Attractors in Architecture

Attractor-based optimization and design solutions for dynamical systems in architecture

2nd edition

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code of space
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#1 Introduction

“A violent order is disorder; and a great disorder is an order. These two things are one.”
Wallace Stevens, Connoisseur of Chaos, 1942

The evolution of something over time is the idea of a dynamical system. A dynamical system is simply a model describing the temporal evolution of a system. The model of growth of a bacteria population (Figure 1) or undamped pendulum that continues oscillating forever might be the examples of the dynamical systems.

Attractors are portions or subsets of the phase space of a dynamical system. We can easily imagine that one individual of the bacteria population (subset of the phase space) is more “attractive” and around it the population growth is higher than around the others. In case of the undamped pendulum, we can think of a huge ball like Earth underneath the oscillating pendulum, that by its gravity force changes the oscillation over time.

In terms of this handbook attractors are understood as simple geometric subsets of three-dimensional space, such as:
- a point
- a finite set of points
- a curve
- a surface (a manifold)

In order to create architectural dynamical system we firstly need to decide what is this “something” that will evolve over time (e.g. panels, openings, colour) and secondly describe the rules that specify how that “something” evolves over time (e.g. rotation, scaling, deforming). In the next sections you will find a few examples of dynamical systems in architecture followed by the architectural case study of the attractor-based static optimization.

![Figure 1. Dynamical system: the model of growth of a bacteria population.](source: http://mathinsight.org/dynamical_system_idea#statespace)
2.1 Movement

Architecture. Responsive / Interactive structures

There can be a large number of interpretations (applications) of the idea of movement in architecture. Movement can be used as a design approach for the form-making process. For example, by positioning (moving) the elements in 3D space depending on certain criteria, such as the proximity to the surrounding buildings, sun path, wind direction etc. In this case, the final design output can be static, whereas the 'movement of elements' approach can be an integral part of the form-making process. The other way to employ the idea of movement in architecture is to develop responsive / interactive structures. This concept is illustrated by the ‘HygroScope – Meteorosensitive Morphology’ (Centre Pompidou, Place Georges Pompidou, F-75004 Paris) project by Achim Menges Architekt et al. ‘The project explores a novel mode of responsive architecture based on the combination of material inherent behaviour and computational morphogenesis. The dimensional instability of wood in relation to moisture content is employed to construct a climate responsive architectural morphology.’ (http://www.achimmenges.net/?p=5083).

Figure 1. HygroScope – Meteorosensitive Morphology’ (Centre Pompidou) by Achim Menges Architekt
2.1 Movement of the elements in the system

*Exercise Objective:* To move elements along the ‘Z’ vector depending on their proximity to the attractor point.

The first step is to create a grid of hexagons (which serves as a base for the ‘dynamic system’) and by creating a point running along the curve - (which serves as an ‘attractor’). The second step is to measure the distance between the center of each polygon and the attractor point. These distance values are used to inform the values for the movement of polygons in space. In theory the elements of the system can be moved in any direction. In this particular exercise the polygons are being moved up, (along the ‘Z’ vector). To get a better control over the behaviour of the system, the distance values are being ‘remapped’ into a new numeric domain. This gives an opportunity to set the minimum and maximum movement values. For example to set the minimum movement as 0.1 mm (start of the domain) and the maximum movement value as 100 mm (end of the domain). ‘Remapping’ allows to easily reverse the effect of the attractor on the movement values. This can achieved by swapping the start of the domain to a larger number and the end of the domain to a smaller number.

![Diagram of the dynamic system](image)

Figure 2. Moving elements along the ‘Z’ vector
2.2 Extrusion

Architecture. Extrusion and deformation as a form-making strategy.

Attractors can influence various aspects of elements’ behaviour in the dynamic systems. Alongside with the movement of elements it can also inform the rotation, scaling, deformation or extrusion values. The application of the ‘extrusion’ idea can be illustrated using the ViscoPlasty project, designed by Alexandra Singer-Bieder, Sofia Bennani and Agathe Michel (the finalist of the international TEX-FAB Plasticity competition, ACADIA 2014, Los Angeles). Designers used small diameter straws and varied the length of the tubes. The ViscoPlasty prototype shows exactly what the fabrication process should be for an architectural scale installation. Using digital fabrication tool (CNC milling machine and lasercut), the mold is the base of the prototype and enable a perfect control of the assembling process by giving the shape the robot has to follow to melt the topographic surface.


Figure 3. ViscoPlasty project, by Alexandra Singer-Bieder, Sofia Bennani and Agathe Michel
2.2 Extrusion

Exercise Objective: To extrude elements along the ‘Z’ vector depending on their proximity to the attractor point.

This ‘Extrusion’ exercise uses the same hexagonal grid and the attractor point set-up as the previous ‘Movement’ exercise. To allow a better control of how the dynamic system responds to the attractor location the distance values are being manipulated by a numeric mapping function (‘Graph Mapper’). The use of this function provides an opportunity to establish a nonlinear relationship between the position of the attractor point and the extrusion value of each polygon.

![Diagram of extrusion process](image)

Figure 4. Extruding the polygons based on the proximity to the attractor point
2.3 Scaling

Architecture. Scaling of elements in the system.

An architectural example of the application of the ‘scaling’ design strategy is a facade of the De Young Museum in San Francisco, USA (by Herzog & de Meuron, Basel (Planning), Fong & Chan Architects (Implementation)). To structure the impressive façade, thousands of copper sheets were embossed and perforated with individual patterns so that the modern architecture would blend into the natural surroundings of the park landscape as much as possible <http://www.kme.com/en/deyoungmuseum>.

Figure 5. Facade of De Young Museum in San Francisco, USA
2.3 Changing size of the elements in the system

Exercise Objective: To scale elements depending on their proximity to the attractor point.

The ‘Scaling’ exercise uses the same grid and attractor set-up as the ’Movement’ exercise 2.1. The panels (hexagons) are scaled around their centers (starting point of scaling). The scaling domain is set between 0 and 1, to avoid the overlapping of scaled polygons.
To further illustrate the possibilities of the dynamic nonlinear response of the attractor based systems the sine (‘Sin’) function is applied to compute the sine of the distance values (see the bottom image of Figure 6).

Figure 6. Scaling elements based on their proximity to the attractor point
2.4 Rotation

Architecture. Rotation of elements in the system.

In architecture one the examples for the ‘Rotation’ form-making approach is the facade of the Eskenazi Hospital in Indianapolis, IN - Completed 2014, designed by Rob Ley. A field of 7,000 angled metal panels in conjunction with an articulated east/west colour strategy creates a dynamic façade system that offers observers a unique visual experience depending on their vantage point and the pace at which they are moving through the site. In this way, pedestrians and slow moving vehicles within close proximity to the hospital will experience a noticeable, dappled shift in colour and transparency as they move across the hospital grounds <http://rob-ley.com/May-September >.
2.4 Rotation of elements in a plane

*Exercise Objective:* To rotate elements depending on their proximity to the attractor point.

This exercise illustrates the rotation of elements ‘in a plane’ (Rotate objects in a plane). For example, rotating panels vertically in a ‘XZ’ plane or rotating panels horizontally in a ‘XY’ plane. Note that the default rotation units (angle ‘A’) in Grasshopper are Radians, but they can be easily switched to Degrees (right click on the ‘A’ input of the ‘Rotate’ component and choose Degrees).

Figure 8. Rotation of elements in a plane
2.5 Rotation 3D

Architecture. Rotation of elements in the system

The idea of interactive architectural structures is illustrated in the ‘hexi’ responsive wall project by thibaut sld. <http://www.thibautsld.com>. The hexagonal panels are situated on the surface of the interior space. The system uses the real-time data collected from motion-tracking technology to decode and interpret the gestures and actions of a person within close range (digital simulation).

Figure 9. Responsive ‘Hexi’ wall fluctuates based on nearby movements

Figure 10. Rotation of elements around the center and an axis vector
2.5 Rotation 3D

Exercise Objective: To rotate elements depending on their proximity to the attractor point (rotate around an axis).

In this exercise the panels are being rotated around the center point and an axis vector. The axis vector is determined by a line between a center of each polygon and the attractor point. The rotation value is determined by the proximity between the center of the polygons and the attractor point.
2.6 Condition / Reduction of elements

*Exercise Objective:* To randomly reduce the number of panels around the attractor point.

The ‘Dispatch’ component is used to split the list of elements in the system into two target lists (list ‘A’ and list ‘B’). The condition for the dispatch is the proximity to the attractor point. The dispatched panels in the list ‘A’ are then being randomly reduced.

![Diagram showing the dispatch and reduction process](image)

Figure 11. Condition based on the proximity. Random reduce of panels, which are close to the attractor.

![Diagram showing the colouring of elements based on proximity](image)

Figure 12. Colouring of the elements, based on the proximity to the attractor.
Exercise Objective: To colour the panels depending on how far they are from the attractor point.

The distance between the remaining elements and the attractor point is used to inform the colouring of the panels. A multiple colour gradient component ('Gradient') interprets the distance values as corresponding colours withing the chosen spectrum. To change the gradient type - right click on the Gradient component and choose the Presets option.
2.7 Grid Deformation 2D + Pattern Mapping

Exercise Objective: To deform a grid of points based on the proximity to a set of attractors.

This exercise uses a series of attractors located on a curve. The deformation of the original regular ‘Hexagonal grid’ is done by the elimination of the points in the grid (‘input stream 0’ in the ‘Pick and Choose’ component), based on their proximity to the attractors (Pattern of input indices) and by using the attractor points instead (‘input stream 1’). The deformed grid of points is then used to build curves running in both ‘U’ and ‘V’ directions (See Figure 13).
Exercise Objective: To map a 2D pattern onto a surface.

The ‘Map to Surface’ component is used to transfer a ‘Grid Deformation’ pattern (from the previous part of the 2.7 exercise) onto a curvilinear surface (Target surface) via control points. Note that the curves in the deformed grid pattern are grouped before being connected to the ‘Bounding Box’ component, which is used as a reference for the initial coordinate space.

Figure 14. Map a 2D pattern (curves) onto a surface
Exercise Objective: To deform a grid of points in 3D.

The ‘Grid Deformation 3D’ exercise uses attractor points to inform the move value and direction of the original points in the grid. The points in the grid are being pushed away from the attractors. The resulting deformed 3D grid of points is used to create a waffle structure.

Figure 15. 3D grid deformation (Grasshopper Definition)
Exercise Objective: To deform a grid of points in 3D. The 'Grid Deformation 3D' exercise uses attractor points to inform the move value and direction of the original points in the grid. The points in the grid are being pushed away from the attractors. The resulting deformed 3D grid of points is used to create a waffle structure.

Figure 15. 3D grid deformation (Grasshopper Definition)

Figure 16. 3D grid deformation (output model)
#3 Attractor-based design strategies in architecture

Several examples of the dynamic systems were presented in the previous section. In this part two attractor-based design approaches will be applied to the architectural design. The discussed case study is located in New Zealand in Wellington, on the top of the hill in the Roseneath district (Figure 3.1). The northern facade of the building is optimized to maximize the insolation in the interior and to have panels overlooking to the two viewpoints in the landscape.

![Image of New Zealand, Wellington City, and Oriental Bay & Roseneath](image)

**Figure 17.** Location of the case study in context.

![Image of architectural model](image)

**Figure 18.** The outcome from two mixed approaches.
3.1 Modelling landscape and urban layout

In order to create the context for the architectural application of the attractor-based strategies, the basic landscape and street layout were created. Landscape was modelled with usage of Image Sampler component and the black and white hypsometric map of the project site.

Divide Surface creates the flat surface based on the point-grid. The grid points are moved up with the vertical vectors, which length depend on the color-code of the hypsometric map. The specific color is remapped to the value between 0 and 190. 0 is the lower bound of Target domain (T) in Remap Numbers as it is the sea level and the 190 is the height of the highest pick - 190m above the sea level. The larger the U and V parameters are, the higher “the resolution” of the final landscape is.

Elk is a set of tools to generate map using open source data from the OpenStreepMap.org. The MinorRoads components generates the street layout, while GenericOSM with the plugged key “Building” retrieve feature points of the existing buildings. Elk can be also used to create the topographical surfaces utilizing the Shuttle Radar Topography Mission (SRTM). The resolution of the SRTM data over United States is 30m and only 90m over the rest of the world. Therefore, in this case study landscape was created with usage of accurate hypsometric map.

Figure 19. Projected layout of the streets and the buildings outlines.
3.2 Modelling the general shape

The main geometry is modelled via simple Loft operation. Two curves are moved up and the third bottom one is projected to the landscape. Afterwards there are divided with DivideCurve. Points at divisions are the input for Interpolate Curve. The rotation of initial Circles (Rotate components connected to the Circles) enable us to choose the desirable part of the skin for the penalization.

Figure 20. Construction of the main geometry. Initial three circle-like curves and the interpolated curves to be lofted.
The interpolated curves are chosen for the loft operation, as the result is the geometry of type Untrimmed Surface that wraps the building. You could also choose directly circle-like curves or some other curves from your design, however every time you have to assure that the resulting geometry is Surface type. Open brep that is not suitable for penalization.

Figure 21. The main geometry resulting from Loft.

Figure 22. The selected part of the surface for the panelization.
3.3 Strategy 1 - optimization for views: multiple point attractor

In this section the attractor points will be used to modify panels of the façade to overlook to the interesting views. Attractors in the 3D space were created as Points in Rhinoceros and in the case study it is the fountain in the Oriental Bay, the top of the Mt Victoria and the point when sun rises.

![Diagram of attractor points](image)

**Figure 23.** Attractor points as points to be well visible from the project site.

In the first step in the Grasshopper definition (Definition 3.3.1) the Hexagonal grid from its 2D form is mapped to the surface of the facade. The coordinates of the grid points are extracted with usage of Deconstruct. The x and y values are translated to the u and v coordinates of the 3-dimensional surface. Firstly the x,y coordinates are remapped (Remap Numbers) to the target domain from 0 to 1. Secondly, they are translated with a simple function \{u,v\} in Expression, to the u,v coordinates of the surface.
The points mapped to the surface have the same data structure as before the mapping and there are 6 points in every tree branch. Polyline connects all six vertexes of the hexagons and recreates the grid on the surface. The Average component connected to the output P in Evaluate Surface finds the centres of the hexagonal panels and Average connected to the N output gives the normal vectors at these centres. Attractor points in the landscape are manually selected in the Rhino viewport (right click on the Point component and Set One Point/Set Multiple Points option).

Hexagonal panels are scaled and moved with direction of their normal vectors. Then they are rotated using the Rotate component. Initial direction is the direction of individual normal vector of the panel, the final direction is the smallest angle between the vectors pointing at the attractor points in the landscape and the normal direction for each panel. For every single panel measurement for every attractor point is given and after synchronized sorting the list of numeric angle values and the vectors, List Item selects the first vector from the sorted list. The selected vectors are the individual final directions for each panel. In this exercise every panel overlooks to one of the attractor points in the landscape by the rotation of its one edge.

Figure 24. The created panels and overlooks’ directions.
3.4 Strategy 2 - optimization for sun path: multiple line attractor

In the second strategy the sun paths are the attractor lines, which affects the size of the openings in the panels. Two sun paths are found and baked with usage of Ladybug_SunPath. One is on the Winter Solstice (the longest night and the shortest day) on 21st of June and the other on the longest summer day (22th of December).

Figure 25. Attractor points as points to be well visible from the project site.
The original sun path is projected onto the building skin. The distances from the panels’ centres to the curves on the skin are the indicators of the opening factor of the panels. All distances are remapped to match the scale factors. The panels closer to the attractor lines have bigger openings. The scaled outlines of the panels are moved in the Normal direction. By lofting the initial panels’ outlines and the scaled and moved ones the Panels B are created.

Figure 26. The outcome from the second strategy.
3.5 Combining strategies.

In the previous sub-sections two design approaches were presented in the design context. In this section these strategies are combined to achieve project which meets multiple design criteria. On the one hand the building skin should provide the best possible interior insolation, but on the other it should still give the possibilities to have openings overlooking the interesting points in the landscape.

In the first proposition the Dispatch component is used to diversify panels on the building skin. Both sets of panels are firstly divided with \{True/False\} pattern. From the Panels A (optimized for views) only every second is taken, while from Panels B (optimized for insolation) the initial row and the complementary panels from the rows with Panels A are combined. The resultant facade is presented below.

*Figure 27. The outcome from two mixed approaches using Dispatch with True and False pattern.*
4.1 Competition entry

Hiriwa Pavilion is a competition entry for the Art in Structure Competition 2015/2016 organized by Fletcher Steel Limited trading as Easysteel, Private Bag 92803, Penrose, Auckland 1642, New Zealand. Hiriwa Pavilion design received runner-up award in the Emerging Designer category and was exhibited as a part of “VirtualSculpture Park” during public voting on 3rd of April 2016 at the Wynyard Quarter in Auckland.

IDEA HIRIWA PAVILION is an experimental structure which endeavor to reinterpret the function of steel. In this project steel is used as textile or fabric. The perforated steel plates form a lattice membrane for a small outdoor pavilion.
4.2 Technical drawings and use of the point attractor

FORM
The size of the pavilion is roughly 4,5x4,5 m x 3m. The form-finding process included methods studied by of Heinz Isler or Antoni Gaudi (e.g. fabric forming, membrane under pressure) and mesh relaxation techniques. Geometry was translated into a grid of non-repeatable steel panels.

STRUCTURE & CONSTRUCTION
The pavilion’s CNC-bent aluminium frame is constructed from 24 sections. The surface of the pavilion includes 128 unique panels from 2,5mm Atmospheric Corrosion Resistant Steel Plates (corten). In the presented project every panel is considered as a single element, so that 6-8 panels could fit to the steel sheet of size 2500x1250mm. However panels could be laser cut either as separate elements or as larger clusters. At the connecting two parts edges there are overlaps, that enable to connect parts with each other.

CREATIVITY & FLEXIBILITY
Parametric design tools give us flexibility and creativity during design and construction process. Design features like size and shape of the pavilion, the amount of panels or the type of perforation could be adjusted for feasibility proposes at every stage before the final fabrication. Automated lay outing will produce immediately updated files for fabrication.

Figure 29. Form explorations.
ROLE OF ATTRACTOR

Point attractor was utilized in rationalizing the openings of the panels. The perforation changes gradually over the surface. The sizing of the perforation is driven be the distance to the attractor point located in the middle point of the mesh projected to the ground plane. (Fig.x). The largest openings are in the middle of the pavilion in order to reduce weight of the skin in the unsupported places.

Figure 30. Front elevation and top view of the pavilion. The attractor point drives the sizing of the perforations.
#5 Conclusion

Attractors are the core of the dynamical systems in architecture. Attractors are used to create gradient, design interactiveness or introduce non-primitive order into architectural compositions. If they are translated as the elements of the environment like people, wind, sun (light), humidity or others, they can also perform dynamic or static optimization.

A simple approach of mixing two types of the building skin panels resulted in the statically optimized building skin. Both presented design outcomes from Section 3 and 4 are the example of attractor-based optimization.

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Figure 31. The visualization of the Hiriwa Pavilion, Runner-up in Art in Structure Competition 2015/2016, by J.Cichocka.