AutoMAKE : generative systems, digital manufacture and craft production

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AutoMAKE: Generative systems, digital manufacture and craft production

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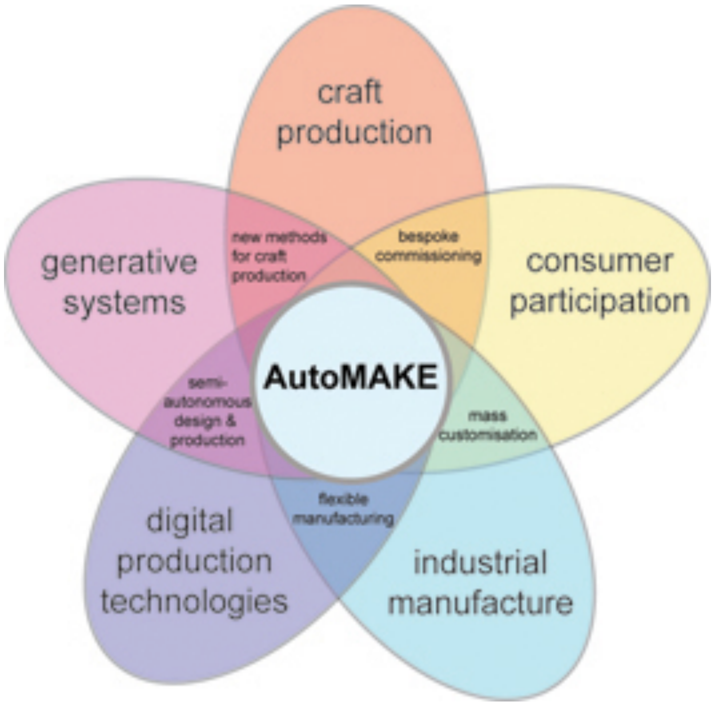
Abstract
The project on which this paper is based concerns combining computer based generative systems with craft knowledge and digital production technologies to create a new way of designing and making works which challenges the boundaries between maker and consumer, craft and industrial production.

This ongoing research project involves the development of a digital generative system for the creation of one off craft/design works based on randomly generated 3D matrixes. The system is to be used by the maker/researcher involved in the project to develop new work, and most significantly, by consumers who will then become 'co-creators' of their own craft/design works. To this end software with a user friendly interface is being developed to facilitate the creation of new works by users with no previous experience of CAD. The data produced by this new software will then be used to directly control a range of rapid prototyping and manufacturing technologies, and CNC machinery, which will physically produce the new designs in a range of materials at different scales.

The introduction to the paper will provide a brief context for this project and include an outline of the principal issues it raises for both consumers and makers. The main body will discuss the development of the generative software and its interface using game authoring software. The procedures developed to translate the generated virtual forms into physical works will also be discussed. The conclusion will involve a critical reflection on the project to date and discuss its future development.

1.Introduction



1. Project's location within the wider field

This project sits within the broad context of the growing interest in the use of generative design processes in theoretical and practice-based research in art, design and architecture. This involves exploring the potential for mathematical algorithms to provide computer generated inputs for the creation of artworks, three-dimensional forms or architectural propositions.

This research was undertaken by maker and researcher, Justin Marshall. His background is in using digital design and production technologies to create physical works, however he has had no previous experience in creating software. As a programmer and CAD expert Ertu Unver has worked in collaboration with Marshall and has provided expertise, support and training for the development of the software within this project. Paul Atkinson, has managed and overseen the project

1.1 Project Aims and Objectives:

The overall aim of this project is to investigate the potential of using a generative system to facilitate the design of unique one-off works by both an established maker and by 'consumers'. An additional aim is to investigate the use of a range of rapid prototyping technologies, along with CNC equipment, as a means of physically manifesting these newly generated forms.

The specific objectives of this project were to:

1. Design a piece of software, involving a generative element, which allows users to easily control the generation of unique and complex forms.
2. Build upon and extend pre-existing systems for the outputting of forms in a format appropriate for digital production.
3. Investigate a range of digital production technologies for their appropriateness to creating physical objects from the data generated by the new software.

4. Test this new form of design and production through the creation of new work by the maker/researcher.

2. Context

AutoMAKE is a discrete project within 'Post Industrial Manufacturing Systems' (PIMS), having its own aims and objectives. Previous work within PIMS has included 'Future Factories'[i] – a research project of work by Lionel Dean considering the development and use of generative software in conjunction with parametric modelling and rapid prototyping to enable the creation of unique products from a continuously, randomly changing form. This work has been conceptualised and developed very much from the perspective of an industrial designer trained in the process of product design and development within a mass production manufacturing context. The project explored the possibilities of and developed a system which essentially allows the mass individualisation of products – the direct digital manufacture of visually closely-related but unique forms of various product types.

While this project has been successful in producing a system for production and work displayed in exhibitions, the most interesting aspect from the overarching view of PIMS has been the philosophical and theoretical debates raised by this work. Issues of authorship of design and the status or value of the products created are two aspects which have been discussed elsewhere [1] as has the debate raised by the nature of the products created. In so far as the products and the envelope within which they mutate are specified by the designer (parametric modelling), they are designed objects (not withstanding that a particular iteration of a design produced by the software and selected by a customer may never actually be seen by the designer). As none of the products are exactly the same, they could legitimately be described as one-off pieces of art – a performance conducted by computer. Yet the variations of similar forms, the limited production runs involved, and the involvement of the customer in the process of selection mean that the relationship between the object and its consumer are elements more associated with the craft production of artefacts. This affinity with craft is in spite of the fact that no item is made, or even touched, by hand in the process of creation. These factors are the ones which are of interest to PIMS – the impact and potential of new and emerging technologies to further blur the already contested distinctions between art, craft and design.

The research question for this project, then (from the point of view PIMS) was to explore the differences in approach taken and the potential of the system to perform differently if the system was made available to be adapted and developed by a craft practitioner as opposed to an industrial designer.

3. The Project

A broadly pragmatic and exploratory approach was taken in undertaking this research. Many makers and craft practitioners approach the use of technologies, not with a rigid predefined aim to achieve a particular result, but to explore the possibilities the technology affords. The attitude taken by the principal researcher falls within this approach and the project was initiated with no fixed aim to produce work of a particular type, or solve a particular problem.

Previous work by Marshall has involved the use of 2D periodic and aperiodic tessellation systems to develop infinitely complex non-repeating patterns and structures[ii]. This broad area of interest provided a starting point for the software development. From Marshall's perspective, the AutoMAKE project provided an opportunity to extend the use of tessellation into 3D with the potential of creating complex and unique matrix structures.

Virtools[iii] game authoring software was employed throughout this project to create the systems described in this section. It was selected for a number of reasons, including;

- All systems developed using this software run on a web browser using the freely available '3D life' player.
- Software development is based on an intuitive building block method rather than hard scripting.
- It allows the creation of highly functional user friendly interfaces relatively easily.
- It can import data from a range of CAD software, including 3Dmax.
- It has been used for creating a range of applications beyond the gaming market, including visualisation for architecture and design, and tools for online learning.
- A strong user community with active forums providing problem/solution sharing.

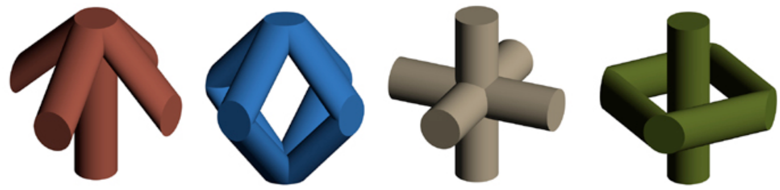
The software described in the section has all been designed with user interaction in mind. However, to date it has been exclusively used by Marshall in the creation of new works and test pieces. Some of the work shown below is the result of a direct translation of the designs generated by the software into physical form, while other works involve a more complex process which involved the employment of other CAD and image manipulation software. Therefore some results of this research are specifically concerned with extending the practice of the maker/researcher, while others focus on users.

In order to provide worldwide access to the software and therefore have the potential to capture a broad constituency of individuals to try the systems developed, a project website has been created[iv].

3.1 Development of 'Matrix Build 1& 2' Software

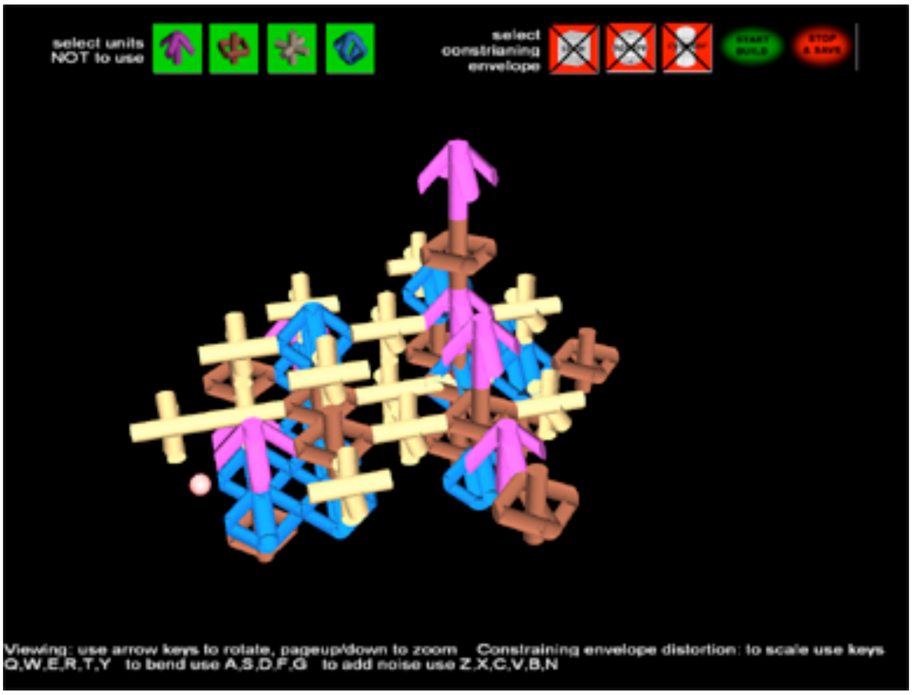
As discussed in section 2, using parametric objects provides a mechanism for creating mutable and unique forms. This approach, adopted in the Future Factories project relies on the setting of an envelope within which mutations of a pre-existing form/s can occur. An alternative method for creating unique forms is to use a modular system where the required complexity is created through rules being applied to the repetition of simple units rather than the mutation of a pre-existing object. Marshall was keen to develop a system for building/growing forms therefore a modular approach was taken with the aim of creating a complex range of 3D matrix structures. Both Future Factories and AutoMAKE provide opportunities for the consumer to interact with a system to create a unique object, but at different levels. Future Factories allows no interaction other than for the consumer to select the exact moment that the product mutation ceases. In contrast AutoMAKE provides a range of mechanisms for users to interact with the process of creating forms.. These opportunities were provided with the aim of engaging the user and so creating some sense of ownership of the forms created.

In order to provide a simple basic structure to the matrixes a rectilinear format was selected and a small series of units designed in such a way that they always joined together when placed next to each other.



2. Original units modelled in 3Dmax and used in first matrix build software

The first software developed gave the user the opportunity to select any, or all, of the units. The generative system was then set in motion. This involved one randomly selected unit, (from those chosen by the user), being placed in one of the free spaces next to the initial unit, the system then checked all the spaces around the units and randomly selected one of the free spaces to place another randomly selected unit. This process continued until the system was stopped and a file saved.



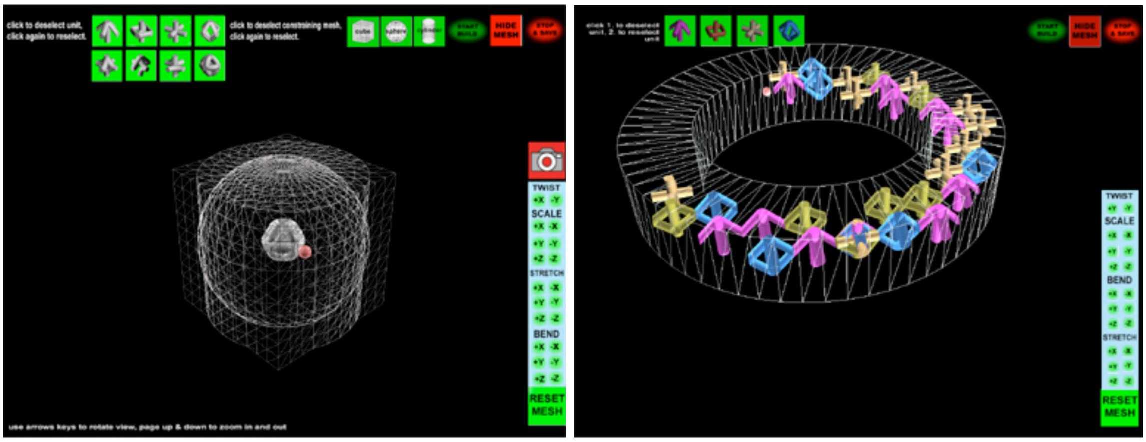
3. The random placement of four basic units to create an abstract form

This process succeeded in creating random matrix structures, however as the structures grew in size the number of spaces which required checking grew significantly, therefore the system became slower and slower, eventually crashing. In addition the file saving process was based on writing a 3D file in the .obj format. As there was no optimization or file compression within our system, the exported files were extremely large even when the matrixes were made up of a small number of units. It had always been intended that the matrixes could be made up of many hundreds, or even thousands, of units. Therefore a new approach to placing new units and to exporting files had to be considered.

These issues were solved by adapting the space checking procedure so that only the spaces around the previously placed unit were checked. This resulted in a system that did not significantly slow down because the number of spaces checked stays constant as the matrix grows.

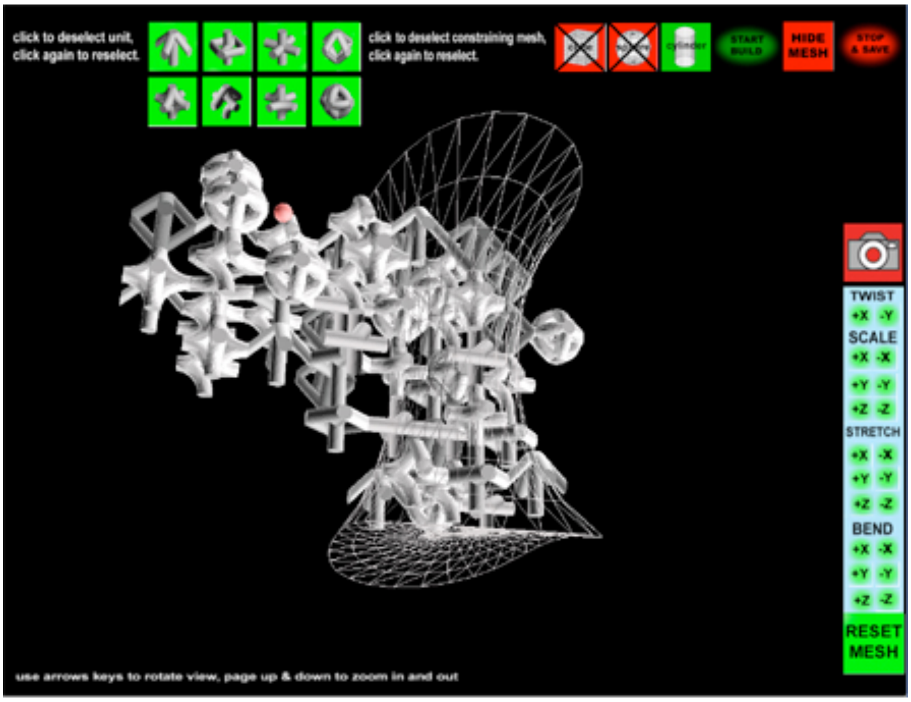
To solve the file size issue a script was created that allowed a dataset of unit codes and coordinates to be exported from the software. These text files are extremely small, and are therefore easily sent via email. This system has proved very successful, however it did require the creation of a script to be run in 3D Max that recreates the forms generated in the build software. 3D Max can then export the structure in a file format appropriate for digital production (i.e. .stl).

To create a greater level of user control and put some restriction on the generation of potentially infinitely large matrixes, a series of constraining meshes were introduced. These meshes function by acting as an obstacle to the growth of the matrixes. In ‘Matrix Build 1’ three meshes were introduced, any of which could be selected by the user and distorted using a range of tools. In ‘Matrix Build 2’ a torus mesh was introduced which restricts growth of matrixes to a shape appropriate for the production of rings, bangles and bracelets.



4&5. Matrix Build 1 interface and Matrix build 2 interface

As a restrictive mechanism, the constraining meshes have been moderately successful, although if the meshes are heavily distorted then units can often ‘leak’ beyond the mesh and once this has occurred the matrix will grow unrestricted. On one hand this can be frustrating and lead to a build being abandoned, on the other hand it produces forms that exhibit visual characteristics that are a balance between the random nature of the underlying generative system and the control the user has attempted to impose, which can have a unique appeal.



6. Example of a build where the form has 'leaked' out of the constraining mesh.

In conjunction with these constructional developments the screen interface went through a series of iterations in order to make it as self-explanatory and user friendly as possible.

There are still issues with the constraining of developing forms and the memory intensive nature of this software which limits build sizes on a standard desktop machine to a few hundred units. However it is believed that this software has reached a stage in its development where enough flexibility and functionality has been created to allow a level of play and experimentation which can engage users and it is ready for testing.

This software has also been adapted to generate 2D patterns and has been employed by Marshall to produce the digital print and CNC cut work described in section.3.5.

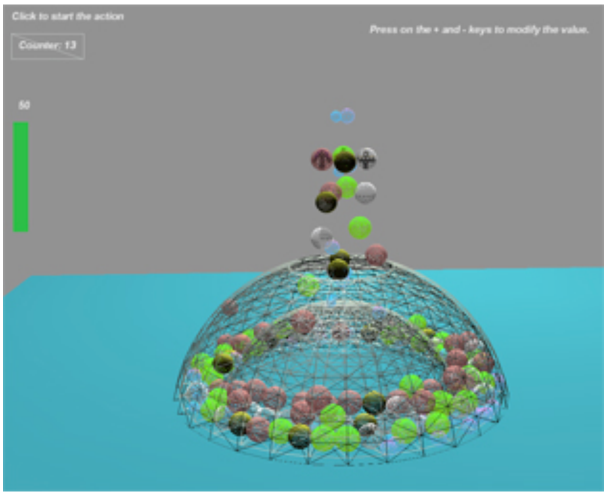
3.2 Development of 'Random Fill' software

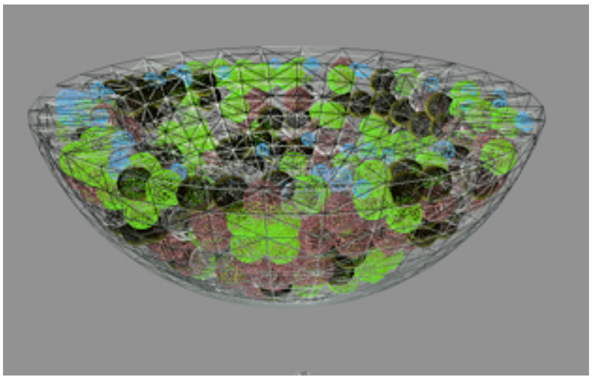
This more recent system was developed in order to counter some of the limitations of the 'Matrix build' software, specifically the high level of memory use and the highly regimented, rectilinear format of the structures.

This system creates structures from the same basic units as the 'Matrix build" software but the mechanism for construction is significantly different. Instead of forms growing through the random placement of units, they are created by dropping units into a hollow form or 'mould'.

The use of physics engine capabilities within Virtools allows each unit to be given a different set of characteristics (e.g. weight, elasticity etc.) and the complex interactions between objects to be modelled. Initially spheres were used to represent the units and a simple hollow bowl form was filled. The use of different scaled spheres helps create both variety in the density of the generated form and greater structural coherency. Once the mould has been filled, (or the user chooses to stop the process), the spheres are replaced by the corresponding units and the complex non-rectilinear structured form can be reviewed and saved for production.

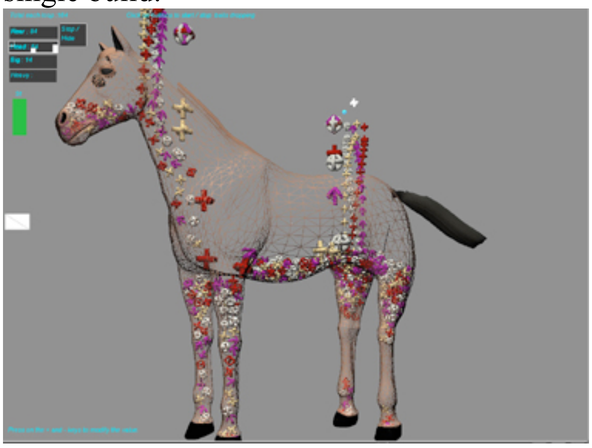
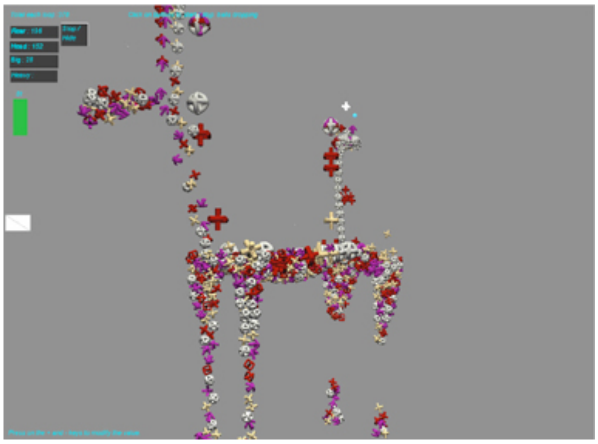
Due to using spheres rather than the more geometrically complex units during the build process and each of the object's movements being controlled by adjacent objects this system has a considerably more efficient use of RAM than the 'Matrix build' systems. Therefore the number of units that can be used within a single build can be increased by at least a factor of 5 before memory usage becomes an issue.





7& 8. First 'random' fill software using spheres to represent units during the build process and image of filled bowl 'mould'

Significant developments have been made with this system which can now use actual units in the build process. To provide an example of how complex a form can be created a pre-existing CAD file of a horse has been employed as the 'mould' and further refinements and optimizations have been undertaken which allow many thousands of units to be used in a single build.

9&10 Example of build in progress, with and without the 'mould' mesh visible

11. Example of build where over 1000 units have been placed in less than five minutes.

Currently an export protocol for this new system is being created which can concisely code the additional geometric information needed to describe all the units' positions and orientations in the non-rectilinear structures created using this method.

When fully functional it is believed that this method will result in a more engaging experience for the user than the 'matrix build' systems and have the potential to create novel and aesthetically engaging new works.

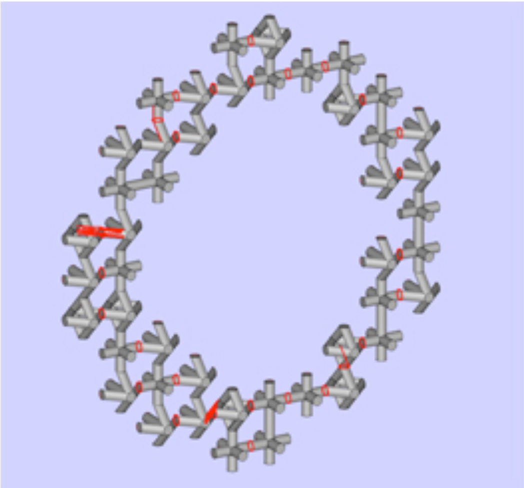
3.4 Post processing

Although one of the aims of the research was to create a method by which objects could be designed online and data could be generated from this process to directly create physical works, currently post processing involves a number of stages.

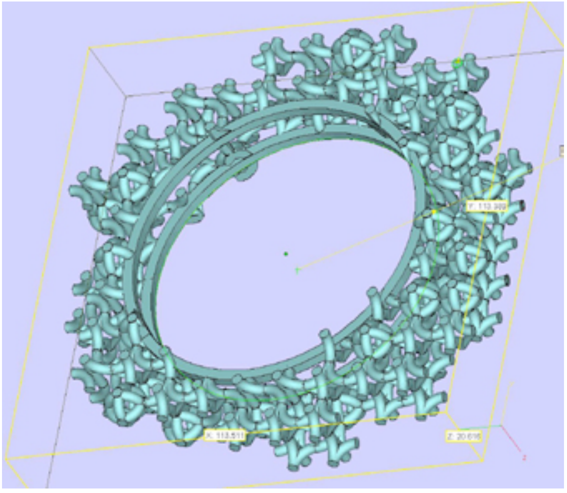
The first stage is the automatic creation of output files by the software once the user has finished creating their designs. These small files, which embody the information needed to recreate a users' design can be emailed to a member of the research team.

The second stage involves the recreation of the matrix forms in 3DCAD software by running a script that places appropriate units in the coordinates provided by the text file and saving the resulting file in appropriate file type for the intended digital production process. The development of this system has been crucial to the success of this project and is considered one of the most significant results of this project.. In theory the files exported from the CAD software should then be able to be used directly for producing physical objects, however this is rarely the case.

The third stage, for the production of rapid prototyped or rapid manufactured objects, involves using specialist file preparation software. Stl models of complex forms, such as the matrixes being generated by our software, are rarely perfectly constructed and require 'mending' before they can be physically produced.

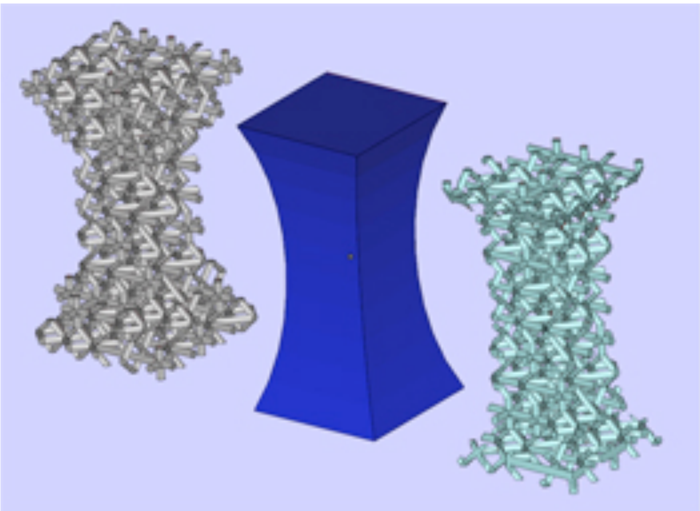


12. errors indicated in a bangle form



13. generated design with additional elements

At this stage the generated forms can also be rescaled to fit personal requirements (e.g. the size of someone's wrist) or to be amended by the addition of extra structural elements. The use of this software also provides the opportunity to 'trim' a matrix with the mesh files saved from the same build sequence, so adding another level of the possibility of creating forms with a different aesthetic.

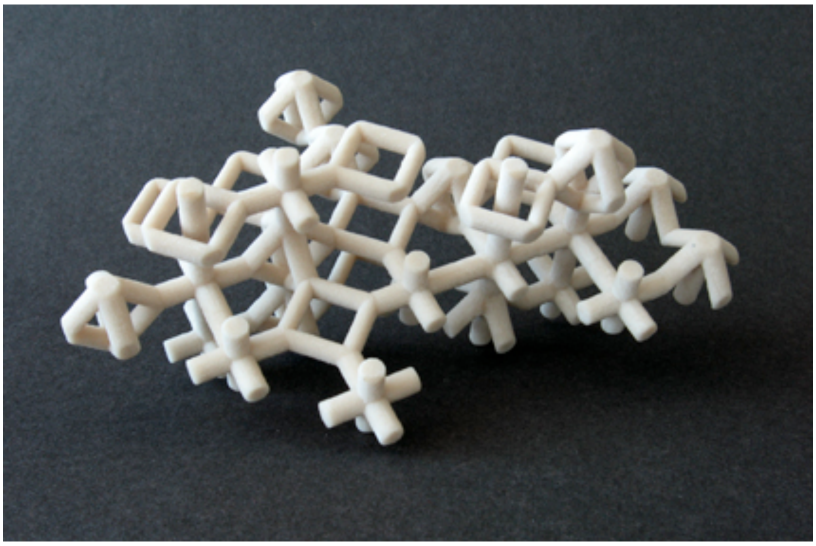


14 Untrimmed form left, exported constraining mesh centre & trimmed form right

The third stage for other types of digital output can range from colouring and layering 2D patterns in Illustrator to output image files for digital printing, to using 3D CAD software to integrate vector patterns with 2D panel layouts which will be CNC cut and used to construct large scale structures.

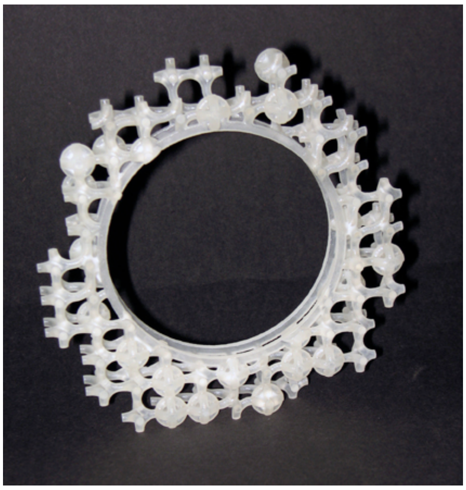
3.5 Digital production of generated forms

A range of digital production technologies have been employed within this project. A Z corp 3D printer[v] has been used to produce some test forms. Compared to many other Rapid Prototyping technologies, it is cheap and quick form of digital production. However it is not a production technology appropriate for small scale or intricate designs.

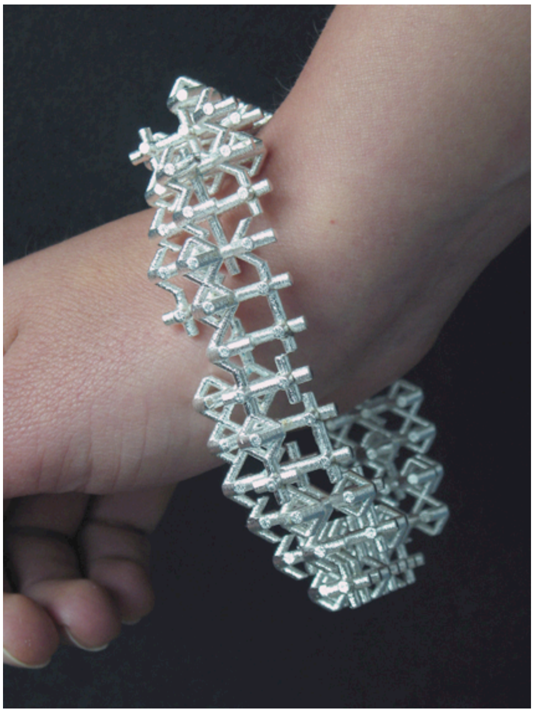


l5. Generated matrix test piece created using Z-corp technology, 150x80x60mm

An Invision 3D printer[vi] has also been used to produce a range of test pieces. This system has the capability to produce relatively cheap highly detailed and delicate structures, however models from this process are not durable enough to produce final works.



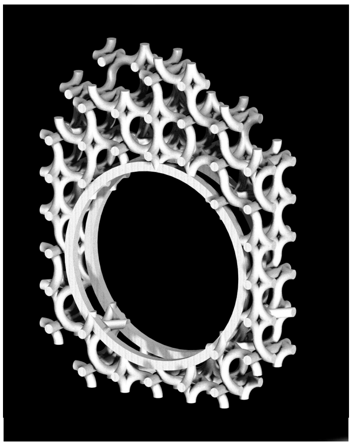
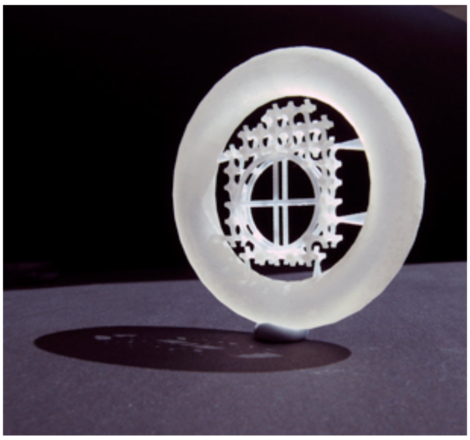
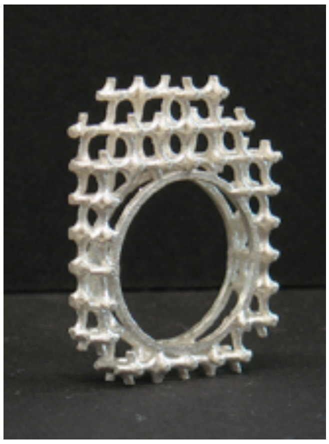
16&17.Two examples of bangle forms created using Invision 3D printer

18&19 Examples of silver plated Rapid Prototyped models

It was intended that rapid manufacturing technologies would be investigated which can produce artefacts metals and ceramics and so produce functional parts rather than prototypes. However, access to these more recently developed technologies proved difficult within the budget available. The well established[vii] Selective Laser Sintering (SLS) process that produces durable nylon parts will be used in the production of medium scale artefacts designed by users.

Rapid prototyped parts can also be used as an intermediate stage in the production of final works. Specialist RP technologies[viii] have been used to produce wax models for the casting of silver jewellery..

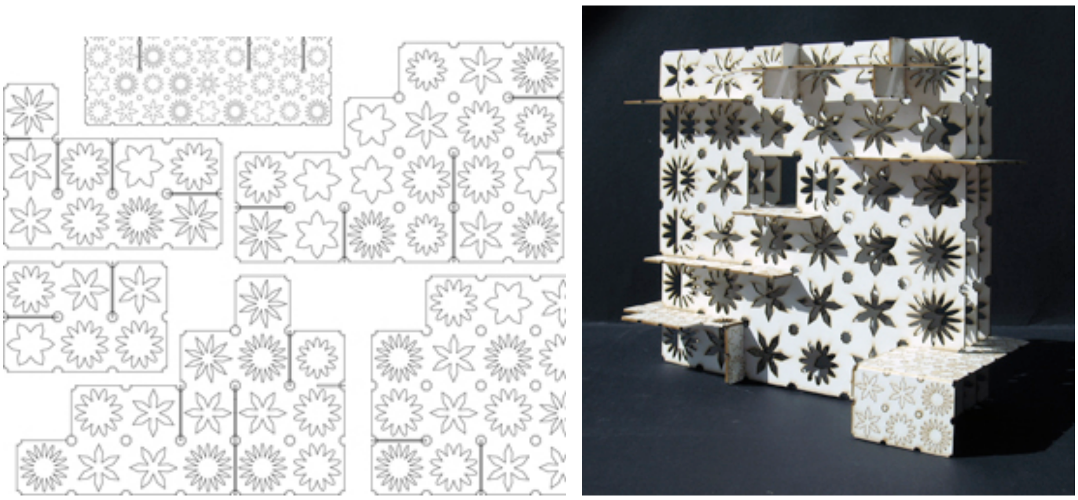
  

20, 21& 22 CAD Visualisation of a ring ,Wax RP model for casting, final silver ring

In addition to the 3D rapid prototyped work, 2D patterns have been created using an adapted version of ‘Matrix build 1’ in conjunction with post processing software and a 2D CAD package. The build software was used to create a series of randomly generated patterns based on a range of selected shapes. Within a 2D graphics software (i.e. Illustrator) these patterns are used as the basis for investigating the visual possibilities of colouring, combining and layering, a number of these generated patterns.

23, 24&25 randomly generated patterns layered and coloured, digitally printed fabric lampshades employing 2D random pattern generation system

Other work based on this adapted software involves the generation of 2D vector paths that can be used by a CNC laser cutter or router/mill to produce 2D elements. In the example below these elements interlock to form space dividers/shelving systems.



26&27 .Randomly generated patterns mapped onto flat panels for the creation of space divider, Laser cut scale model of 3mx3mx35cm space divider

4. Conclusions and Further developments

In relation to objective 1, a range of software applications at different stages of development have been created, all of which have the potential to create unique objects. However, user testing of these systems has yet to be systematically undertaken and it is recognised that further development of both interface and functionality will be required in response to user feedback. In addition to responding to user feedback, there is a range of developments the research team would like to investigate further, these include;

- Increasing the role and significance of the generative processes in the software through the introduction of more complex rule systems based on cellular automata or evolutionary algorithms
- In order to introduce further complexity and structural interest, introduce more complex aperiodic grid systems using 3D Denzer or Penrose tessellation into the Matrix build software systems.
- Create a more interactive experience for the user when generating designs.
- Using the physics engine capabilities of Virtools as a mechanism for creating new algorithmic methods that have the potential to compile and reveal embedded orders. These methods could potentially be used to construct forms which are not only aesthetically novel, but also have useful physical characteristics (e.g. structural coherency, increased strength, superior rigidity etc)
- Increasing the choice of build units available to the users by providing a library of 3D CAD models or create the ability to drop their own models into the design system. This would provide a greater variety of outcome and increase personalisation of generated designs while reducing the control the software developer/designer has on the final aesthetic of pieces being created.

In relation to objective 2, systems have been developed which create concise data files appropriate for transfer by email and which can be used to recreate the complex designs generated by online users/co-creators. However further work is needed to produce design files which require less post processing, automate the post processing stage to the point which files can be sent directly to digital manufacturing bureaus, and to create more sophisticated online experience for users.

In relation to objective 3; a range of digital output devices and strategies have been investigated. However, to some degree a pragmatic approach has been taken and technologies have been employed to which the research team have had affordable access, these tend to be more appropriate for the production of tests pieces than final products.

Rapid Manufacturing technologies which can produce objects directly in desirable and durable materials are currently undergoing rapid development. There is considerable work to be undertaken in studying the application of these technologies to the production of art, craft and design works. It is an area that Marshall intends to investigate in the future.

In relation to objective 4; the design and production systems that have been developed have been tested through the production of a range of physical works by Marshall. Economically viable medium and small scale products are being produced using rapid prototyping technologies[ix] and Marshall's jewellery based work illustrated in section 3.5 fit within this context.

Some work large scale work (see figure 27) has also been created, chiefly by converting the 3D structures generated into 2D sections that could be cut on a flat bed CNC router. For the independent maker the economic viability of producing large scale 3D complex forms using digital production technologies is problematic. It is an area which requires further research and the development of new production techniques based on scale and affordability, rather than precision and repeatability, as is the case to date.

4.1 Final thoughts

The most significant outcome of this project, is not the development of the generative systems themselves, which it is recognised is relatively unsophisticated, or any other particular element. Its significance is in the integration of a number of processes and procedures to create a range of systems that have the potential to engage individuals in a form of design and production that questions their familiar relationship with consumer products.

If seen in the wider context of a post industrial manufacturing era involving increased use of smart technologies and the development of personal fabrication techniques, these systems can be considered as part of a growing number of speculative projects and theoretical debates that seek to redefine the relationship between people and objects. Bruce Sterling, for one, has considered the effect on this relationship when the integration of technology grows to the state where the embodied information within a product becomes more important than its physical manifestation [2]. Research projects into advanced manufacturing such as the FAB Lab [3] and forums such as MAKE magazine also consider the social impact of these technologies.

In relation to established craft practices, it could be argued that the digital systems developed within this project propose a new way of creating objects which can be related to the older tradition of bespoke commissioning, but potentially in a more democratic and widely available way. Therefore this type of system has the potential to rekindle and expand a craft tradition in which maker and client work together to develop a design that is unique to the individual. However, as Emily Campbell argues, craft contains the idea of personal meaning, which she feels has been lost in much recent product design [4]. This personal meaning for the owner of a craft object is created through a complex range of psychological associations. There is a question whether the new design and production systems described here have the potential to produce objects which have enough 'craft' characteristics to retain the ability to create personal meaning. On the one hand they produce unique objects, but on the other hand, they are not 'handmade'. There is a range of skills employed within the development of the systems that allow the creation of new artefacts, however they are not the traditional skills associated with craft practice. Furthermore, the aesthetic characteristics of the objects produced are inherently a balance between the generative system, the software designer and the user, rather than solely the vision of the maker. As users begin to try the software and the systems tested, the significance of these issues can be reviewed and the hybrid nature of the project assessed.

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[i] See: www.futurefactories.com
[ii] Visit www.autonomatic.org.uk for documentation of previous projects.
[iii] See: www.virtools.com for details of this product
[iv] Visit www.automake.co.uk

[v] See: www.zcorp.com
[vi] See: www.3dsystems.com
[vii] The SLS system has been used by many designers over the last five years for the creation of RM lighting, seating and other domestic products, see www.materialise-mgx.com and www.futurefactories.com for a range of examples
[viii] See: www.3dsystems.com/products/multijet/invisionHR/index.asp
[ix] See: http://within4walls.co.uk/ for an example of retail outlet selling a wide range of rapid prototyped work.