

Beyond Equilibrium: Sustainable Digital Design

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Abstract

Implicit in current understandings of sustainability is the presence of a closed system with the capacity of equilibration. Sustainable practices, including design practices, are therefore assumed to possess a redemptive role: design is deployed (as environmentally sustainable design, etc.) to change habits, develop new technologies and recover marginalized practices in the hope of righting the balance between the environment and human endeavours.

Recent developments in experimental digital design have demonstrated non-linear and highly complex relations between topological transformations, material change, and the temporal dimension of forces. More importantly, this method of design is bottom-up, because it does not rely on design solutions presaged by conventions, or restricted by representation, but is emergent within the performance of computational design itself. We argue that digital design processes need to move beyond the flux of determinates and solutions in equilibrium, towards a radically continuous but consistent production, which is in effect, an expression of sustainable pedagogy.

The role of emergent digital techniques has significant impact on the methods in which computation is utilized within both practice and academic environments. This paper outlines a digital design studio on sustainability at the University of Tasmania, Australia that uses parametric modelling, digital performance testing, and topological morphology, concomitant with actual material fabrication, as a potent mode of collaborative design studio practice towards a sustainable design pedagogy.

Keywords: digital, computation, process, morphogenesis.

1 Computational Representation

In the past three decades, the role of the computer in architecture has been restricted by the imperative of representation. The integration of digital technologies has centred on the replication of traditional modes of practice and communication. Primarily, this mode has aimed for greater efficiency within professional practice through reducing the need for manual

repetition on both individual and multiple project scales. Computers have also been generally used for visualisations of conceived designs, that is, as a tool to communicate visually to clients and stakeholders, in order to build expectations of the design project to come. In essence architectural computing has become an extension of the ink on tracing paper paradigm (Leach 35), a hallmark of the architectural office throughout the twentieth century. In the early days of digital architecture, computational processes were rarely integral to the practice of design itself; other than reductive practices such as “shape grammars” (Radford and Stevens) based on the computation of pre-established languages and patterns of historic or iconic architectural examples; owing firstly to the belief that design is a jurisdiction of the human creative genius irreproducible by computers, and secondly, to the fact that experimental modes of digital process integration were rarely explored due to lack of hardware and software development, and computational power in the area.

The move to digital representation has become ubiquitous across the profession, and it has had lasting effects on the ‘style’ of buildings it helped to produce and communicate. Exploiting the residual neo-modernist (more a formal style than philosophy) tendencies for the ease at which standard drawings and details could be produced and replicated, it can be argued that computing has inculcated in architectural design a forgetting of the intrinsic richness associated with traditional modes of material and constructional expression. Instead of an investment into the development of project-specific fixtures, fittings and details, standard details through replication from previous projects became a norm due to the convenience - and cost efficiency - bestowed by computing in architecture.

It was not until the early 1990’s, almost 15 years after computers become commonplace within offices, that practices began to engage with the wider capacities of digital computation in their work, both physically and theoretically. Early pioneers in digital architecture, including the likes of Frank Gehry and Greg Lynn, took grasp of the new toolsets that were on offer from allied professions (primarily visual effects, mechanical engineering and industrial design) as they allowed easy creation and manipulation of complex curves and surfaces. During this early period the numerous ‘blobs’ and ‘organic’ forms emerged and were championed as the next-generation of architectural expression, the new avant-garde.

However, like many of the digitally orientated projects of this period, the process was still bound to a top-down model of design computation. Looking at the work of Gehry in particular, there is a preoccupation with forms and surfaces that are obviously recognizable as digitally designed. A closer inspection of Gehry’s design process however, reveals that digital techniques are brought into the mix only later in the design process primarily to resolve issues associated constructability, efficiency and cost. This is, in effect, a form of digital post-justification, in which computation is utilised in a stage of the process in which the outcome is already known. The computational processes merely served to rationalise the architectural form towards the realisation of a pre-determined outcome. In this mode, the potential in computational power is diminished, as the design process defaults back to models of production that are conceivable by human means.

Gehry's Guggenheim Museum in Bilbao, 1997, provides evidence of this representational (top-down) approach to digital computation. Its titanium-clad surface wraps the separate gallery wings in an amorphous skin, unifying the different parts of the building into an identifiable whole. Putting aesthetics aside for a moment, the skin flows over the ornate surface in regularly sized panels that pay little attention to the unique curvature, or the intrinsic conditions, of that particular part of the façade. The panellisation is a result of cost efficiencies in construction and it was at this point that computation assisted by sub-dividing the skin of the building into individual panels that could be fabricated with ease. Computers may have simplified the process greatly, but as Leach states "[the] objective here was simply to use the computer to make the designs of the architect realizable." (36) (Gehry's current work however does integrate digital techniques within the design process to a much greater extent, leading to richer architectural results.)

2 Process-Based Digital Design Methodologies

There is an alternative bottom-up approach to digital architectural expression. The widely published work of the Emergent Design Group alludes to this approach. Its proponents, Michael Hensel, Achim Menges and Michael Weinstock call it "morphogenesis." Directly translated from Latin, morphogenesis means *form creation* (Leach 35), but what the Emergent Design Group implies by using the term is form creation through the processes of evolution, iteration and differentiation. More explicitly, morphogenesis refers to a bottom-up approach in which the designer has a certain degree of control over the computation processes (Kolarevic 12-28).

Architectural practices and researchers in this field are adopting specialist software, that is allowing computation to develop into a new realm of integration between human intelligence and creativity; the human being becomes a fully active agent within the design process again. In addition, new processes including parametric control, associated geometry, component-based modelling, generative iteration and algorithmic expression are allowing greater 'embedded intelligence', or intrinsic intelligence within a system, in architecture that relies on full human participation. It is the combination of such processes that is empowering architects to control and utilize the affecting conditions of a project in a bottom-up approach, rather than rules or conventions that govern the design process in the traditional top-down method. In effect, computation becomes an intrinsic part of the design process, not merely a slave to it.

Embedding computational processes allows complex design variables to be interplayed within the process itself, enabling direct consideration and feedback of design suitability, which in turn allows changes to be made in real time and tested again, towards a process of efficient and consistent design exploration. Sustainable parameters including material consideration and optimisation, structural suitability and solar performance can be integrated within the computational process, offering real-time feed back on design iterations, with more efficient, better performing, and constructionally viable architectural outcomes to be achieved.

It is relatively obvious how a bottom-up approach in contemporary digital architecture can directly integrate current knowledge of sustainability and ecological agendas into design pedagogy. However, this approach also leads the way to a 'sustainable pedagogy', or a pedagogy in design that is sustainable in itself. Because a continuous, but not closed, feedback loop is established in the design process, architecture can be understood as a non-linear performance-based design methodology in perpetual continuity. This non-linear approach to design suggests that the relationship between problems and solutions are not necessarily a causal. Every solution potentially enacts a set of finite variations and outcomes, establishing an environment in which there are compounding fields of solutions, rather than a singular outcome. Morphogenesis sees digital computation as a 'topological' process that is constantly fluxing and unpredictable. As it relies upon fields of potential possibilities owing to the computational, and computable, relationships between a set of variations, an outcome is always already within a specified scope or range, but is never fully predictable or pre-determined. So, without only relying upon preconditioned knowledge and methodologies with their concomitant anticipatable outcomes, a performance-based approach to architecture allows design teaching to continue anew in each project and in each design move. Here, design teaching moves from postulating optimally appropriate solutions, to catering for how students (and staff) improvise to attend to the indeterminacy of results that arrive at the moment of their encounter in the process.

To some extent this bottom up approach to computational design process is being to be assimilated into many offices around the world. The work of Foster & Associates, KPF, Arup and SOM, to name a few, are integrating non-linear computation within their design workflow. In a commercial sense however, it is often difficult for practices to integrate bottom up computational methods within an established design process. At its very core, variables within a computational design environment must be described numerically, geometrically or relationally. Often architectural projects contain parameters that are near impossible to encapsulate and bracket computationally, including building function and design intuition. In the light of this, practices are increasingly engaging with academia to conduct experimental projects and research that are comparably free from the inherent constraints that the practice of architecture presents. An academic environment offers fertile ground for the unencumbered exploration of emergent computational processes.

3 Practice-Academia Collaborations in Experimental Digital Architecture

The work of Chris Bosse's studio LAVA (Laboratory for Visionary Architecture) produces projects through a series of installation-based projects, often in collaboration with university programs. For example, *Digital Origami* was a workshop conducted in collaboration with the University of Technology of Sydney (UTS) in which students were encouraged to interrogate current trends in parametric modelling, digital fabrication and material science (Bosse). Bosse's previous work on the Beijing National Aquatics Centre (PTW Architects, 2008) was used as a starting point for the workshop. The students used the three-dimensional tiling of the Weaire-Phelan structure that can be arranged in seemingly different formations and potentially

produces 'growth like' forms and spaces through simple connection relationships. The connection arrangements established a 'rule set' that allowed the installation to metamorphose from a pair of unique elements into a seemingly random organic form that fitted within a specific context, subscribing to a general design scope and intent. In essence this is a result of a *semi-computational* process in which a basic rule set was adhered to throughout construction, resulting in a computational form without the use of a computer.



Figure 1. Digital Origami (Bosse)

Moving beyond a semi-computation driven process, there are numerous examples of academic research in collaboration with practice that looks at how computation can be fully adapted into a design process. The *elfFormStructure* project, completed by Kristina Shea while studying at the Academie van Bouwkunst, Amsterdam 2002, utilized a computationally generative design process. The performance-based digital model investigates design resolution through a series of determinates that are established at conception that governs the process within certain limits of a design intent. Once these parameters are set, possible solutions that meet the design and performance criteria are generated iteratively. The digital generative process, described as 'Structural Shape Annealing', incorporates processes of grammatical parametric shape generation, performance evaluation, structural analysis and stochastic optimization that produce fully realizable design iterations that directly relate to spatial suitability and cost performance (Shea, Aish and Gourtovaia 554). Intrinsically embedded within the digital model are overtly visualized and computationally probable considerations for

structural and material optimizations, with abilities of formally adaptation to contextual and spatial concerns. Traditional constraints play a secondary role to the design process, as the digital model can respond to a multitude of conditions as it is generated by design parameters and conditions rather than a traditional method of explicitly described geometry (Leach 36).

The two sides of Marc Fornes's work deliver even further experimentations in the developing field of architectural morphogenesis. Based in New York, both his teaching and research investigates algorithmic generative design processes, with a focus on developing built prototypes that are entirely originated from a set of codes (Bessa 122). His work *Aperiodic Vertebrae v2.0.2*, in association with Skylar Tibbits and Jared Laucks, demonstrates the fabricated prototype of an entirely digital design and generation process. The parasitic form is able to adapt itself digitally, based upon prescribed fabrication requirements. Through a generational iterative process the digital model searches for equilibrium between material and form. It is the consideration of material and fabrication constraints that allows the algorithmic adaptation to deliver a unique and realizable structure each time the software is run, in order to achieve a state of digital materiality that is inherently performance-driven. The generation process itself evaluates and optimizes the material usage, enabling the fabrication process that follows to utilize as little material as possible, embedding a sustainable production cycle within the digital model.

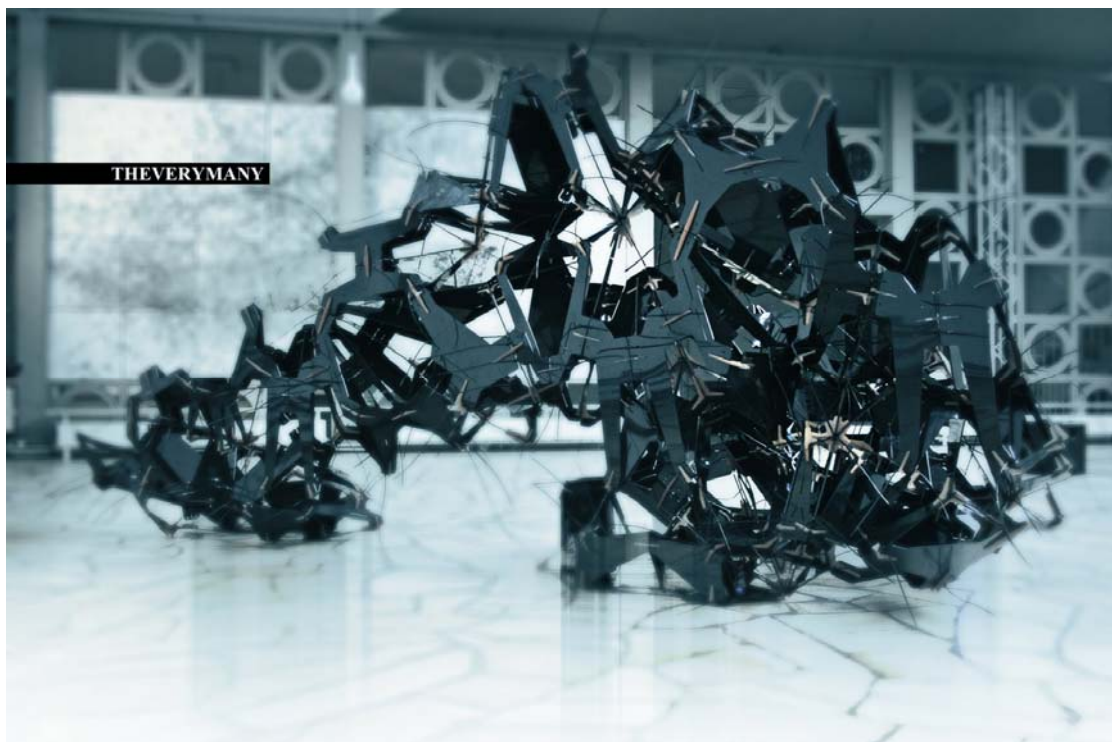


Figure 2. Aperiodic Vertebrae v2.0.2 (Fornes)

Central to successful exploration of digital design methodologies is a shift in design focus from explicit to implicit means. Rather than explicitly describing the outcome, the latter only needs be implied by a region or field of possibilities consistent with the exigencies of contexts within the generative process. This focuses the designers' creativity on formulating determinates, rule sets and relationships, rather than it remaining in the realm of judging aesthetically suitable forms. And the factors that influence the 'design' of rule sets and determinates are *real* ones, ranging from the available fabrication capacities, material behaviour, environmental considerations, conceptual ideas, functional programs, spatial performances, etc., all of which generate data that can be converted into computational parameters. The main difference between this bottom-up approach to the conventional top-down one is there is no imperative of immediate causality between the parametric factors and their associated data that give rise to the rule sets or determinates, and the forms that arise from the process. The latter is seen as a partial concretisation or effectuation of a possible field of solutions, all of which possess a consistency and logic with the parametric factors that initiated the design project. What this means is that all resulting solutions have a higher possibility of 'being within range' of the technological contextual and functional determinates of a design project brief. Such an approach presents a considerable shift in design and theoretical thinking compared to traditional means of teaching design. Design pedagogy is 'sustained' because such a process maintains the essential indeterminacy in the process to avoid closing down possible solutions, but yet ensures that students and staff are always within range of the criteria set implicit within the context, project brief, site and fabrication/constructional capacities of the project.

4 Digital Processes and Pedagogical Sustainability

It is evident in the examples above that academia can play an important role in the development of new digital design processes within architecture. The collaborative engagement of research, practice and teaching provides fertile ground for both development and experimentation of emerging modes of architectural computation.

From an educational perspective the integration of computation into design methodology beyond a representational approach is often a difficult challenge to overcome (Chiu et al. 583). Part of a University's role is ensure that graduates have the capacity to engage with a professional environment, which inherently means the use of computation, governed by a representational mode of practice, to assist in the communication and the visualisation of design, the production of drawings and three dimensional modelling either to aid perspectival viewing or immersive engagement.

Ultimately digital design education should provide students with a range of digital technologies and promote the use of these as a natural part of the design process (Duarte 430). But because the representational mode of computation forms the basis of much of professional practice, it is obvious that it has an important place within architectural education, as reflected in nearly all architectural schools globally. However, Chiu states that "future emphasis should be in ... the integration and implementation of the design *process* digitally" (35). Therefore it is

important to bestow a working knowledge and understanding of process-based digital methodologies will prepare students for a wider range of computational environments upon entering the profession. Often architectural schools treat emergent digital methodology as an 'extra' or specialist field where technology is considered as a skill rather than a process-based design tool. This disassociation inherently constricts digital design thinking and its relationship to process. It is therefore critical that pedagogical methods are developed and implemented that allow for digital toolsets that arrive in a large part from non-representational thinking to form part of design methodologies.

Particularly important in developing new digital methodologies is a healthy deference of traditional modes of design that inherently reduce the scope of experimentation because they allow well entrenched methodological and ontological assumptions to permeate the design process. On the other hand, digital methodologies that engage with a performance-orientated design processes, whereby the understanding of determinates and rule-sets arrives from an engagement with the process itself without predetermined ideas about the role of architecture, sets up an educational paradigm which we argue as sustainable. No longer is the process closed by the conventional idea of equilibrium, where the feedback loop in design follows a path organised by known ideas, assumptions and anticipations. The performance-oriented process we are describing here goes beyond a closed model of equilibrium, where agential control in the design process is not directed toward the most appropriate or desirable solution, but rather to particular determinates and rule-sets. The learning outcomes of design studios move away from the generation of the most appropriate solution, to the most productive determinates that allow the process to keep producing consistent outcomes; that is, a sustainable design process. Equilibrium is never static, but constantly in flux. But this idea of flux does not mean formless fragmentation; rather is what Felix Guattari would see as possessing a consistency that is indissociable from heterogeneity (Guattari and Genosko 9). What shape would such an experimental digital architecture take?



Figure 3. Cardboard CNC fabricated prototype of student work in the Digital Design Studio (Author)

5 The Eco-logics of Flow: Digital Design Studio, University of Tasmania

Digital Design Studio 7 (Year 1 Masters of Architecture) at the University of Tasmania aims to establish a computational design platform that frees students from conventional paradigms and precedents of design process. Establishing the physical notion of ‘flow’ as a means of performance orientated computation and evaluation, students were required to develop a form that affects flows and is affected by the flows. The conditions of flow are open, whereby students were asked to investigate the logic of flows – whether particle flow [dust, smoke, fire, people, ants, sand, etc.] or fluid dynamics [water, wind, sludge, colloids, etc]. The only initial restrictions placed upon the form were the overall size and that it had to be able to be fabricated on the school’s CNC 3-axis milling machine. No pre-established building function, site, etc. were provided, except that students were informed that the broader aim of the studio was an investigation into the modes of sustainable design.

Utilizing Rhinoceros 3D (hereafter Rhino3D), a non-uniform rational b-spline (NURBS) modelling package, students experimented within the set constraints. Rhino3D was chosen specifically for its ability to translate digital models into a medium suitable for fabrication. The resulting digital models were then transferred into the Cinema4D environment that enabled testing of the conditions flow around and through the object. A semi-automated feedback loop is established by modifying the form within Cinema4D to have an immediate impact on the effect of the flow, and then transfer the digital model back into Rhino3D where it could be tested for fabrication. This feedback loop enabled students to engage with a design process

cycle that allows for iterative experimentation, testing, analysis and simultaneous and immediate modification as a direct result of 'environmental' performance.

The second stage of the project required the development of a set of rule based performance criteria outlining how the building would respond to different circumstances. In essence the rule-sets should encapsulate the performance driven design intent of the first stage allowing the project to evolve from a pure form that is independent of context, into a responsive system that can alter itself once specified contextual consideration is introduced. Examples of rule-based conditions that were developed within the studio included environmental and contextual considerations, material performance and efficiencies, cost and full-scale construction ideologies. By describing a building form in terms of performance intent, rather than function, etc., further shifts the design process towards a non-linear approach, freeing the designer from conventional representational approaches.

It is only when the project reaches the third stage that traditional constraints are introduced. At this point, students were asked to select a site and function for the project. It was envisaged that the previously established rule sets would provide a basis for manifestation, organisation and structure within the final project and that criteria, such as environment and context, would be self-resolved within the inscribed set of performance conditions. Inevitably situations arose where the rule set was mismatched with the chosen site or function (or both). In these circumstances the established regulations were utilized in a more notional manner, providing a guide for manual adaptation of the design until a best fit was found.

In this design studio, we aimed to develop a pedagogical approach that did not merely provide students with technical computational competencies, but a performance-based methodology that allowed them to use digital computation to formulate highly specific and consistent parametric possibilities within given project boundaries. That is, this approach allowed architecture to be found from within sets of determinates with viable fields of design solutions. The relationships between form, function, material and structure are not immediately determined by conventions of representation, but emerge through feedback loops and iterative testing stages, leading to notion of sustainability in design pedagogy. The design process moves beyond achieving equilibrium between extant parameters, functional brief and architectural conventions played out within a computational design arena, to a wider definition of the architectural through new associations between possible forms, given contexts and relevant parameters, governed by a consistent but associative heterogeneity.

These projects are evoked here not for their striking range of new forms in animated evolution-ary sequences, but for their indeterminacy of affect and the impossibility of perceiving the whole. In this method, there is a substitution of technique for content, and topology of field relations for place centeredness; all of which work towards a feeling of potentiality whose intensity is not reliant upon knowing the limits of actualisation. The results of such digital processes widen the pedagogical approach to sustainable design that has conventionally emphasised the specificity of place, the appropriate technologies relating to

environmental reality, and the presence of the individuated perceiving-thinking human designer.

6 Conclusion

Many recent developments in experimental digital design that demonstrate non-linear and highly complex relations between topological transformations, material change, and the temporal dimension of forces still rely on an assumption of an infinite flux of determinates and solutions in equilibrium. We argue that for a pedagogy of sustainable design, *and* sustainable pedagogy in design, we need to move from abstract and methodological knowledge of problem-based teaching and learning, towards thinking that is immanent to an engagement with material presences, but without full concretization. In this way, the performance-orientated process widens the definition of sustainability itself, because it arrives from a process that increases the potential of designers in new and unanticipated ways, while critically working within current environmental knowledge, site constraints, and technological capabilities. Such a bottom-up process moves *beyond equilibrium*, towards a radically continuous but consistent production, which is in effect, an expression of a collaborative and sustainable pedagogy. This evokes an ethics of sustainability that arrives 'practically' through the unfolding aesthetic practices of a sustainable digital architecture pedagogy that is in itself sustainable.

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