Tuning Heavy Design

Parametric structural form generation

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Abstract. *This paper discusses a methodology for generating architectural form parametrically from structural logics such that an architectural vocabulary can be generated for use in design. It intends to further the discussion of how parametrics can play a role in architectural design. Parametric applications are facilitating the use of engineering design feedback into the architectural process, allowing architects to 'tune' their designs. In this case, structural form is discussed. The nature of parametrics makes the use of structural principles relatively simple because they are already in the numeric form of equations. As well, parametrics make the generation of alternatives easy because of the iterative nature of the tool. As such, including the basis of structural principles in the logic of the parametrics allows the design to function performatively in both an architectural and a structural sense.*
Keywords. *Parametric; form finding; structural analysis; algorithmic.*

PARAMETRIC DILEMMAS AND EXPANSIONS

Those involved with engaging parametrics in architecture understand the power of the increasingly broad but also increasingly technical realm and many academics and practitioners are attempting to bring parametrics into design culture in a highly performative way (Oxman and Oxman, 2010, Weinstock 2006). Firms such as ALA and Arata Isozaki and engineers such as AKT and ARUP as well as academics such as the Oxmans, the AA in London and others have made inroads, incorporating complex logics about material, space and forces into their generative parametric models. Potentials exist in both computation of complex demand systems such as environmental conditions with such feedback as wind and air flow analysis, the programmatic analysis of contested territories with such feedback as agent based spatial analysis, as well as the relatively simpler issue of structural form and material variations (Oxman, 2010).

As computational power increases and interfaces to programming become simpler and more integrated with architectural drawing tools, we are seeing increasing use of parametrics. The easy access to the computational tools and the ability of the tools to interface with other programs allows cross disciplinary work to take place more easily. When highly technical analyses can take place within the process of architectural form generation, both the physical environment as well as the social and cultural environment benefit. When FEM of wind or structure is accessible to architects as they design, they have the ability to tune their designs live. No longer is there a technical barrier to architects and they can easily use the engineering models to tune their designs and even to question conventions currently used. We can currently see this happening in many areas in architectural software – Revit and other larger established software companies are integrating engineering analysis and on a more grassroots level, independently designed Grasshopper programs such as Millipede, Topostruct, Kangaroo and Galapagos are all taking on engineering design issues in an architectural forum [1].

The breakdown of disciplinary boundaries to architects and the ability to acquire technical knowledge about their designs through use of parametric software is perhaps where the most critical change in architectural design will manifest. The power of this knowledge is invaluable to an architect and whereas other professionals may have access to architectural software and be on an equal footing in 'drawing' with the architect, the architect has the design training to integrate the technology with societal and cultural considerations, defining forms and making space in a way that the training of other disciplines cannot replicate with an analysis program.

The resulting integration will allow architects to 'tune' their designs to the performative criteria of their choosing. The visual demonstration of forces that results from this integration provides clear information which the architect can take as design fodder [Figure 1].

HEAVY DESIGN

Where we can perhaps see the future as I have described it, that time has not quite yet come. 'Heavy design' is a process which tries to produce such a process – it attempts to integrate gravity through structural logics within an algorithmic form generating environment in architectural modeling. The outcome of the process is intended to be a vocabulary of structure used to create space. In addition to trying to employ the power of finite element analysis software for conceptual architectural design, the heavy design process also attempts to use structural logics within the process of design itself and then tests the logics, iterating the process to produce a design which performs both architecturally and structurally. So while any design may be tested

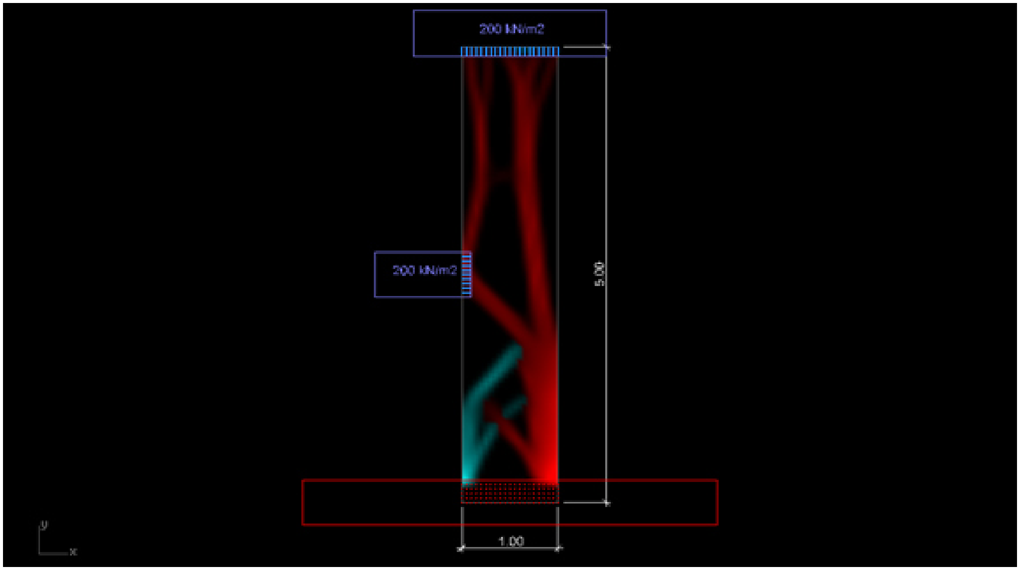


Figure 1
Principal stresses in an eccentricallty loaded column structure – output from Grasshopper Millipede.

for structural soundness or better or worse performance, a design based on structural laws should perform structurally and should be able to be parametrically 'tuned' to minimize materials and equalize stresses.

The process as it is uses Grasshopper or Matlab as the parametric tool embedded with programming which includes structural principles and from there the form is exported and imported into CSI SAP 2000. This conventional structural engineering analysis tool provides detailed numerical feedback on stresses and informs the tuning of the grasshopper file. This can be easily done by moving the sliders in the original model and checking the resulting performance in SAP. While this feedback loop is currently completed manually, future research will try and integrate this process.

To illustrate more clearly, the concept takes natural laws and mines their structural principles and equations for concepts with which to work. For a column, we look to the equation that governs buckling:

$$P_{cr} = \frac{\pi^2 EI}{L^2} \qquad (1)$$

where P_{cr} is the critical loading for the column, E is the modulus of elasticity, I is the moment of inertia of the cross section of the column and L is the effective length of the column**.** Any of these variables can be modified but the algorithm which is designed should play with one that has architectural significance and can play a physical role in design: in this case effective length is the most effective. Playing with this equation has resulted in a wall which genetically rearranges its elements to try and limit the effective length of the structure while disintegrating the wall into smaller less dense elements which dissolve the wall into a visual field [Figure 2] (Meyboom, 2011).

Another example looks at the bending behaviour in a frame, for which the distribution of moments can be seen in [Figure 3]. This diagram gives us the shape of the material distribution and the tuning of the structure allows us to play with material distribution. Through analysis of the equations for the applied and resisted moments, we can see a direct relationship between span and depth of the resisting elements and can modify our algorithms as such.

TUNING CRITERIA

The criteria for structural performance are measurable and defined: they are based on a quantitative engineering analysis which results in a numerical stress which can then be compared to a material's stress capacity. The optimal result uses the least material to carry the load required. Orientation of the structure, either externally or internally can be modified and optimized as well. To use the minimum material, one applies the 'axiom of uniform stress' which states that to have an optimized structure, the stresses must equalize within it to use material more efficiently. If you have a non-uniform stress on a structure with a constant material and section, then either the structure uses too much material overall with the correct amount at the point of maximum

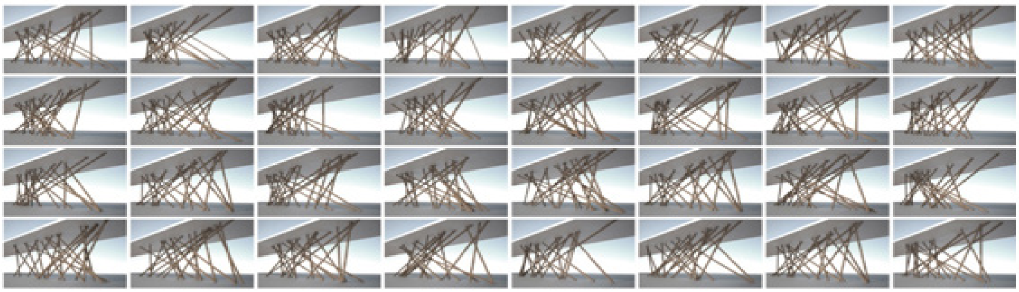


Figure 2
Algorithmically generated genetic variations on Heavy Wall.

material or the structure is overstressed at some point (Mattheck 2005).

While evaluating the structural performance based on its structural behaviour requires some is basically quantifiable, many other design quality issues are architectural decisions which are less straightforward and considerable judgement is required. The advantage of parametrics in the process is that the design can be altered in the parametric software 'live' and multiple options can be seen by the architect with minimal effort – in fact, with a hand movement. Issues such as entrances, relationships to site and scale of the body in relation to the structural elements are still very much up to the judgement of the architect – at times these decisions are embedded into the programming and at times they are independent of the coding. Part of the process of parametric design is understanding what assumptions are embedded in the coding – what design is coding and what design is decision making outside of coding. It is, of course, possible to code everything in a building but the time required to program the consideration of an entrance location, for example, may not be sensible. This judgement can be thought of as part of the parametric design process just as choices of materiality are part of the design process.

The other factor to be noted in the parametrics of 'heavy design' is that often there are multiple factors to adjust in a structure because there is more than one variable in an equation. If a designer is unhappy with the outcome of the modification of one of the variables, another of the variables can be chosen to play with. If, however, too many variables become incorporated, then it is difficult to assess the performance as too many elements are varying and the structural behaviour will be more difficult to tune [Figure 4 to 6]. To begin, as the structure is tuned, it is helpful if all variables except one are held still and the design tuned variable by variable. Other methods of tuning the structure with a multiple of variables are available but likely unnecessary for this type of exercise. The decisions on architectural matters can then inform which variables are constant and which change – again giving maximum design freedom. In general, the methodology is intended to produce options and not limitations for the architect and the methodology used to evaluate the options (the vocabulary of structures now available) is still up to the architect.

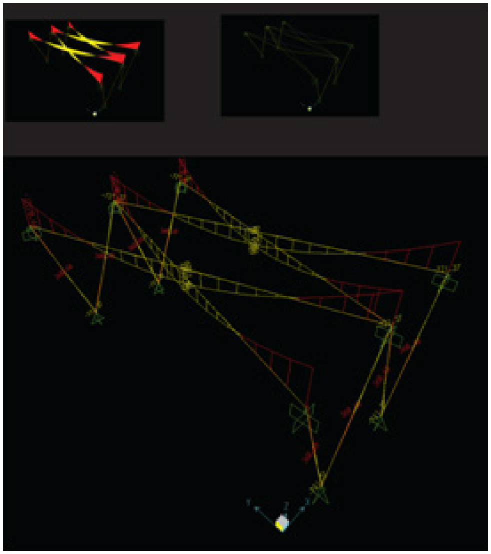


Figure 3
Frame analysis for tuning.

PRODUCING VOCABULARIES

Typical parametric processes either optimize outcomes based on parameters (multiple is more interesting) or generate multiple results and then select from these results. In both cases sometimes unforeseen results occur which can lead to interesting design outcomes but the programming is still deterministic in some form. This raises the question of how to incorporate parametrics into design. Perhaps one of the strongest attributes of a parametric process, however, is not to come to a singular answer or generate an unlimited amount of options, but to develop a vocabulary: a series of variations, each related to the next but with varying characteristics which can be employed for architectural spatial intent. Within this produced vocabulary, variation can

Figure 4
Sliders showing a multiple number of variables relating to structural equation (project work by Nic Robitaille).

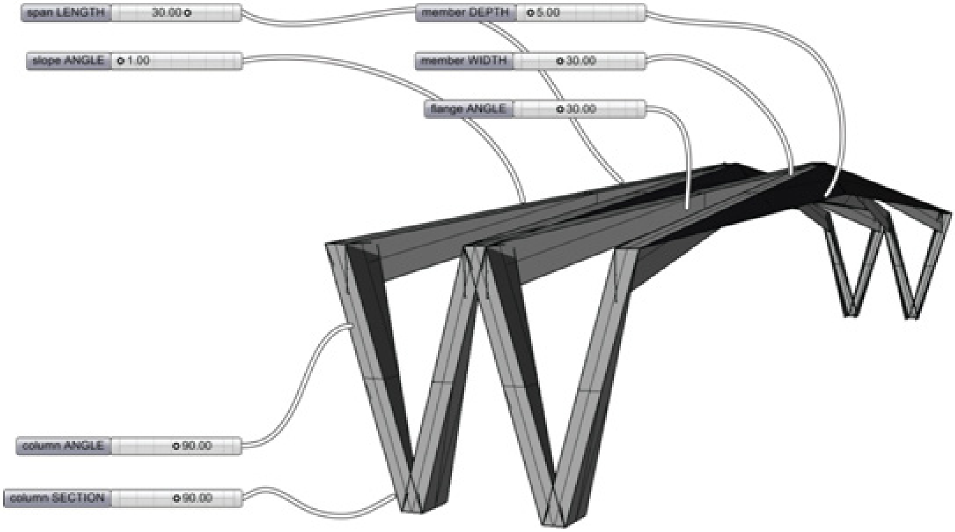
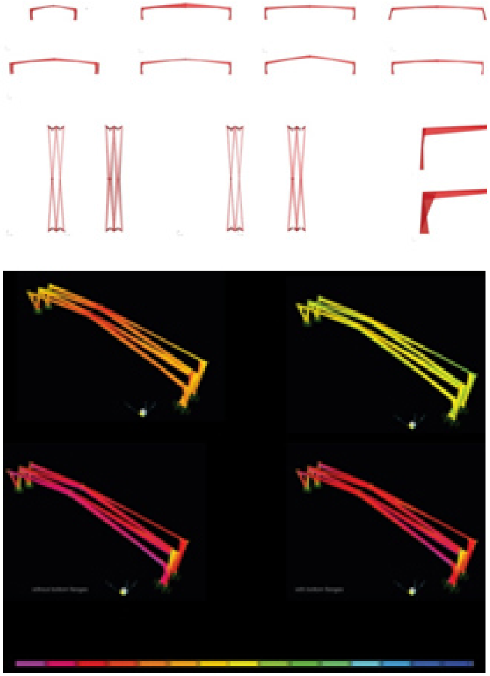


Figure 5 & 6
Variations of a structure & Analysis of the variations (project work by Nic Robitaille).



be used to enhance design and the design can flex in multiple ways to respond to the changing conditions (Figure 7).

The production of a parametric vocabulary in architecture can be likened to a more historical understanding of architecture where a set of rules for proportion and a scale or system of structure and space is established and then played with according to spatial or qualitative requirements of the space. The contemporary version of this is the control of the programming and application of this in inventive ways to the spatial occupation.

CONCLUSIONS

Heavy design puts forward an approach which incorporates gravity into the architectural form generation process using parametrics in order to experiment with how we can best engage parametrics in the design process. This method seeks to have the architecture perform structurally as well as define space and participate thoroughly in the architectural discourse. The discourse takes place in the architectural software with input from the structural

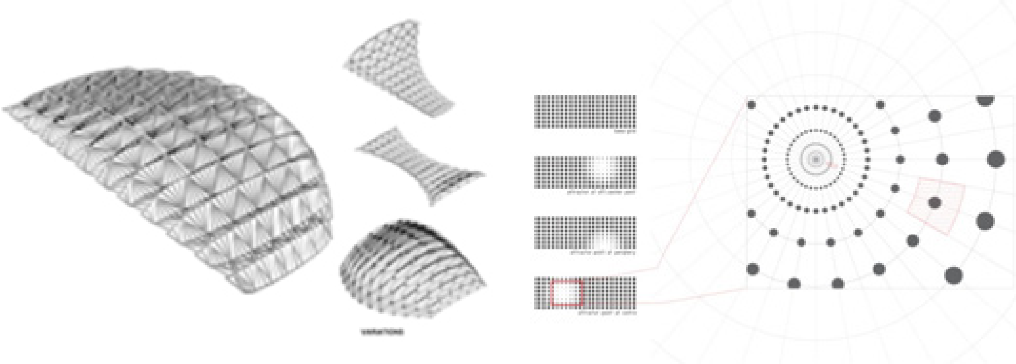


Figure 7
Variations on a design based on bending moment in a beam and on a column spacing design based on shear in a slab (project work by Cristian Schmitt and Sinduha Mahadevan).

iterations for analysis and iterative feedback, helping to tune the architectural design as well as the structural performance.

Future work in this area is taking place by applying this methodology to program and site as well as attempting to automate the iterative feedback between analysis and parametric realm. Other areas of similar investigation include soft kill analysis of structural elements and applying this method to find architectural vocabularies by use of Millipede and Topostruct.

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