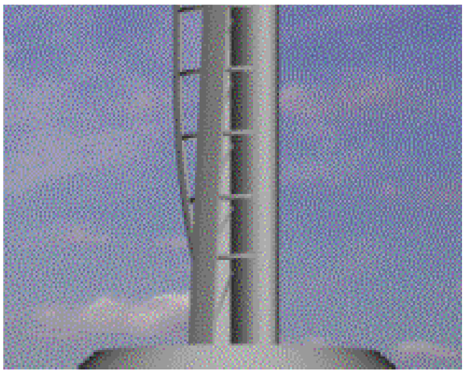


Fig. 3: a computer image of the Millennium Tower

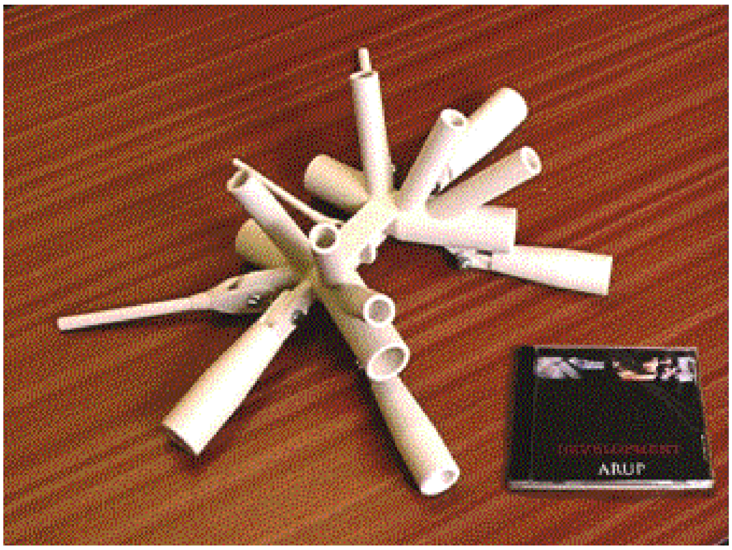


Fig. 4: the joint built with the 3D printer

Once the virtual models were completed work began on preparing them for use in the VEL and the RDM centre.

First they were exported from the modelling package into VRML format and projected in the VEL. The process proved to be fast and reliable. The VEL also enabled the fine detail of the models to be carefully checked.

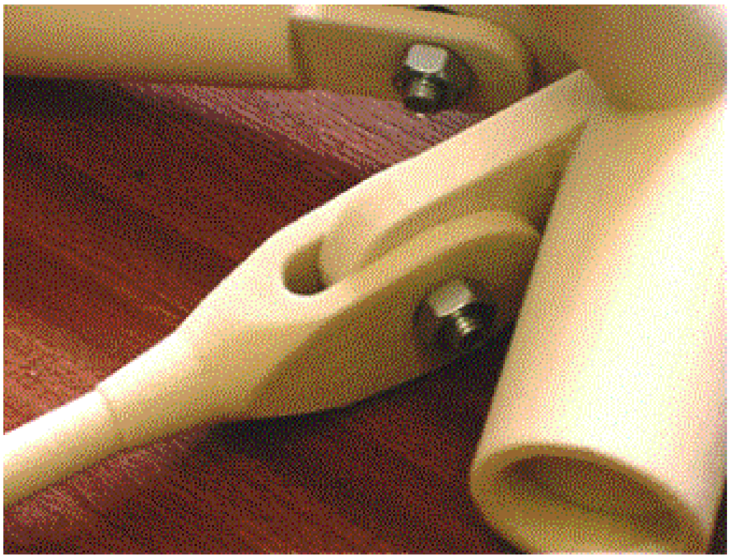


Fig. 5: a detail of the joint

Architects and engineers were invited to evaluate and discuss the projects in the Virtual Reality lab. After checking the design solution the models were exported in STL format to be built by the RP machines.

It was decided that a section of the Sheriff Court (See Fig. 1) and a structural joint of particular spatial complexity (See Fig. 3 and 4) should be built.

Regarding the physical construction, the section of The Old Sheriff Court the main part of the prototype (the end part of the side walls and the end wall) were built with the 3D printer, because the process was faster and cheaper. The more delicate structure, the roof truss, was built with the FDM 3000 which provides the option of building finer detailed and complex objects.

The process was repeated after the design of the truss was changed and a new model built to visualise the result. The same techniques were used to build the second model.
Also in the second model was decided to rebuild both the structure of the wall and the roof truss in order to test a new and more efficient powder which allowed better rendering of fine texture and increased resolution.

As regards the Millennium Tower was decided that the entire model should be built using the 3D printer, by dividing it into sections and then gluing the various elements together.

4.1 Achievements and Problems

Each of the projects contained a high level of spatial complexity (See Fig.3 and Fig. 6) and therefore represented benchmarks for evaluating the effectiveness of both technologies.

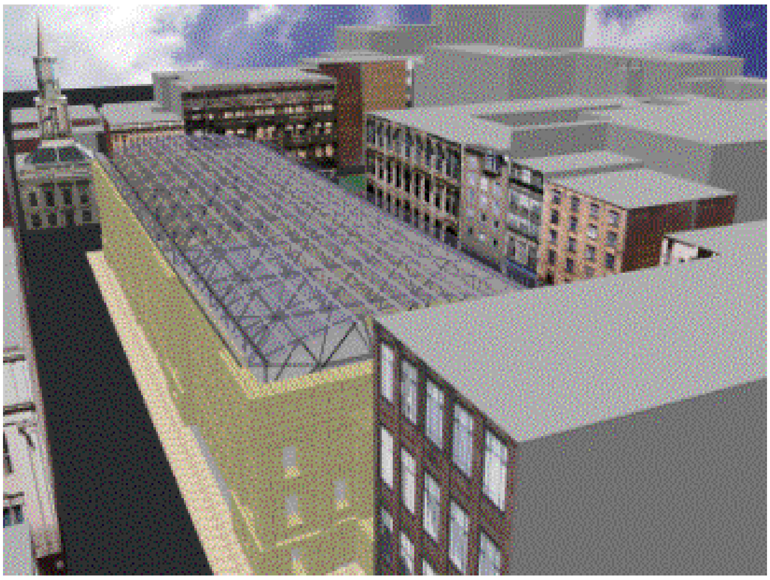


Fig. 6: the 3D model of The Old Sheriff Court project

Architects and engineers were invited to experience their own project in the VEL. Generally speaking both were excited by the chance of evaluating and discussing their design ideas in an immersive environment, and pointed out problems and possible design faults not previously noticed.

It was interesting to observe on one project, that most of the engineers were interested in the very high level of detail contained in the structural work, and they paid less attention to the rest of the model. The opposite was observed with the architects who were more interested in the general impression than the fine detail of the structure.

Furthermore the chance of being able to handle the model of a building or design feature via RP proved to be a powerful catalyst for evoking positive design change. The detection of errors, a usually slow and often incomplete operation which is usually verified only at the end of the cycle after the construction of the building, was accelerated by the rapid and highly visual feedback provided by RP and VR.

Their combined use provides huge potential for reducing design 'flaws' and offers tangible representations of design that may serve to progress the design community.

4.2 Technical Issues

A few problems had to be solved during data exchange between the PC used for modelling and machines in both labs. For both projects a PC was used and detailed 3D models were built using Autodesk 3D STUDIO VIZ release 3.0. Generally speaking this software package was appropriate and extremely flexible considering the complexity of the case studies.

Autodesk's 3D Viz 3.0 was chosen as a modelling package for several reasons:

- Both the VEL and the RDM lab are not only used for research purposes but by private firm and professionals. Therefore our goal was to develop a method which was reliable and at the same time compatible with industrial practice. 3D Viz 3.0 is in common use among a large section of the design profession.

- It is currently taught and used widely by architecture and design students.

- 3D Viz 3.0 has a good set of AEC tools particularly useful if working with architectural 3D models.

However although the package was found to be a good in terms of speed and final graphic result, it did have some limitations when interfacing with the VEL and the RMD.

As regards the VEL, during the process of exporting the 3D model in VRML 1.0 format some of the AEC tools (especially railings and stairs) were not exported correctly in VRML format. The resulting object appeared to be rotated and distorted. This problem was solved "collapsing the stack" and converting the model into an editable mesh before exporting in VRML format.

To enable the construction of RP models the STL data format was chosen, but transfer from the modelling package was not straightforward. In the case of mirrored objects the normals of the faces in the STL files were flipped. This was corrected by applying a "normal" modifier, thus inverting their state. The STL file looked correct however the file was now difficult to work with using 3D Viz. It was eventually discovered that normals could be corrected more effectively by applying a boolean operation to non-mirrored objects.

Furthermore with particularly complex geometry such as the Millennium Tower the exportation was not completely correct because of missing triangles. This required further refinement of the STL file before the prototype was built. One of the necessary conditions of 3D printing is that the model needs to be perfectly "watertight" i.e. in the case of surface modelling not a single triangle has to be missing.

Probably the choice of 3D Viz represented a small compromise in term of precision and reliability of the final model if compared to other packages such as ProEngineer and CATIA but generally speaking it has given good results in terms of speed and flexibility.

5. Conclusions

"We are in the midst of a very exciting change - a revolution in 3D design tool that I think will lead us to the day when we truly do have 3D [5] design tools on every engineer's desktop [...] I think a key benefit of solid modelling is communication".

With the use of computer modelling and Virtual Reality applications it is possible to create not only an immersive view of a 3D computer generated space but also the experience and the "sensation of presence"[6] this may be the answer to the need for a natural interface both for the architect and for the client.

6. Future Developments

- Another technology worth investigating may be the use of 3D laser scanning. Using this the first part of the design process would not be the abstraction but the sampling or scanning phase.

- It might be interesting to investigate how the teaching process could take advantage of the combined use of VR and RP technologies.

- This experience has only studied one aspect of the designing phases: the communication between architects and engineers. It may be interesting to see if communication between architect and client can be improved by using VR and RP during the early stages of the design process.

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8. URLs

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The Reality Centre: http://www-europe.sgi.com/global/uk/centre/

The Cardiff Rapid Prototyping Centre:
http://intell-lab.engi.cf.ac.uk/department/rpdprot.html

The Phidias Project: www.phidias.org

Stratasys Corp.: www.stratasys.com

Z Corporation: www.zcorp.com

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