"Pushing the Envelope" a modeling-based approach to the development of organic, responsive architectural form

David Yearley, University of Portsmouth

Abstract

This paper tests design procedures for the development of complex, organic architectural forms. It illustrates a post-graduate student design process, implementing a development sequence based on the intelligent manipulation of architectural envelopes using a variety of existing modeling tools and emerging digital techniques. These stages of development respond to imposed spatial and environmental constraints.

The tests began with full-scale modeling of small segments. The major constraints at this stage were spatial requirements and the physical characteristics of materials. The forms derived from the bending properties of pre-stressed green timber and the dimensions of shingle cladding. This was followed by digital 3D modeling using common commercial applications. At this stage initial models were derived from a traditional space requirement brief. The envelopes for these activities were then manipulated to respond to the spatial limitations imposed by surrounding buildings. This digital modeling process metaphorically "pushed the limits" as vertices of the envelope model were stretched and shifted to achieve a perceived "fit" between the two sets of spatial dimensions. The spatially manipulated geometry was then imported into Ecotect, an environmental analysis package. As an example, the envelope's morphology and cladding material options on the acoustic qualities of the surrounding space were tested. The improved geometry was then imported into a Virtual Reality room, in which the spatial experience was simulated in presentations to the design team and potential occupants. This room utilized six projectors to create an immersive experience to users wearing stereoscopic goggles, and moving in a space surrounded by three large screens, creating a CAVE-like presentation space. Finally there was an attempt to complete the circle by returning from the simulated world to the physical worlds, by creating full-scale models from the digital geometry. This included low-cost techniques such as the generation of paper facets, and the use of more expensive rapid prototyping technology.

Organic Forms

Close examination of archaeological evidence uncovered in the excavation of an iron age settlement in a Glastonbury lake in Britain, has revealed to Jonathan West the possibility that the organic placement of dwellings and patterns of clustering, were even at that time, beginning to be replaced by the rectilinear geometry with which we are all now so familiar. He has formed this hypothesis from comparison of detailed chronological drawings made, and as a result is able to conjecture that the people of this settlement, which was mentioned in Arthurian legend, may have found it necessary to make more efficient use of scarce land on the island location in the face of expanding requirements, necessitating the integration of residual space between the simple circular dwellings, creating previously unseen linear alignments. In recognition of this, he observes that it is possible the previously informal arrangement of cluster groupings of dwellings became more regular over time, making rectilinear patterns discernable, and thus the placement of the circular dwellings was beginning to be influenced by a desire to "square the circle". Based upon this hypothesis, it is not unreasonable to also speculate upon similar tendencies which can be can recognized in the excavations of the Danebury Hill Fort, where religious pressures of the necessary rituals are thought to have influenced the forms in a similar way.[i] Even today, the sophisticated adobe enclosures found in West Africa lay testimony to the influence of this linear geometrical pressure, despite the natural structural tendency for the material to form into strong organic shapes. Primitive and primeval natural organic forms have been subsumed by the necessity for progressive geometrical efficiency and symbolism.

It comes as something of a surprise to some of us therefore, that there now appears to be an emerging interest in the use of natural organic forms to create architecture once more. According to David Pearson, *"In the new millennium a more holistic and organic image of the universe is emerging, and demanding new forms of expression that reflect the variety and creativity of nature itself"*[ii]

It seems that the recent advent and development of Computer aided design has enabled architects to engage with a complexity of form not previously economically realizable. Amongst the new forms emerging, organic shapes, harking back to the Iron Age, are once more being contemplated.

Understandably, many designers, particularly those liberated from the constraints of the "real", joyously explore the seemingly unending possibilities for creativity provided by this new environment. Many of us are fascinated by the “virtual” nature of works emerging from architects such as Greg Lynn and Asymptote depending upon “biomathematics” carried out in cyberspace, realized in beautiful graphics. It is now technically possible to construct many of these visionary forms with the aid of advanced software, enlightened consultants, specialist manufacturers and gifted contractors, as they have shown. Helen Castle, in a recent article stated that *“The onset of CAD/CAM interfaces that allow the designers to design directly for manufacture has placed production potentially back in the hands of the architect.”* [iii]

Other architects such as Zaha Hadid, Frank Gehry, Peter Eisenman, Norman Foster, Richard Rogers, have also trialed the realization of this new wave of “bespoke” form. It is becoming increasingly apparent that any form initially imagined in a virtual world can eventually, after some compromise and adaptation, be successfully built and inhabited. It appears to make little difference whether the original intention of the designer was to make an architecturally achievable form. In the case of this kind of architecture particularly, the process of realization acutely determines where the “edges and boundaries” of possibility exist, and comparisons between initial idea and realized project often reveal marked differences. The final built form shows the absolute reliance upon technology and expertise required.

This purposeful utilization of technologies and informed harnessing of resources in pursuit of a holistic organic architecture, aims to provide a perfect synergy between the “external” and “internal” condition. The resulting modifying envelope, a seamless barrier whose contortions have been tailored to an exact fit, is a fascinating “skin” which seems worthy of further intellectual and physical investigation. To this end, and in order to evaluate the contribution, which this new genre of enclosure makes towards architectural debate, one must be able to understand the freedoms and constraints of its manipulation. How far can one “push the envelope”?

Making and Design

Bob Shiel in a recent publication, states that *“Most architects do not make buildings – they make information for buildings. They turn ideas into drawings, models, texts and data, where many results inform the production of buildings and others do not.”* [iv]

He also points out that *“some architects, such as the members of Rural Studio, do make buildings without any dependency upon conventional design information”.* [v] The development of a design idea in this environment, is measured against the constraints of knowledge, skill, the properties of materials used, and location / function. With this in mind, and in order to evaluate the context within which to carry out an investigation into the constraints of envelope manipulation using virtual techniques, an experiment was initially conducted in the manner of Rural Studio.

Inspection of a recently completed grid shell project by Cullinan Architects at the Weald and Downland Museum in Hampshire, revealed clearly, both the lineage of historical derivation and also the importance of craft in the modern organic artifact. The constraints of uniformity in the two way spanning structural system used, has been skillfully integrated with the enclosing envelope to maintain the freedom of spatial enjoyment, whilst also providing visual delight at a detailed level of resolution.

With this in mind, a Woodland location and suitable vehicle for “making” research, were selected. The tests began with full-scale modeling of small elements. The major constraints at this stage were spatial requirements and the physical characteristics of materials. The intention was to provide an enclosure for the purposes of children’s storytelling in order to impart an awareness of woodland crafts. Various forms derived from the bending properties of pre-stressed green timber and the dimensions of shingle cladding were considered, but rejected in favour of a traditional “Bender” type. *(fig 1)*

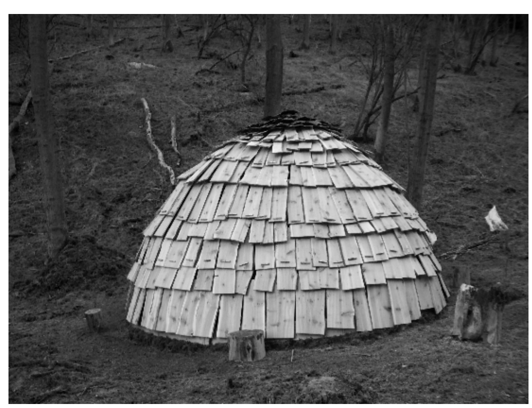

fig 1 Completed woodland “Bender”

Throughout the making process many new craft skills needed to be acquired, and a familiarization with the materials was essential. In response to these an intuitive solution emerged, which was both functional and appropriate. The form's strength and lightness was achieved by deliberate use of a pure geometric shape. Slight imperfections of shape and inconsistencies in construction made a significant difference and were noted with interest. The development of an envelope, which also contributed structurally to the integrity of the form, was essential to the economical use of material, and to the understanding of the potential behavior of more complex organic forms to be considered. Pragmatic solutions were explored, which enabled the envelope to achieve greater structural cohesion between individual elements. For example, tools were designed to assist with the assembly process, and construction techniques were developed to assist with the repetitive production of small elements.

Virtual and Physical Modeling

The "making" exercise provided "hands on" experience of real physical constraints and enabled participants to evolve new skills in woodcraft, and sensitivity for the requirements of context and material. However, the acquisition of intuitively involved design techniques during this period, proved to be the skills most useful in the unfamiliar design territory of the Virtual.

Two related projects were trialed in a parallel research exercise with the common aim of testing further the extent to which a continuous envelope can be manipulated in pursuit of the holistic resolution of complex requirements. Within the parameters of a real physical context, functional brief and performance requirements, the design of two appropriate organic forms were developed, requiring the acquisition of new design skills. The forms were designed from the outset, either to be read as a pair, or as individuals of similar typology. The design exercises were carried out by the same participants of the Making exercise (above) and over a 6-week period.

Development of Organic Forms related to an existing building

The research experiments were carried out by pairs of designers. Both designs were to be located within the constraints of an existing building context, and both aimed to find a holistic and appropriate architectural "fit", as well as aiming to contribute in a positive way to the existing visual, contextual, functional and physical environment. The designs were also to be capable of being built, requiring minimal alteration to the existing fabric. The materials used were to be sustainable.

The first design was to relate to an internal condition, the second to an external one. The design teams were allowed to develop and follow an intuitive design procedure to suit the progress of the emerging solutions. The first team was asked to utilize and trial "unfold" modeling software for the preparation of physical models, and also to utilize VR 3D visualization equipment. The second team was asked to use traditional modeling techniques, and also to trial Rapid Prototype modeling equipment.

Development of an Organic Form related to an existing internal enclosure

A suitable location and function for the new internal organic form was defined, relating to an existing major Forum/Entry space in the chosen building, connecting an existing first floor lecture theatre to a ground floor break-out space. The provision of a pre-lecture arrivals bar and gathering space, physically connected to both the Theatre and Forum break-out space was identified as a principle requirement, and became the basis for the functional brief used in the design experiment. To achieve this, a staircase connection between Bar and Forum break-out space was required.

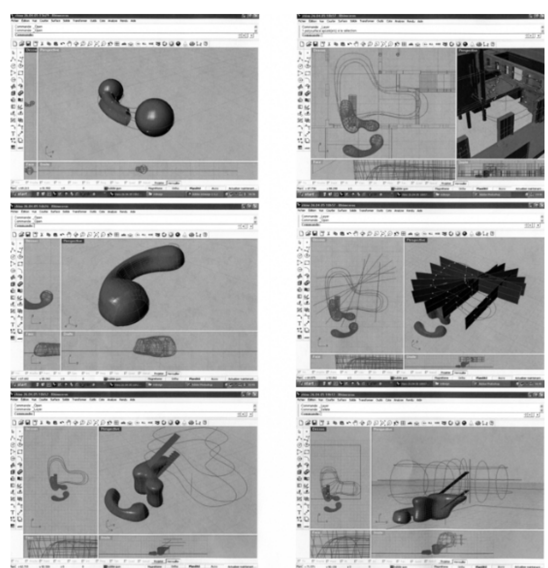

fig 2 Typical "screen shots" of design progress.

With this in mind, a 3D CAD model of the existing building was constructed and exported as DXF files to the environmental programme Ecotect. A systematic log of all stages in the research exercise was kept during the design process. Below is a summary of the documented progress charting the emergence of the first final form.

Initial forms

The first step was to make an initial sketch response to the design criteria. This was then directly attempted in the software by means of the adaptation of standard form volume templates. Two different sized Spheres were introduced into the 3D model of the building, sized and located by means of plan and section views to make the main body of the form. Horizontal rails then joined the spheres. Then a further, lower part of the form to include a staircase, was similarly made and joined to the upper form.

Trial and Error

As discovered during the Making exercise. the acquisition of skills through trial and error based upon an iterative process, began to define the emerging form. To a certain extent, the ability of the designers to master the difficulties inherent in the software learning curve, also equated with the limitations of form chosen for the woodland shelter. In both cases, technical limitations coupled with skill levels tended to determine the final result.

By pushing and pulling the envelope, the shape began to mould to the holistic constraints set. Many attempts were made to overcome practical difficulties presented by the software, particularly relating to the necessity for strict regulation of the complexity of grids, control points and smoothness parameters. At every stage checks were made with the existing building model to ensure that the emerging form was within the physical constraints of the existing building fabric. *(fig 2)*

Virtual Reality experience

When the form had developed sufficiently to be represented in a basic rendered computer model, it was viewed in a Virtual Reality suite.

The designers were able to “walk around” the model, and with the aid of glasses and special equipment, to experience “being there”. The interface between CAD software and Virtual Reality software and equipment proved initially problematic, but was resolved by using vrml files as an intermediary exchange.

Structure and Construction

The construction of the form was envisaged from the outset as a site assembly timber clad envelope connected to a preformed glulam construction “skeleton”. In order to integrate the structure with the emerging model and to evaluate the remaining interior space, an inner skin was created, providing a zone for the structure. Within this zone, templates were generated from the parameters of the form at centers suitable for interior and exterior cladding systems. The frames were arranged along a principle “backbone” or “spine” beam formed from curved glulam timber.

Physical modeling

At various stages of design, physical checks were made by means of small-scale models. Readily obtainable freeware software was trialed in an effort to find a simple and affordable solution to the physical interpretation of emerging organic forms.

The first type of model used was generated by an output of templates created in a NURBS based programme, covered in various alternative fabrics. Cling film proved very successful, being suitably malleable and shape retentive.

The second type of physical model was a paper type based upon the output of TouchCad (a Vector Works derivative) and Pepakura Designer, a readily available freeware programme popular with schoolchildren everywhere.

Both these programmes have an “unfold” capability, and can accommodate reasonably complex organic forms. The resulting “unfold “ templates can be printed out on any material with or without fixing tabs. However, the scale models produced in this way are less convincing, and require much time and skill in making.

Pepakura Designer

Pepakura Designer is freely available and understandably limited in application. However, it proved useful in making fast although basic, scale representations of complex shapes. The programme’s restricted output, representing curvature through triangulation, was a major limitation in the visualization of emerging forms.

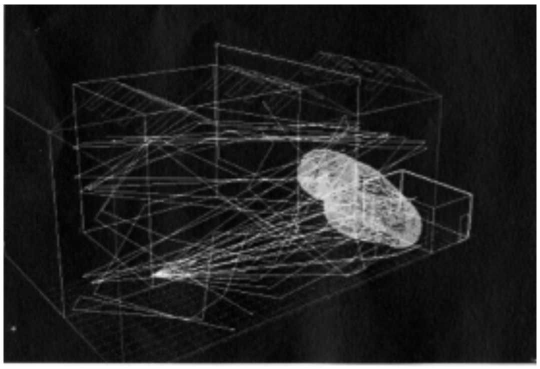

fig 3 Typical Ecotect acoustic visualization

TouchCad

TouchCad is an adjunct to Vector Works and is a sophisticated 3D design CAD tool capable of very complex "unfolds". It was generally felt that the output of TouchCad would be better used for larger scale mock-ups, where CNC compatible files could be used for direct cutting.

Acoustic Analysis

At various stages of design the emerging model was analyzed against Thermal, Lighting and Acoustic criteria using Ecotect. The limitations of this programme in relation to the analysis of complex organic forms was quickly realized.

Although theoretically possible, the Thermal and Lighting analysis proved difficult and time consuming, particularly the thermal calculations.

Intuitively, it was always considered that the best contribution to the existing acoustically "lively" space of the Forum would be the installation of large areas of acoustic absorption, particularly when the space was used for teaching purposes, or as a performance area.

This assumption was tested by means of the acoustic analysis software incorporated into Ecotect. Noise criteria for Multi Purpose usage was used as the bench mark for comparative calculations performed by Ecotect Output from the software *(fig3)* showed conclusively that the organic form would indeed make a significant contribution, provided that the external envelope was designed to provide a sufficient acoustic absorption.

Acoustic response

A detailed examination was made of possible envelope solutions related to structure, construction and the functional parameters. A stainless steel link outer mesh was selected in conjunction with a translucent inner insulation bead to provide acoustic absorption also providing dynamic concealed lighting possibilities. Artificial lights were incorporated into the intermediate structural zone to provide nighttime background luminance to the interior of the form through shapes cut in the interior timber lining, and to provide effect lighting to punctuate the Forum space.

Form objectives and resolution

It is difficult to make judgments about virtual design proposals. A new system of formalized architectural analysis is required to match the ever-increasing output of "possible" forms. However, despite the fact that this form was not physically realized, it was always the intention that it could be. On this basis, it was possible to evaluate the solution, and conclude that if built, this form would have made a very positive contribution to the existing context, and would have achieved the majority of the original aspirations. *(fig 4)*

Development of an Organic Form related to an existing external enclosure

The location and function for the second organic form were very different from the first form (above). Although notionally linked by proximity and typology with this form, the aim here was to provide a positive contribution to the existing courtyard space with its complex circulation patterns, hard and soft landscaping, rigid symmetrical geometry and asymmetric volumetric enclosure. At the outset, the fabric of that courtyard enclosure was to be "harnessed" in the design of the organic form, to promote further the already powerful dynamic of user participation. The provision of a centre for post graduate research relating to the virtual and physical digital interfaces necessary between imagined and realized organic forms was conceived. The external form was to be low cost, low energy, sustainable, and contextually related. The brief was to provide, a number of research carrels and a small conference/meeting space. The idea of projection onto the external wall of an existing building was considered

fig 4 View from within the Forum space

important. The possibility of daytime back projection of exhibition work and nighttime front projection of research data was to be incorporated.

The same 3D CAD model of the existing building used in the first organic form (above) which was constructed in Vector Works and exported as DXF files to the environmental programme Ecotect was used for this second form. As previously, a systematic log of all stages in the research exercise was kept during the design process. Below is a summary of the documented progress charting the emergence of the second final form.

Spheres

In a similar way to the first form, using a NURBS based modeling software the initial design step was to make a sketch response to the design criteria. This was then directly attempted in the software by means of the adaptation of standard form volume templates. Different sized Spheres were introduced into the 3D model of the building courtyard, sized and located by means of plan and section views to make the main body of the form.

Folds

An alternative approach was also taken to the above, by warping a plane in order to envelope function. The language of forms, which emerged, was rejected visually as being too linear and insufficiently inclusive.

Spiral

A combination spiral form emerged, which was considered to have symbolic as well as functionally necessary characteristics, and promised to be a better "fit". The envelope of this emerging form was manipulated to provide adequate space for the internal function on a trial and error basis as before. The overall template controlling the design decision-making process was the necessity for a close relationship with an underlying spiral ramp set at a minimum slope, and the requirement for this ramp to elevate a fixed distance during one revolution. Guidelines were set up in the software to constrain the manipulations of the envelope within specific parameters. In this way, the development of the form was progressed to a conclusion as described in the following account.

Physical Modeling

As with the first design exercise, at various stages of design, physical checks were made by means of small-scale models. In contrast however, more conventional models were made of this emerging form using traditional craft modeling skills and appropriately selected materials. In addition to this, Rapid Prototype models were also produced.

Although the design team were encouraged to make trial physical models, the time taken in preparation and the visual reliability of the output were judged to be constraining. The speed of the interactive and iterative process of virtual design was considered to be far more liberating and productive. The necessity for traditionally made models as a visual check was replaced by the output from the Rapid Prototype equipment.

Rapid Prototype Models

The attractiveness of this modeling technique to the virtual designer is obvious. Models are produced quickly from information generated as a byproduct of the design process. Without further effort from the designers, models

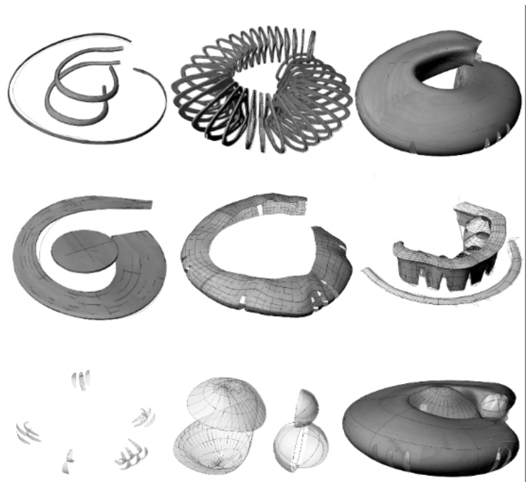

fig 5 Elemental components

are produced which visually replicate the onscreen view in a time scale, which does not unnecessarily constrain the iterative design process. However, the cost of equipment purchase, tuition and subsequent maintenance is prohibitive, and many design practices now prefer to pay for the use of facilities operated by others. It is important to establish the software interface requirements at the outset. Unfortunately, this was not done and the design team wasted time in resolving incompatibility difficulties.

Ramp Design

First, a series of diminishing spheres was arranged around a regular spiral. Then further, more complex spirals, were generated from the interlocking surfaces of spheres, which had been manipulated in size to contain function. In this way, the basis for a ramp, which was to be both a principle structure and also an internal circulation route was created. A flat plywood plane supported by tapering joists fixed to a structural curved glulam timber spiral was devised, providing void space below for service routes and air plenums. The form was to be naturally ventilated by means of spiraling air, cooled by passing the intake over the pool of water in which the form was to be located.

Structure design

From the spiral ramp geometry, a series of profiles were set up at intervals along its length to provide structural ribs within the zone between the inner and outer envelope allocated for this purpose. *(fig 5)* The parameters for these ribs were derived from constraining guidelines and the intermediate ribs were automatically generated by interpolation. The ribs and spiral ramp were designed in combination to be the structural skeleton for the form's envelope.

Envelope

The exterior skin of any enclosure subject to weathering, provides a critical interface with the elements, and also provides an opportunity for the inclusion of internal / external thermal modifiers. The design of such an envelope, which also has a flowing and seamless organic surface and is sustainable is particularly challenging.

Initially, new materials and technology transfer from the design of Yachts, were considered, using carbon fibre reinforced plastic composites in the formation of a stressed skin structure. However, the need to find a sustainable solution to this curvilinear problem, led to the proposal for a cross laminated plywood exterior treated with spray applied water based marine paint finishes after a suitable preparation stage. *(fig 6)*

Controlled perforations in the envelope covered by glass "lenses", were used to introduce daylight and provide ventilation. The orientation of the form within the Courtyard space as well as the design of the aerodynamics of the spiral profile shape were carefully considered. *(fig 5)*

Prefabrication

The resulting envelope solution was conceived and developed as a set of components, with prefabrication in mind. *(fig 5)* Indeed a complete "kit of parts" was eventually developed, leading to the possibility of simplified and speedier construction and greater quality control.

Carrel design

The functional requirements of the internal brief "pushed" against the external pressures beginning to shape the envelope design. The necessity for internal spatial and environmental resolution finally formed the definitive envelope shape. The study carrels were arranged off of the circulation ramp, spiralling around a large internal video conference suite. These bays were conceived as intimate post grad computer work stations, accessible on a drop-in basis.

fig 6 Postgraduate study centre in courtyard

Video Conference / Projector

Located at the centre of the form, the Video Conference area, was to be symbolically and physically the very nucleus of the Post Graduate centre, providing state of the art video conference facilities.

At the top of the spiral ramp, a projection facility was located, enabling live web casts and conference proceedings to be projected onto the existing building.

Form objectives and resolution

As has been previously stated, meaningful judgments about virtual and unrealized design proposals are problematic. However, the rigorous design process has revealed a holistic solution, which undoubtedly could be taken further to realization. There is no doubt that this form, if realized, would have made a significant contribution to the existing courtyard space, and would have achieved the majority of the original aspirations.

Conclusion

There is much historical precedent underpinning the return of organic forms in architecture. The desire to "square the circle" for purposes of spatial and organizational efficiency are both cultural and social, and are closely related to the new and emerging technologies and skills of the period. In a similar way, the recent re-discovery of organic forms is stimulated in part, by a desire to re-engage once more with nature and the environment, is closely related to cultural and social awareness, and is also promoted by emerging technologies and the skills available today.

The importance of an understanding of the "making" process, as a datum for the eventual realization of architecture designed in a virtual environment, is revealed by the necessity for, and its close relationship with, the finalized artifact. The knowledge and skills gained during the Woodland exercise, helped to equip the designers with an awareness of the requirement for practical ingenuity in a virtual world. As a result they were able to interrogate each iterative stage in a process of controlled rationalization and realization.

The first design was initiated by means of hand drawn sketches illustrating intention. Supplementary sketches produced during interim design discussions, to clarify detail, supported these. The final form produced, showed remarkable similarities to the original concept sketches, establishing the possibility that throughout the process, the designers were engaging in an act of "extended confirmation" of an idea that they already had knowledge of.

The second design was initiated directly onto the computer without the aid of "familiar" hand drawn sketches. In this case, several alternative models were trialed by the designers before one specific organic form emerged above all others as appropriate. During this period, selections were made on the basis of evidence on screen only, indicating the possibility that the designers were engaged in an act of "speculative creation", a process of conjecture and refutation in an unfamiliar world.

The methodical recording of each design stage by "screen capture", enabled the designers to make sense of the fast moving and dynamic evolution of the design and to maintain the necessary control over the emerging form.

Many architects currently working in the field of organic architecture find it necessary and useful to be able to compare virtual designs with physical scale models, and there is no doubt that this also helped to provide a reassuring "reality check" in a format familiar to the designers. However, the visual quality of the "unfold" models, was disappointing when compared with the promise of the on screen display. In contrast, the rapid prototype model output was far more reliable although expensive.

The experience of a "near reality" virtual reality, provided by the VR Lab, was of considerable design value to all involved. It provided the apparently absolute confirmation of "being there", enabling myriad further design judgments to be made instantaneously in a recognizable context.

In their efforts to manipulate the envelope of the emerging organic form, and to find an acceptable holistic solution, it was necessary for the designers to "push" hard against the many external and internal requirements. It was necessary for them to develop further design skills in order to negotiate the new virtual environment.

David Pearson has stated that *"The re-emergence* of organic design, represents a new freedom of thought; an expression of hope for the future"[vi] That may be so, but it is clear that in order to interrogate these new organic forms in any depth architecturally, a new set of criteria are now required. However, it seems possible, based upon the above observations of a design process, for designers with relatively little experience in the creation of organic architecture, to harness the potential of readily obtainable and relatively inexpensive software in pursuit of realizable holistic organic architectural designs.

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Illustrations:

Figure 1, "Completed woodland "Bender"
Image from location at Whitelands Wood Hampshire England.
Figure 2, "Typical screen shots of design process"
Image from Fifth Year Design project, School of Architecture, University of Portsmouth, England, Spring 2005.
Figure 3, "Typical Ecotect acoustic visualization"
Image from Fifth Year Design project, School of Architecture, University of Portsmouth, England, Spring 2005.
Figure 4, "View from within the Forum space"
Image from Fifth Year Design project, School of Architecture, University of Portsmouth, England, Spring 2005.
Figure 5, "Elemental components"
Image from Fifth Year Design project, School of Architecture, University of Portsmouth, England, Spring 2005.
Figure 6, "Post Graduate Study Centre" Image from Fifth Year Design project, School of Architecture, University of Portsmouth, England, Spring 2005.

Contributors:

During the period Feb-June 2005, the following Portsmouth University School of Architecture Diploma students prepared the designs, and were involved in the "making" exercise referred to in this paper: Christopher George, Stuart Winter-Rimmer, Romain Ecorchard, Johan Colin.

End Notes:

[i] Jonathan West "woodland project," 21 Feb 2005 University email (6 Feb 2006): John Coles and Stephen Minnett. Industrious and Fairly Civilised; The Glastonbury Lake Village. Site Structure Final Phase, figs 4.10-12.
[ii] David Pearson. New Organic Architecture; The breaking wave. (Octopus Publishing Group – Gaia Books 31 Dec.2004) p2.
[3] Helen Castle "Design through Making," Architectural Design 75, no. 4 (July/Aug 2005): p4.
[4] Bob Shiel "Design," Architectural Design 75, no. 4 (July/Aug 2005): p6.
[5] Shiel "Design," p7.
[6] David Pearson. " New Organic Architecture," p1.