Engaging Generative BIM Workflows

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Summary
Generative tools such as Grasshopper3d are being utilized to explore architectural projects and influence design decisions with increasing popularity. Rapidly produced multitudes of options will not be utilized to full potential if entire design team assessments take days or weeks to fulfil. Maintaining and coordinating external documentation models is redundant and consuming work. To maximise the potential of these tools, teams must efficiently assess multiple objectives and criteria, to seek optimal solutions. Utilizing the generative information model as input to analysis and simulation tools (including structure, services, environmental, construction programming and cost assessments) can facilitate superior design decisions.

Keywords: Modelling, Generative, Parametric, BIM, Interoperability.

1. Introduction

This paper outlines software developments enhancing Grasshopper3d as a generative design tool for the architecture and construction industry. Third party customization enables designers to assign attributes of project elements that can be exported in an information model for wider design consideration. Present industry practise typically utilizing multiple models independently require consuming efforts in maintenance, updating and coordination. Duplicated, abortive and redundant design efforts are rife.

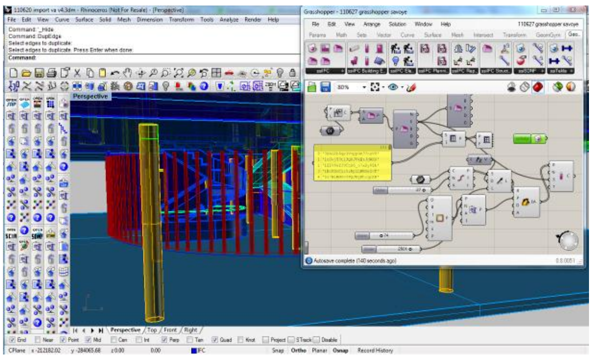

Fig. 1: IFC Model Manipulated generatively in Grasshopper3d

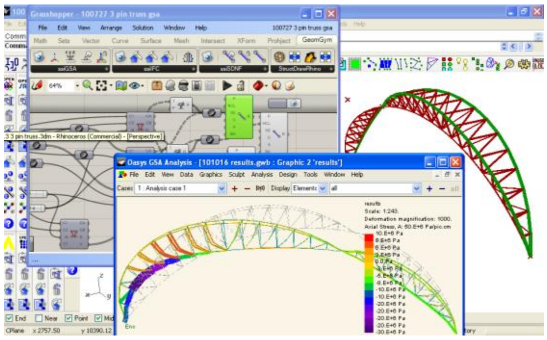

Fig. 2: Structural Analysis extraction from Grasshopper3d

Enhanced generative modelling also enables efficient procedures for commencement of detailed design and documentation. Prevalent BIM software can import and export data using neutral standards such as Industry Foundation Classes (IFC). Designers can then utilize model data freely in the most apt software available, permitting more effective problem formulation and assessment, in lieu of present time consuming model generation and management. Interoperability of model data also enables powerful partnership of analytical software with multi-objective solvers such as the Galapagos solver within Grasshopper3d.

2. Opportunities for improving design development

Traditional concept and detailed design work flows have typically seen architects and the various design consultants generating and maintaining independent models of their design projects. An iterative process of assessing and evaluating the current design proposal, proposition of alternatives for improvements, and coordination meetings to resolve conflicting aspects and determine the basis for the next loop of this process.

Coordination of independent models and documentation is a particularly difficult and time consuming process, and is an obvious candidate for improving design efficiency. Recent developments in computer hardware, and BIM software are enabling model utilization across multiple disciplines that can reduce/eliminate problems at earlier phases of development (where they can be resolved with less implication) and produce higher quality solutions.

There is scope for substantial improvements for this process in the earliest phases of design, when identifying the strongest concepts can have the greatest impact on the final product and the least constraint is experienced to change.

Generative design tools have existed for years, but popularity amongst designers and students has been encouraged by recent improvements to the user interface and the flexibility of operation. These permit consideration and assessment of many alternatives in quick succession. To maximize the benefits offered by generative modelling, present manual coordination of independent models should be minimized.

3. Software interoperability and collaboration

Interoperability of software has emerged with substantial improvements in recent years, permitting some exciting developments to aid and assist designers in considering alternatives and identifying advantageous design decisions.

A prominent example of this is the software developments by Robert McNeel and Associates (RMA), focused around their nurbs CAD software Rhino3d [1]. On top of manual modelling tools, Rhino3d offers a multitude of options for users to operate their software from basic scripting to Application Programming Interface and plug-ins. openNurbs [2] is also a RMA initiative to enable and encourage interoperability of geometric models.

Grasshopper3d [3] is a generative design tool that operates as a Rhino3d plug-in. It is a very popular choice amongst designers primarily due to the user interface as the alternatives typically require significant technical or programming experience to use as effectively and efficiently.

The accessibility and functionality provided by RMA to independent developers has encouraged and fostered numerous third party plug-ins, for both Rhino3d and Grasshopper3d. This paper will introduce a small number of these tools, particularly those for architecture.

Geometry Gym Limited [4], formed by the author of this paper, is one of these third party developers, concentrating on specialist sub consultancy and provision of software tools for designers. Geometry Gym has primarily developed 3rd party plug-ins for Rhino3d and Grasshopper3d for the architecture market but not exclusively so.

This paper focuses on developments based and derived on Rhino3d/Grasshopper3d, primarily responding to the experience and expertise of the paper author. Similar and equivalent developments are available using alternative software platforms.

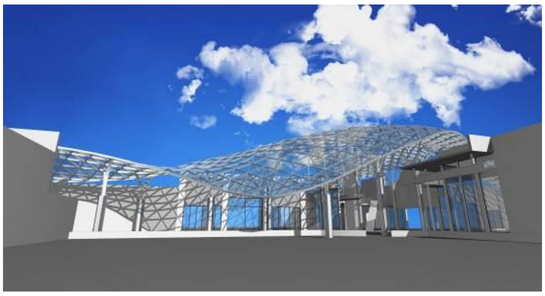

Fig. 3: Grasshopper generative model of Ballito Lifestyle Mall canopy imported into Archicad via Geometry Gym IFC translator

4. Building Information Model generation in early phases of design

4.1 Freeform Shape Representations and BIM Interoperability

Rhino3d and Grasshopper3d can offer a number of advantages for project design including generative model creation and nurbs shape representations that are easily produced/manipulated and capable of representing advanced forms. However this software is not focused on architectural industry, or any industry in particular. There are many tasks and reasons why designers would need to utilize the model data in external software.

Geometry Gym has released third party software tools to enable assignment of attributes relevant to BIM data, and enable exchange of these models primarily using neutral BIM standards such as IFC2x3, CIS/2 and Steel Detailing Neutral Format (SDNF) (Fig. 4). IFC2x4 (imminent release) incorporates nurbs geometry representations and will allow more accurate model representation of the freeform architecture commonly modelled in Rhino. Presently many shapes and forms require approximated representation such as facet boundary representations. IFC certification for coordination viewing only requires a small subset of the shape representations incorporated into the standard, also reducing the effectiveness of this neutral format.

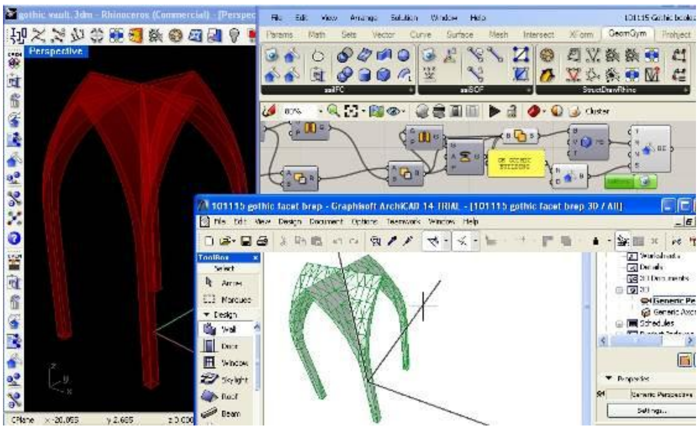

Fig. 4: Grasshopper generative model of Gothic arch imported into Archicad via Geometry Gym IFC translator

4.2 Measurements and Quantities

Recent developments have included tools to assist designers with assigning BIM attributes to generative models and measure performance including costing and functionality. (Fig. 5) The tools allow the user to prescribe the information for exchanging to other BIM software by using property sets and similar. This can include performance characteristics including cost, floor usage, egress, and project quantities.

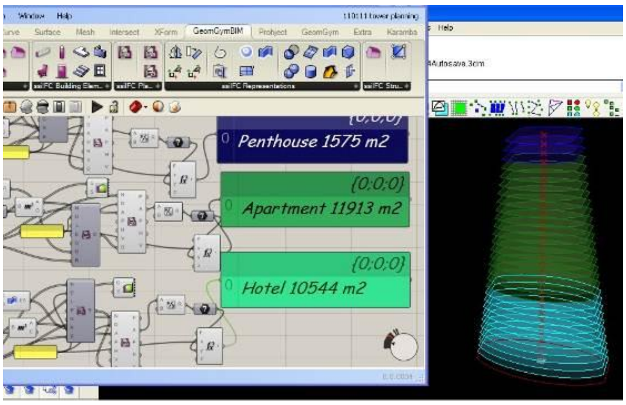

Fig. 5: Generation of IFC property sets utilizing Geometry Gym tools within Grasshopper model

4.3 Building Services and other building attributes

The IFC specification includes data spsecification for building objects and attributes for building services and MEP, and the Geometry Gym Grasshopper plugin is progressing means to generate and edit these attributes of this project.

4.4 Detailing and Fabrication

Fabrication models and generative detailing is a powerful opportunity to utilize these techniques and strategies where modular parts are not prominent, and the Geometry Gym developments are being used to automate these modelling procedures in a more cost effective manner (Fig. 6).

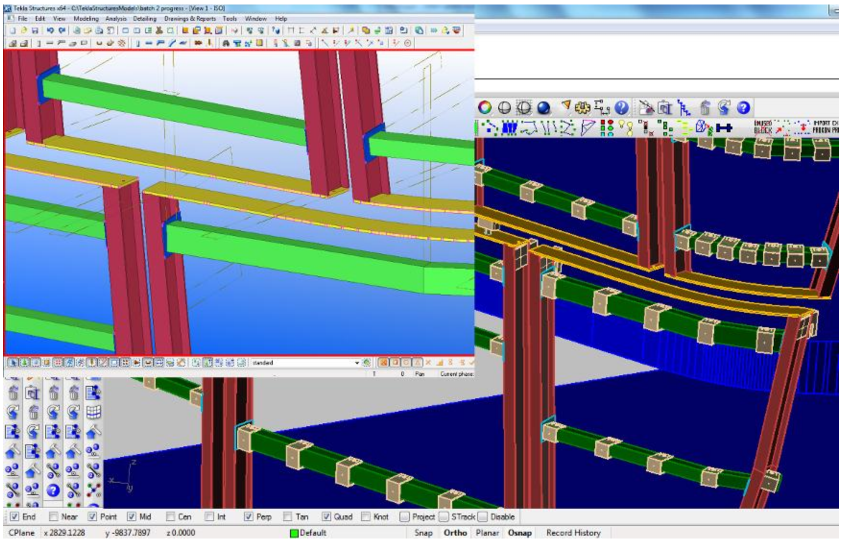

Fig. 6: Automated extraction from Rhino3d to Fabrication model in Tekla Structures for NC fabrication

4.5 Present and Future Development

Neutral BIM formats present a powerful opportunity to convey and exchange models with a multitude of software. However direct links and exchange of information permitss attributes that are not exactly prescribed by the neutral format, so direct links to external modeling software is under development.

Also under consideration are further tools and means to assess building performance, including measurements of sustainable and environment characteristics.

5. Generative Model Analyses and Simulation

5.1 Structural Analysis

Generative modelling for developing structural analysis models has been prevalent for years, primarily in the form of authoring spreadsheets. Geometrical description using imports such as DXF or DWG cad models has also been used extensively, although this process typically requires manual application of analysis attributes not supported such as constraints, materials and loads.

Evaluations of performance relating to alternate design scenarios is accelerated by producing automatically the structural analysis attributes as related to the generative model as shown for a finite element assessment (Fig. 7).

A very successful example of this is the 2012 Olympic Games Velodrome, where comprehensive design loop evaluations were considered, incorporating performance objectives including appearance, cost, services and structure with very successful outcomes.

Direct interaction with commercial structural analysis software including Oasys GSA, Robot, SAP2000, Sofistik, Space Gass and Strand7 has been progressed in a combination of text based file formats and API (Application Programming Interface) interaction.

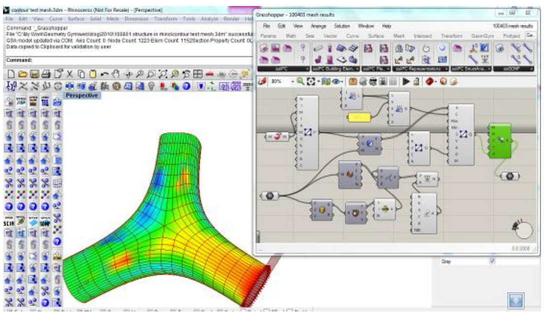

Fig. 7: Geometry Gym generation of structural analysis model data and representation of results

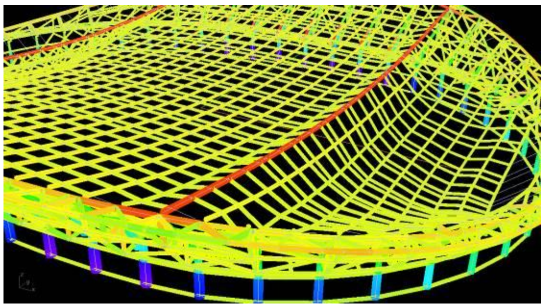

Fig. 8: Structural Analysis results of the 2012 Velodrome cable net roof in erection scenario.

5.2 Form Finding

Model exchange with commercial solvers capable of form finding against geometric constraints, pre-stress, orthotropic materials and imposed loading conducted with greater productivity by ease of model preparation in Grasshopper. Fig. 9 shows a membrane with imposed internal edge locations, a minimal surface is produced in this case as no external loads have been applied.

The technique applies to varied structures, a simple tensegrity arrangement is demonstrated as a generative model in Fig. 10.

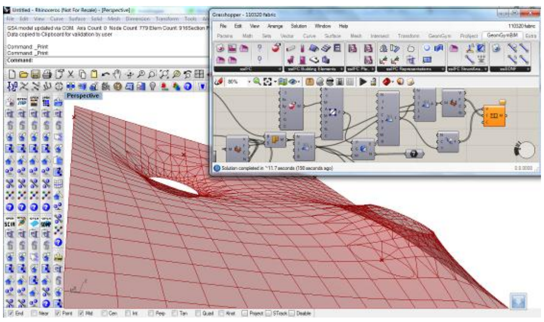

Fig. 9: Generation of membrane form finding model solved using Oasys GSA GsRelax.

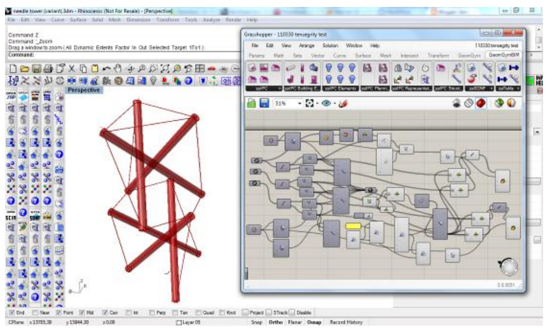

Fig. 10: Generative model form finding for tensegrity arrangement

5.3 Building Energy Analysis and Environmental Impact

Geco [5] is a Grasshopper plug-in developed by [UTO] enabling extraction of generative model data to Autodesk Ecotect and Radiance. These tools offer a range of simulation and building energy analysis functions used to improve building performance, including whole building energy analysis, thermal performance, solar radiation, day-lighting, shadows and reflection (Fig.11).

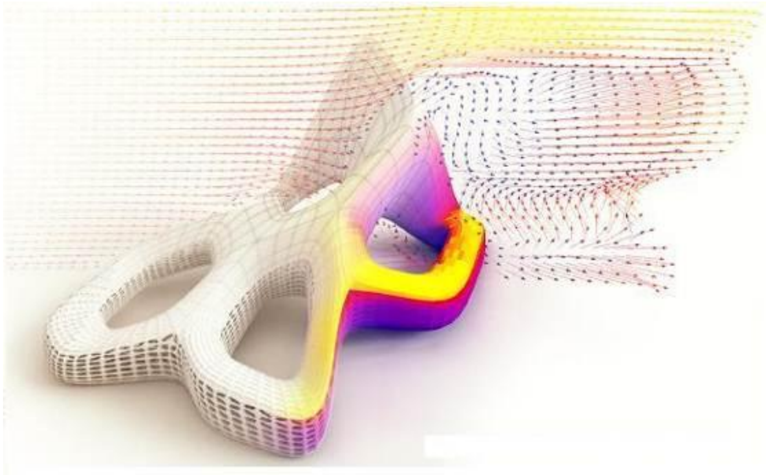

Fig. 11: Geco generated model for building energy simulation and assessment.

5.4 Physics Simulation

Kangaroo [6] is grasshopper plug in containing a live physics engine developed by Daniel Piker. Capable of simulating particle system physics relationships including form finding, dynamics and collisions capable of real time manual interaction (Fig. 12). Under research is means to enable rapid response for materials representative of real world use, presently very elastic stiffness is required for real time response.

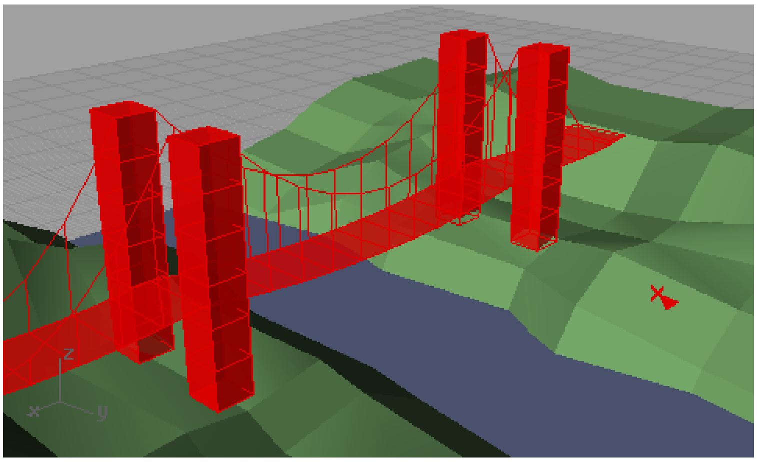

Fig. 12: Depiction of Kangaroo model simulating a bridge experiencing time varying force experienced as per Tacoma Narrows oscillation.

6. Genetic Algorithms and Multiple Objective Optimization

6.1 Evolutionary Computation

Optimizing of multiple design objectives has typically been conducted manually, drawing on designer's experience and intuition. The first solver publically released within Grasshopper is Galapagos [7] which implements a genetic algorithm for goal seeking and multiple objective optimisation. Similar tools used to date have been "By programmers for programmers", highly technically based and typically very problem specific.

Galapagos, in combination with Grasshopper allows a much easier generic problem/objective specification and solver to operate (Fig. 13). Multiple numeric range sliders are generated in permutations to define genomes. A single fitness objective is defined by the user that may weight importance of multiple measurement characteristics (including penalties for undesirable traits).

The figure presents a simplistic example truss optimisation, Galapos has access to three sliders that control number of segments and member sizes. The fitness function is to simply minimize deflection for an internal point load. In reality the fitness may incorporate many other assessments including weight, number of connections etc and the inputs could be extended to profile candidate table selection and further.

The potential application for this solution technique is very exciting, although users must carefully select the appropriate problems to solve and efficiently define the problem. It is hoped other solvers may be enabled that will suit specific problems more adequately than a genetic algorithm.

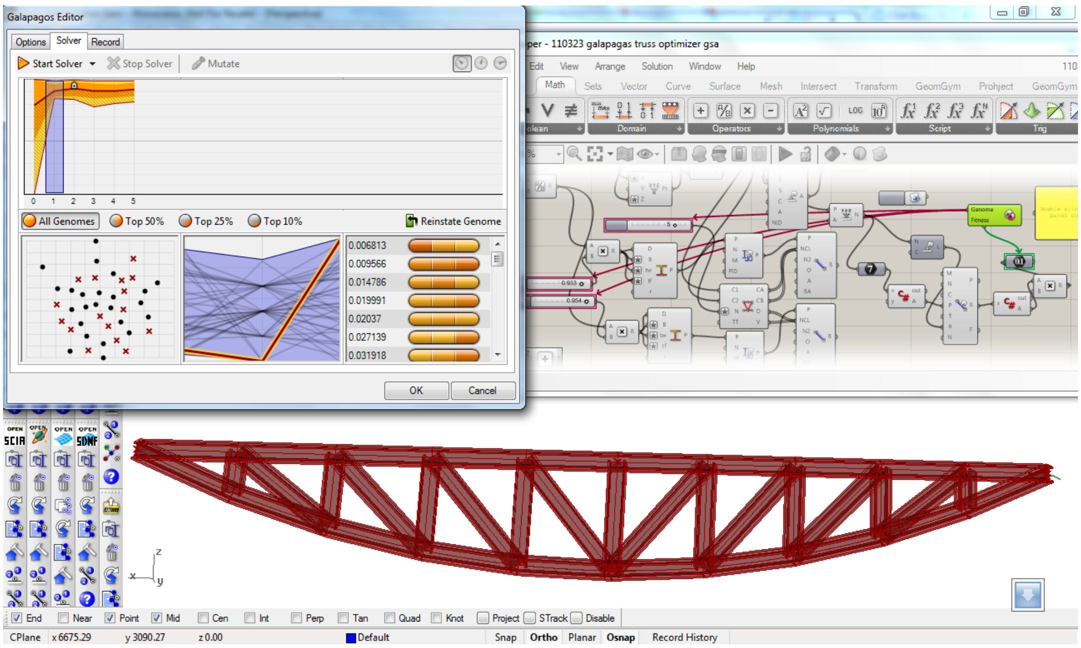

Fig. 13: Evolutionary Computing in progress using Galapagos, demonstrating Grasshopper problem/objective specification and solution progress for truss optimization.

7. Conclusion

The emergence and rapid development of generative tools to aid architectural design development including analysis and simulation is benefiting many inspiring projects and proposals. Emergence of many new projects and tools are imminent, and the common belief that this is just the beginning makes for exciting times in architecture design.

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