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WHITE PAPER

Generative Design

Evolution to Revolution

Generative Design

Generative design is nothing new, our natural world has been using these processes of evolution for millions of years to optimise and perfect life on earth. Let us take the development of trees as a prime example of generative design. Trees are, of course, a very common sight in most habitats, but have you ever stopped to think about why a tree looks the way it does? For example, trees in forests need to grow higher than their neighbours to gain access to important sunlight for photosynthesis, but this means they need larger, deeper root systems to support their enormous weight. Trunks and branches have developed as structural and vascular systems to support the trees weight and provide nourishment. Natural forces such as wind, rain and snow acting on the trees leaves also need to be resisted by the tree's structural system. Trees in deserts have learnt to emulate the design of cacti having sharp spines as leaves to minimise water loss and bulbus trunks to store and conserve water in time of drought.

All these factors lead to an incredible diversity of species which have evolved to different climatic and geographic locations on our planet. Nature has, over millions of years, generated the perfect solutions to these challenges. We can, and absolutely should, learn from nature and use these processes to lead us to better, more sustainable designs.

However, generative design does not need to take millions of years to happen. We can now harness the power of cloud-based computing and complex algorithms to test hundreds of designs against our desired inputs and outputs to generate, optimise and refine design ideas.

As designers, we only have a finite amount of resource available to allow optioneering for alternative design studies. This may lead to a better design solution being overseen due to time and financial constraints. This is particularly relevant in the construction industry. Often a construction project is a one off, a totally unique design that will likely never be repeated. The short period from the initial design to final completion does not allow time for optioneering and design alternatives to be fully explored. However, a mass-produced component may have a production run of millions of cycles and, due to economics of production numbers, have a much longer design time allocated to refine and optimise its design.

Defining Design Goals

Regardless of industry, all generative designs start with a well-defined set of design goals. We must first be able to define and describe what is a good, average or bad outcome for a design. For example, a residential tower block may need to fit on a specific plot of land, not exceed a certain height, and make maximum use of floor space for residential use whilst using minimal materials and remaining structurally safe. Using these set of inputs, a generative process can be put into place to produce a series of solutions that meet design criteria.

Typically, components for the aviation industry need to be strong, lightweight, inherently safe and able to resist the extreme temperatures found at high altitudes. Traditionally, the components may have required the use of expensive, exotic materials such as titanium, but with modern generative design techniques a bespoke component can be engineered to perfectly perform its task. This can be partially accomplished with modern manufacturing processes which change our preconceptions of how components should be designed. For example, if a part is traditionally machined from a solid billet of material then the limitations of the machine tool restrict the form of the finished component. However, if the part is to be manufactured using additive processes then the form and shape of the part is unlimited.

Generative Design in Architecture, Engineering and Construction (AEC)

Generative design in the AEC sector is a developing technology for solving complex design tasks ranging from floor layouts and site optimisation, conceptual massing through to facade engineering, and individual component design. The uses for generative design in the AEC sector are endless, many new techniques and workflows are being innovated daily to solve complex problems. As mentioned in the introduction, the key to successful generative design is in the definition of inputs, outputs and measurements of good and bad design outcomes.

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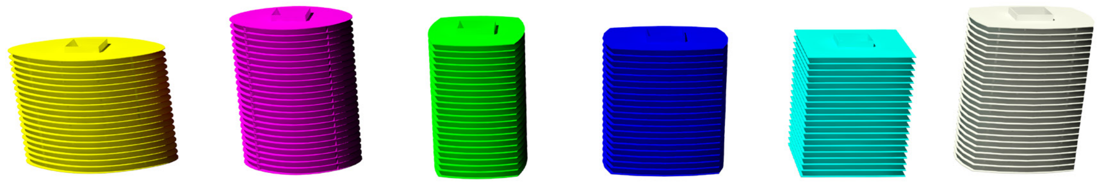
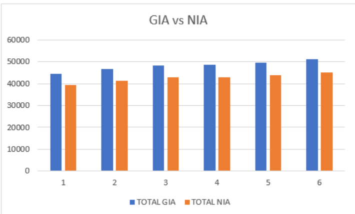
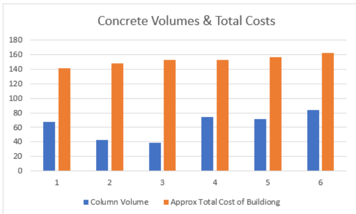
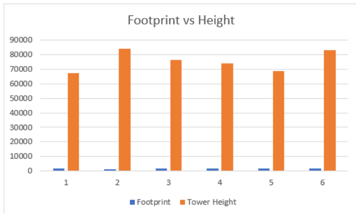
Autodesk's Project Refinery is the emerging technology that is facilitating the optimisation and iteration through different designs via Dynamo. Refinery is currently in Beta but already proving very useful in the architecture, engineering and construction sector. The software uses algorithms to select the best designs based on multiple iterations though design inputs. In the below example a massing and building structure model has been setup in Dynamo, and Refinery is utilised to select the best design based on minimum material usage, minimum site footprint, economical structural systems and maximum Net Internal Area.

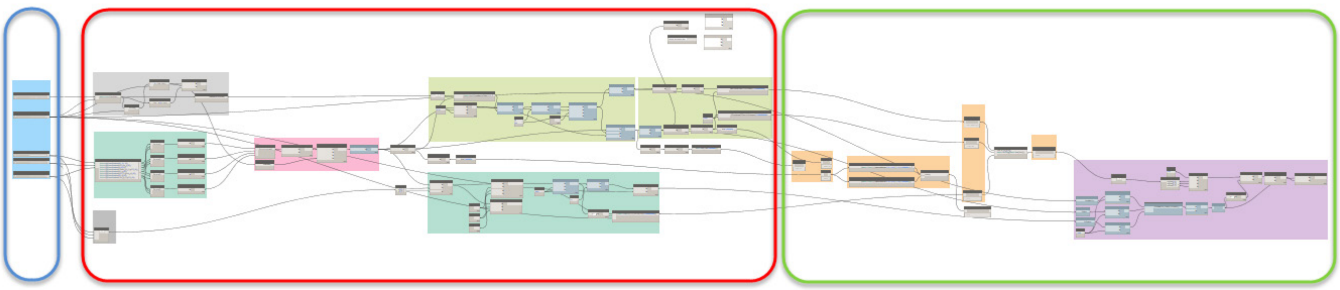








The most important aspect of the process is the design logic which is configured with Dynamo. Dynamo is a visual programming tool that can be used to create geometry or data in a variety of Autodesk applications and interface with other software. In the example below, the inputs are defined in the blue area, the geometry computations are calculated in the red area and finally, the data and outputs are shown in the green area.



The Dynamo program is generating a structural layout, estimating the core size and then costs based on geometry and material costs. These outputs are then used by Refinery to find the optimal solution.

In the image below you can see a screen capture of Refinery working on the optimisation of the tower's structural layout. The scatterplot in the top right-hand corner plots the approximate cost of the building in the Y axis vs the height of the tower in the X axis. The size of the plots is increasing as the expense of the structure increases.

The various models are shown below, each colour coded to reflect the cost of the structure based on metrics such as material volumes, height of structure and the core size. The user can then sort and select the best matching design from either the scatterplot or the previews. Dynamo then creates this version and the model is then created within Autodesk Revit.

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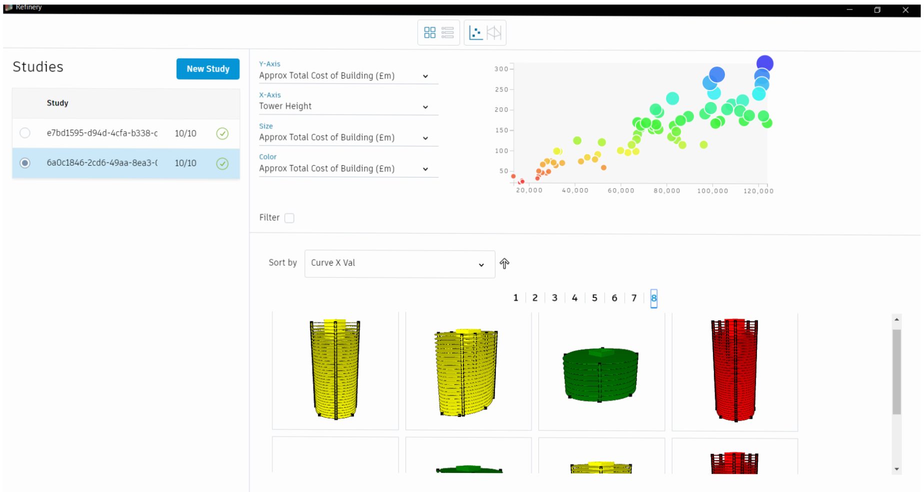
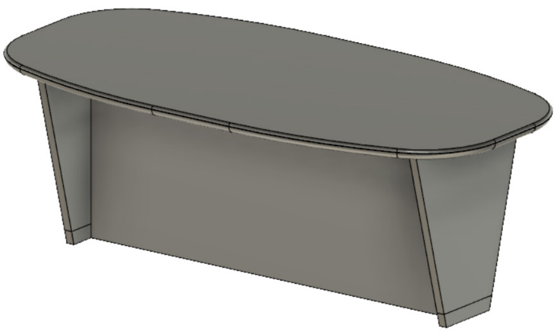
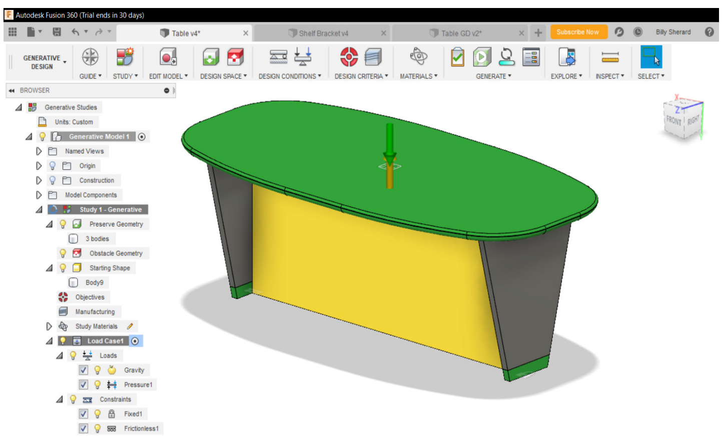


Generative Design in Manufacturing

The primary use for generative design processes in manufacturing are for weight reduction, efficient use of materials and aesthetics. In the example described below I am using Autodesk Fusion 360. The process starts by defining loads and boundary conditions on the component, these will be used to check the structural performance of the part and forms the basis of the algorithms to generate efficient shapes and forms. The next stage is to specify the geometry that you want to preserve. This geometry is typically areas that cannot change, for example, a mounting plate that needs a certain geometric shape or the feet of a table. The criteria for the optimisation is then set, this will typically be to minimise the mass or maximising the stiffness of a component whilst meeting a factor of safety that you specify. Multiple materials can also be selected for the study which will yield differing results.



In the image above I have modelled a basic table, leg and stiffening rib along the centre. The tabletop and feet are the features that I intend to preserve but the generative design has free reign to change any other aspect of the model. In the image below the green areas are the areas I would like to preserve, and the yellow area is the starting shape for the design.



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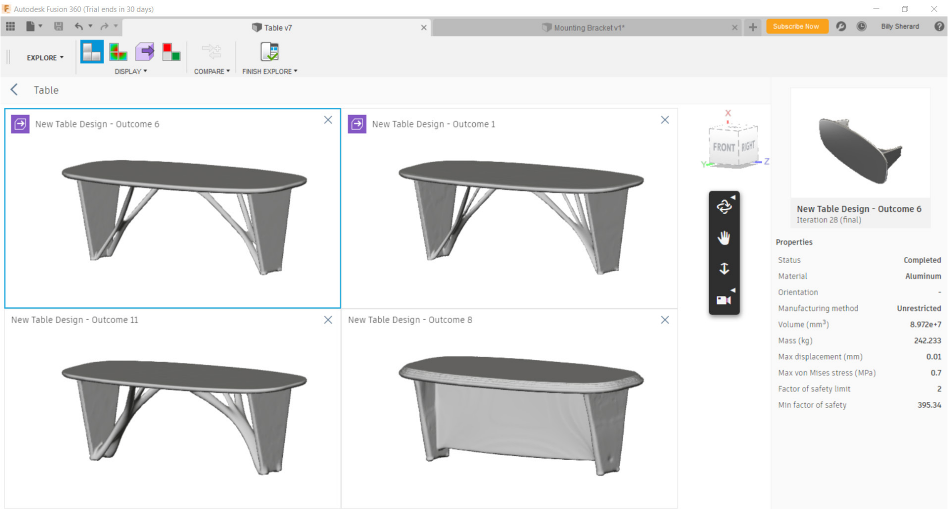
The generative design process is then started. Fusion 360 uses the power of cloud computing to produce hundreds of design alternatives and refine these into useable models that I can download and edit if required. The real power here is the automated approach, quantity of design iterations and speed and variety of designs. There are many different methods of viewing the design iterations in Fusion 360, the thumbnail view enables you to visualise all the differing designs with the possibility of filtering the models based on differing criteria. For example, you could filter by the desired manufacturing process, by weight or, perhaps by the factor of safety. All the design outcomes are presented along with a model view to facilitate the selection of your precise solution.



A few minutes later I selected and downloaded this model, produced automatically to perfectly satisfy my design criteria. The shape is aesthetically pleasing and meets the structural requirements of the table. In this example, additive manufacturing would not be used but this could be manufactured from many laminates creating a final composite.

The Human Touch

According to recent research, 46% of design companies are aware of generative design and out of these, 37% are using the processes. Many see the benefits of generative design in the early, conceptual design phase where many different and sometimes unexpected designs are required. It is worth noting that the user is still required to decide on the correct inputs, the correct design decisions and then which option best meets all these options. The generative process simply enables early versions to be created ‘cost’ free and give you the confidence that all possibilities have been explored and evaluated. Without these approaches, design costs can spiral which will naturally limit the amount of effort creating alternative designs.

In manufacturing and architecture, the final product must meet all the design goals whilst being aesthetically pleasing. This is commonly described as function follows form. Whilst algorithms can decide what is functional, they cannot judge what is beautiful. This is still a large part of any design consideration so, don’t worry, we are all still required!