Generative Design Methods

Implementing Computational Techniques in Undergraduate Architectural Education

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In continuation to the Deceptive Landscape Installation research project (Agkathidis, Kocatürk 2014), this paper investigates the implementation of generative design techniques in undergraduate architectural design education. After reviewing the main definitions of generative design synoptically, we have assessed the application of a modified generative method on a final year, undergraduate design studio, in order to evaluate its potential and its suitability within the framework of a research led design studio, leading to an RIBA accredited Part I degree. Our research findings based on analysis of the design outputs, student performance, external examiners reports as well as student course evaluation surveys indicate a positive outcome on the studio's design approach, as well as its suitability for an undergraduate design studio. They initiate a flourishing debate about accomplishments and failures of a design methodology, which still remains alien to many undergraduate curricula.

Keywords: CAAD Education, Generative Design, Design Concept

INTRODUCTION: DESIGN METHODS IN ARCHITECTURE

Generating form poses one of the fundamental questions in architectural education and practice. Architectural production is frequently accompanied by debates about the legitimacy of its design approach, questioning the relationship between function and form, aesthetics and construction systems, context and structure, user needs and construction costs, in all possible configurations. In recent years, computational tools have introduced innovative form-finding techniques, revolutionizing architectural design and production. These techniques are often described by terms such as ‘generative design’, ‘parametric design’ or ‘algorithmic design’, to name but a few. These offer new design paths to architects by breaking with predictable relationships between form and representation in favour of computationally generated complexities, thus enabling the development of new topologies. They shift the emphasis from ‘form making’ to ‘form finding’ (Kolarevic 2003). The critics of such design approaches claim that they disconnect architectural output from its context and its users, and lead to a decrease in spatial quality and a building’s integration within the urban environment. Furthermore, some argue that a totally computerized approach leads to disconnection from physical mod-
elling and drafting techniques - once essential foun-
dations of architectural education - and so risks the 
loss of material qualities, effects and properties. Yet 
various generative form-finding techniques existed 
in architecture long before the digital revolution. At 
the start of the twentieth century, many visionary ar-
chitects, engineers and designers, such as Frederick 
Kiesler and Frei Otto, were applying design methods 
that were very similar to today's computational ap-
proach. It seems that today's new computational de-
sign techniques are not as new as they seem, nor im-
possible to practise without the use of computational 
tools. So is it the tools or the design method that 
should be targeted by critics of so-called digital ar-
chitecture? The following paper will try to cast light 
on that perpetual conflict.

Why, though, should anyone follow a method 
for designing architecture in the first place? Can ar-
chitects not simply rely on personal inspiration or 
their own sense of beauty? Throughout the evolu-
tion of architectural design there have certainly al-
ways been schools of thought that have encouraged 
a design process based on inspiration or an initial 
stimulus. However, others have promoted adher-
ence to a specific design method, based on rules 
rather than intuition, and many now argue that de-
sign methods are necessary in order for architects to 
deal with today's hyper-complex design briefs, or to 
prevent self-indulgence and stylistically driven for-
mal language. Others affirm that emerging computa-
tional design and fabrication tools are changing the 
architect's role, making design methods a necessity.

DEFINITIONS OF GENERATIVE DESIGN
There is no single definition of the term, but many 
complementary definitions with common charac-
teristics, which vary according to different architectural 
thorists. Overall it can be described as a design 
method where generation of form is based on rules 
or algorithms, often deriving from computational 
tools, such as Processing, Rhinoceros, Grasshopper 
and other scripting platforms. During the late 1980s 
and early '90s, just before the boom of computational 
architecture, Peter Eisenman started applying a set 
of design techniques, such as scaling, fractals, over-
lay and superposition, influenced by Jacques Der-
rider's Deconstruction theory (1976). Eisenman ap-
plied these techniques in relation to rules of order, 
developing several projects on this basis, such as the 
Biocentrum in Frankfurt and the Nunotani Corpora-
tion headquarters in Tokyo (Eisenman 2004). One 
could claim that his design method was the first con-
temporary generative design attempt. As software 
started to offer new possibilities, Eisenman intro-
duced other techniques to his approach, such as mor-
phing images, which was soon followed by UNstu-
dio and their concept of the 'Manimal', a computer-
generated icon that merges a lion, snake and human 
to represent the hybrid building (van Berkel and Bos 
1999).

The technique of folding appeared in Eisenman's 
Rebstockbad in 1991 (Eisenman 2004) and, as com-
putational tools advanced further, Greg Lynn started 
applying new tools such as animation, splines, nurbs 
and isomorphic polysurfaces, influencing a whole 
wave of architectural production, often described as 
'blob architecture' (Lynn 1999). As algorithms and 
scripting become more accessible to architects and 
designers, and digital fabrication more affordable, 
parametric and panelization tools, simulation soft-
ware, optimization and generative algorithms are 
dominating today's generative design techniques.

In their book Generative Gestaltung (Lazzeroni, 
Bohnacker, Groß and Laub 2009) the authors define 
generative design as a cyclical process based on a 
simple abstracted idea, which is applied to a rule 
or algorithm (figure 01). It then translates into a 
source code, which produces serial output via a com-
puter. The outputs return through a feedback loop, 
enabling the designer to re-inform the algorithm and 
the source code. It is an iterative operation, relying 
on the feedback exchange between the designer and 
the design system.

Celestino Soddu (1994) defines generative de-
sign as 'a morphogenetic process using algorithms 
structured as nonlinear systems for endless unique
and unrepeatableresults performed by an idea-code, as in nature'. Indeed, the notions of generative design and digital morphogenesis are strongly associated. The term 'morphogenesis' derives from the Greek words morphe (μορφή, meaning 'form') and genesis (γένεσις, meaning 'birth'), so could be literally translated as 'birth of form'. As with the term 'generative design', there is no unique definition for morphogenesis, and it seems that the terminology is changing in relation to emerging technologies and techniques.

Branko Kolarevic (2003) describes digital morphogenesis as follows: 'The predictable relationships between design and representations are abandoned in favour of computationally generated complexities. Models of design capable of consistent, continual and dynamic transformation are replacing the static norms of conventional processes. Complex curvilinear geometries are produced with the same ease as Euclidean geometries of planar shapes and cylindrical, spherical or conical forms. The plan no longer "generates" the design; sections attain a purely analytical role. Grids, repetitions and symmetries lose their past raison d'être, as infinite variability becomes as feasible as modularity, and as mass-customization presents alternatives to mass-production.' In addition, he sees such methods as unpredictable mechanisms of creation, relying on digital tools, where traditional architectural values are replaced by complexity, asymmetry, curvilinearity, infinite variability and mass customization. Architectural morphology is focusing on the emergent and adaptable qualities of form. Form is no longer being made, but found, based on a set of rules or algorithms, in association with mainly digital, but also physical, tools and techniques. They imply the rules; the entire process follows.

Michael Hensel describes digital morphogenesis as a 'self-organization process, underlying the growth of living organisms, from which architects can learn' (Hensel, Menges and Weinstock 2006). In their latest book, Rivka and Robert Oxman (2013) categorize form generation into six dominant models in relation to its main driver: mathematical, tectonic, material, natural, fabricational and performative. They see digital morphogenesis as 'the exploitation of generative media for the derivation of material form and its evolutionary mutation'. Its key concepts include topological geometries, genetic algorithms, parametric design and performance analysis.

Finally, Toyo Ito compares 'generative order' to the growth mechanism of trees, whose form derives from the repetition of simple rules, creating a very complex order (Turnbull 2012). A tree's shape responds to its surroundings, blurring the boundaries of interior and exterior spaces - qualities that are easy to recognize in Ito's Serpentine Gallery Pavilion in London.

Based on these key definitions of generative design, a modified design method was developed in order to be applied in a year 3 design studio module at the Liverpool School of Architecture.
AIMS AND RESEARCH QUESTIONS

Main aim of this research paper is to evaluate the suitability and implementation of generative design methodologies into undergraduate design studio. Its main research questions can be described as follows:

- How can generative design methodology be integrated in an undergrad design studio module?
- Which are its strengths and weaknesses?
- Does the applied design methodology achieve its objectives in producing innovative design solutions and increase students' design skills and future employability?
- Does the integration of generative design methodology in undergraduate level seem appropriate?

DESIGN STUDIO MODULE TEACHING FRAMEWORK AND RESEARCH METHOD APPLIED

Our research method was based on monitoring the design path of Analysis - Morphogenesis - Metamorphosis (Figure 02) aiming the production of complete architectural proposals. It was applied in a research led design studio unit of 57 students (studio 04). The studio was led by the author, tutored by four additional tutors and it is part of a 230 student cohort in the entire year. The design module had a teaching period of 12 weeks. Students were allowed to choose among the four studios offered, according to the different studio briefs and teaching methods.

Analysis focused on data collection of various aspects, such as context, programme, material, structure and performance. Morphogenesis, digital or physical, targeted the generation of abstract prototypes, based on spatial and organizational principles, including unit accumulation, surface continuity, faceting, volume deformation or subtraction, and algorithmic patterning. The phases of Analysis and Morphogenesis have certain similarities to those described by Paredes Maldonado (2014), however deriving from a different starting point and emphasizing strongly on physical model outputs. In many cases notions such as genetic algorithms, cellular automata or shape grammars as described by Fischer and Herr (2001) were applied by using physical modelling only, according to the students individual skills and preference.

After undergoing a phase of iterations, the resultant not-to-scale 'proto-tectonic' structures (Frampton 2001) were then 'transformed' into building proposals, including floor plans, sections and elevations, as well as physical and digital models and all their derivatives (atmospheric images, visualizations, etc.). The Metamorphosis of an abstract prototype into a building proposal could occur in two different ways.

Figure 2
Generative Design Method applied in Studio 04
It could either be literal (a direct transformation into a building envelope and structure) or operational (functioning as an apparatus, which could generate design solutions in various scales and arrangements).

Studio marking consisted out of two components, split between 30% for research and 70% for design. In Studio 04, the studio presented here, students had to work collaboratively during the first four weeks allocated to research (analysis and morphogenesis) and develop their individual projects in the remaining time of eight weeks. Students were offered introduction workshops in Rhinoceros 5 and Grasshopper as well as in digital fabrication techniques. Each group was given a precedent to use as a starting point for their analysis, from which they had to derive design principles and rules in order to produce iterations of abstract physical prototypes.

The remaining 70% design component was dedicated to the design of a middle sized project (in that case a regional ferry terminal). Students were asked to 'transform' and apply their research findings from the 30% component into their final design proposal. Deliverables were consisting of all typical drawings, physical models, visualizations and detailing, as required by the RIBA and were identical for all four studios offered.

All projects were reviewed three times by external juries before being marked by the entire group of studio tutors, moderated internally and examined by external examiners. All data was collected throughout the entire year from student assessment and feedback forms, external examiner reports, submission of design project data, as well as an anonymous student survey. Marking criteria for both studio components (30% and 70%) were co-decided by all studio leaders and were made available to all students and examiners. In particular the marking rubric for the 30% research component was composed out of following marking criteria:

- Quality of site investigations / design exercises
- Evidence of research into architectural precedents
- Evidence of design drivers / process work / strategy
- Clarity of architectural arguments / overall presentation

Marking criteria for the 70% design components were as followed:

- Development of design process, utilising findings from component 1 / innovation
- Architectural agenda and design approach, expressed through diagrams, sketches, models.
- Quality of layout, drawings, 3d exploration, models
- Quality of tectonic approach and structural considerations
- Quality of the 1:20 detail drawings
- Overall body of work and presentation

Analysis of the monitored design output, marking rubric statistics and student survey, which will be presented in this paper are offering an analytical evaluation overview of generative design methodologies integration in undergraduate education. Obviously a decrease in students' average marking, or negative comments by external examiners and students would be a strong indication that the teaching method applied is not delivering the expected results, thus may not be suitable for undergraduate design studio education and vice versa.

External examiners reports are based on the examiners annual review of the cohort’s studio projects as well as a 10 minute interview every student. They do not relay on a specific list of criteria, but on the examiners' long year experience in practice and education. Student surveys were held anonymously through 'vital' the schools on-line operating system.

PRESENTATION OF STUDIO OUTPUTS AND COLLECTED DATA

By monitoring students' studio choices for the 4 different studios offered, first positive signals arise. Studio 04 turned out to be very popular, with 1st choice
demands exceeding the available 57 slots. In addition the studio’s cohort had a high marking average of 64.5%, considerably higher than the other 3 studios (any mark on 70% or higher, is considered as a 1st class project). Overall there were 12 students with a 1st class average mark, the highest concentration of firsts in all 4 studios.

Proceeding with the 30% research component outputs, which included the phases of analysis and morphogenesis it proved to be very successful due to the enormous amount and high quality of design production, including hundreds of models, diagrams, sketches and drawings (Figure 03). High variety on geometrical exploration, typology innovation, scale, geometry and structure has been documented.

Students managed to tackle the studio’s design approach and requirements quite well, even though it was the first time they have operated with such a design approach. This becomes evident by looking at their marking statistics, putting studio 04 at the highest range with an average score of 69% (Figure 04).

Continuing with the 70% design component, student performance drops compared to the 30% component as expected. In comparison to their studio performance in the previous year, the average studio mark stays almost unchanged moving from 64.5% into 63.5%. Out of the 57 students, 28 improve their score while 20 worsen it. 13 manage to move on a higher grading band while 13 move to a lower one. Band changes of grades moving up from 63% to 80% and from 55% to 72% are among the most extreme ones. On the negative site were students who dropped from 70% to 58% and from 60% to 48%.

By looking at the on-line studio 04 survey, results appear very encouraging. Its overall participation rate reaches 65%. In the question ‘How did you find studio 04’s overall design method?’, 40% find it very useful allowing them to achieve new outputs, 48.6% useful, neutral 8.5 % and none finds it not useful or would rather design the conventional way. That shows an overall acceptance of 88.6%.

In reference to the morphogenetic component, the question ‘How important were the 1st phase and the development of the generative models for the design of your final building?’ receives 37.1 % for very important, 54% for important (has influenced the building in one or the other way), 2.85% has ignored the generative models and 5.7% consider it as neutral. Again an overall acceptance of 91.1% occurs.

Considering the freedom in design creativity, the majority sees the method as a mean to express their creativity with 51.5% strongly agreeing, 34.3% agreeing, 2.9% disagreeing and 11.4% seeing it as neutral.

Referring to taught skills in 3D modelling and digital fabrication 88.5+8.5% strongly agree or agree that they are useful for their future employability while only 3% think this they are irrelevant.

Finally in the question ‘Do you think that the new skills you have developed in this studio helped you to produce a better project than last semester?’ 54.3 % find their current project much better than their previous, 31.4% a little bit better, 8.5% don’t like their current project and 2.8% see it about the same.
By monitoring the external examiner's comments and remarks, based on their annual report, studio 4 is not being considered as problematic or inappropriate. They don't seem to differentiate it from all other studios which follow conventional design methods, except for one complimentary statement. All examiners 'complained' about the lack of context engagement in the entire year except for studio 04: Andrew Peckham stated: 'It was ironic that it was the studio concerned to 'search for new typologies' that best registered a contextual urbanism on a constrained site in the city centre'.

DISCUSSION AND CONCLUSIONS

By reviewing the design projects and outputs assessed here, a set of conclusions and discussion points arises. Many architectural educators are very sceptical about such unconventional design methods, fearing the loss of design control, materiality, craftsmanship, functionality and relationship to context. They tend to blame generative-based design for all the negative aspects of contemporary architecture. However, the design method applied here proves them wrong. It manages to support a high degree of differentiation between the schemes, despite the fact that many of the projects were developed using the same techniques (e.g., triangulation). It also inevitably supports creativity and innovation, which is why so many of the projects managed to move beyond standard building typologies and layouts such as the market hall building (Figure 05). Innovation emerged not only in formal design aspects, but also in terms of building programme and spatial solutions, offering new building type hybridizations, such as the ferry terminal proposal (Figure 06).

The mix of different design tools and techniques, switching from traditional physical modelling, such as plaster casting, to advanced 3D printing and CNC fabrication in one continuous modelling scheme (Figure 07), proved to be of great educational value. It offered students the opportunity to test materials with their hands, and to experience the advantages, difficulties and opportunities advanced technology has to offer - a design path that is often excluded, due to dogmatism, or ignorance of (or lack of respect for) either handcrafting or computerized techniques. Neither banning computers nor abandoning traditional craftsmanship offers a solution for the future of architectural education.

Digital tools can often be seductive for designers. However, while speeding up the design process, designing with digital tools makes gravity and materiality disappear. Physical modelling helps designers and students to reconnect with these two key elements, which are so important for architectural production. In addition, the switch between analogue and digital tools allows students to filter out excess complexity within a digitalized design process. By testing digital findings with physical prototypes, they can begin to assess whether a complex solution is really offering spatial, aesthetic or programmatic qualities to a project. The issue is not so much whether CAD and 3D modelling software should be banned or embraced in undergraduate architectural education, but rather to what extend they should be applied, in which educational year and for what purpose. The same principle applies for the use of digital fabrication. It is indeed irrational to apply such techniques for cutting out rectangular panels, but more than appropriate for mastering fabrication of complex geometries.
Alongside the loss of materiality and craftsmanship, many critics of generative design methods argue that the resulting architectural proposals are totally detached from their context. This is a criticism often applied to modern architecture as well. During our programme, the degree of integration or non-integration within a context was up to the designer. Building up a relationship between a building and its context can be achieved in many different ways. It can rely on form, materiality or programme, or all of the above. One can choose to harmonize, ignore or break with a building's context, a decision that does not depend on the design approach but on the designer's attitude towards the site. Nevertheless, external examiners overviewing the projects expressed surprise at the high degree of site-specific proposals, despite the unconventional design approach. All of the finalized projects managed to comply with standards and requirements defined by the accreditation body (RIBA) and the module descriptors, as evident in the drawing and modelling outputs. In that sense, the generative design method applied proved highly appropriate for design education, helping students to develop their skills and self-confidence, and enhancing their future employability. This became evident by the student survey, where 97% of all participants expressed their confidence about gaining higher employability perspectives.

Looking at the difficulties accompanying such an approach, findings varied. Scepticism from other colleagues and fellow educators was definitely among them. This included guidance from tutors involved in the process as well as criticism from others observing the approach. From a student's point of view, the shift away from conventional design methods certainly appeared to be very demanding. That became particularly evident after the completion of the form-finding phase; it was the Metamorphosis that presented the biggest challenges. As liberating and exciting as Morphogenesis might have been for some, abandoning the abstraction of the prototype and transforming it into a building proposal, overcoming obstacles of structure, urban context, planning and materiality seemed to be very difficult. Many tended to start from scratch, leaving everything behind and following the conventional approach they were most familiar with. Some chose a brutal landing of their prototype into the site, without developing an attitude towards the context, while others failed to use their prototype for something more than simply trendy decoration.

Another issue that arose using this approach was having to manage the geometrical complexity that occurred. This was often a problem of representation. Complex geometries are easily produced in a digital environment, but controlling and representing their outputs often requires non-standardized methods as well. This can be a consequence of using software incorrectly, or of using inappropriate software for the task required. How can complex geometries be rep-
resented in floor plan, section and elevation? How can such geometries be built in a physical model? This is when guidance is needed. Tutors play a critical role here. Educators need to guide students and enrich academic curricula with new design methods and tutored skills. But it is the student culture that plays an even more important role: the intercourse that occurs between students, either through daily procedures and presentations or through social media, websites and on-line forums. Today’s young designers belong to a generation that has grown up with smartphones and computer tablets instead of crayons and paper, granting them familiarity with digital technologies from a very early age. These are designers, therefore, who are more than able to deal with unconventional design methods, and who will hopefully revolutionize architectural production in the future.

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