Using Histogram Matrices as an Interface for Designing with Parametric Point-Clouds

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This paper presents an innovative approach towards parametric design. The use of histograms is suggested as a design interface representing the spatial parametric relationships in an unfolded tabular form. The unfolded tabular and bar histogram provides a schematic representation of the design model and allows creating parametric relationships between the design components.

Keywords: *Parametric design; constraint-based design; histograms.*

Introduction

Parametric modeling is becoming more accessible to architects and does not require high-end computing power like in the early days of CAD. However, the task of creating complex parametric design models introduced architects and designers with the need to acquire new skills including advanced knowledge of complex geometry and scripting languages. Hence we notice a bottle neck in design processes relying on the application of complex parametric modeling by designers who already acquired those skills. The development of a new parametric modeling method that simplifies the complexity of design models is described in this paper as a means to overcome this problem.

Using Smart Cloud of Points (Nir, 2005) as a parametric point-cloud system provides a platform for exploring new parametric techniques based on histogram matrices. Histogram matrices are considered as an alternative interface to traditional constraint-based parametric modeling. This new parametric modeling approach is based on a multi-layered matrix that unfolds the complexity of a 3-dimensional design model into a set of histograms which describe parametric relationships assigned to the design model components. The proposed approach simplifies the design interface making it accessible to all architects including non-CAD users.

Constraint-based Systems Limitations

In a typical design process the architect creates and modifies the design models many times. The direct manipulation of CAD models requires a comprehensive understanding of modeling and navigating in the 3-dimensional Cartesian space. When the model geometry is non-planar and more complex, the task of altering the design model becomes difficult especially when using CAD tools which are based on Cartesian coordinate planes. Handling such complexity led to adopting constraints-based modeling and parametric design techniques from the automotive and aerospace industries that typically construct curvilinear forms and complex geometries. Observing the design processes in those industries and comparing them to the building industry reveals that the number of engineers designing a square meter in an airplane or a car is much higher than the number of architects designing a square meter of a building. Therefore the level of complexity and the technology used in one industry should not be transferred directly to the other.

The use of parametric modeling in architectural design is continuously growing. When applied, the parametric modeling process results in a geometric representation of the design components using parameterized attributes (Hernandez and Roberto, 2005). The use of geometric constraint-based systems to define relationships between the components of a design model requires rationalizing its geometry. Rationalizing the design using geometric constraints allows performing complex modification to a design model, optimizing it and assuring it yields a constructible design solution maintaining the design intent (Glymph et-al, 2004). Sometimes the rationalization process is introduced prematurely in the design process and therefore may result in a fixation related to bounding the design solution to a predefined topology. For example, rationalizing a free-form curve into a fixed number of tangential arcs constraints the number of inflection points of the curve, while using a B-Spline curve allows introducing additional inflection points by simply adding control points. When topological changes are introduced in a parametric design process, the design model requires adding or removing constraints or even reconstructing the whole design model. Most parametric design tools are complicated to operate and require a profound understanding of geometry to establish constraints within the design model. The constraints solvers typically operate in two-dimensional planes. By creating relationships between those planes, parameter values can be exchanged resulting in a spatial definition of a form. The schematic representation of these relationships is typically drawn as a tree, expressing the mono-logic parent-child hierarchy of the design model, hence its poor ability to support non-linear design processes.

Parametric Point-Clouds

The use of point-cloud geometries is suggested in this paper as a parametric design media extending the common use of point-clouds as a surveying media (Schall et al, 2005). Point-clouds are very interesting in the sense that they are zero-dimensional due to the nature of the point entity; having no size, no shape and no orientation. Yet, we have the cognitive ability to recognize a 3-dimensional object represented using a dense point-cloud. The use of point-clouds as a design media is based on the very basics of the digital domain having a pre-defined size and order, typically referred to as resolution. An ordered point-cloud has a given resolution and enables us to define relationships between its points according to their location within the resolution matrix (the row and column numbers provides a fixed address for each point just like a pixel in our computer screen). Any given point-cloud can be re-sampled as an ordered point-cloud by simply projecting a grid through it, resulting in a dual-layered matrix describing the altimetry and batimetry of the original object. The resolution of the point-cloud matrix is derived from the projection-grid size (Figure 1).

Applying parametric relationships to point-clouds require handling an extensive amount of constraints when no relationships between points are previously defined. Therefore, the use of point-clouds geometry appears inefficient at first glance. For example, an arc requires only three points to define its geometry while a point-cloud or point-string definition of an arc will consist of a much higher number of points according to the sampling resolution. However, this additional data is not redun-

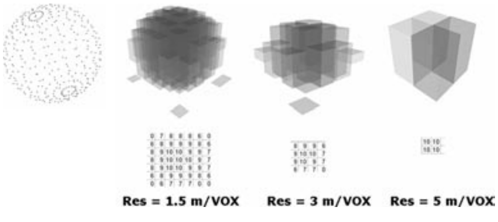
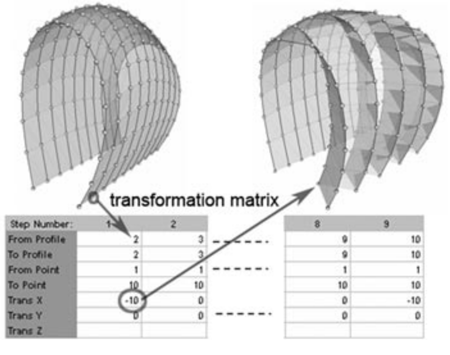


Figure 1
Re-sampling a sphere point-cloud at various resolutions.

Figure 2
Topological transformation of a point-based geometry.

dant, it provides the ability to introduce topological changes and remove the geometrical constraints of the original sampled arc. Using point-cloud geometry, a sampled arc can be easily transformed into an oval shape based on two arcs and a line connecting them, while a parametric model of an arc can only change its radius and not its topology (Figure 2).

A parametric point-cloud can be represented in a multi-layered matrix, referred to as Smart Cloud of Points (Nir, 2005; Nir and Capeluto, 2005). The first layer consists of the points coordinates while additional layers define relationships between the points according to their location index derived from the matrix size. Let's assume a point-cloud matrix that consists of 10 point-strings of 20 points each, sampled from a NURBS surface. The sampling process provides the first matrix layer containing the points coordinates. Each point has a numeric ID representing its location in the matrix that allows creating relationships between the points. The numeric ID is the product of the position of each point on the point-string and the string position in the point-cloud. We can than apply spatial transformations on the six degrees of freedom to any point or a group of points. The transformations can be described in an additional matrix layer. Figure 3 shows a transformation-matrix describing a translation along the X-axis assigned to selected points according to their ID.



Step Number:	1	2	8	9
From Profile	2	3	9	10
To Profile	2	3	9	10
From Point	1	1	1	1
To Point	10	10	10	10
Trans X	-10	0	0	-10
Trans Y	0	0	0	0
Trans Z				

Figure 3
Transformations matrix layer of an ordered point-cloud geometry.

Histograms as Design Interface

We draw an analogy to using histograms in digital photography (a 2D bar histogram for a 2D rectangular pixel space) as a basis for developing histogram-matrix interface for 3D models. A histogram is used to graphically summarize and display the distribution of a process data set. A histogram representation of design model parameters is suggested as an interface for 3D modeling using a 2.5-dimensional histogram to represent parameters values of a point-cloud. The histogram provides a simplified unfolded interface which allows creating and managing parametric values and relationships between the points of a point-cloud.

Unfolding the parametric values read from the ordered point-cloud into a rectangular matrix of the same dimensions allows creating mathematical relationships between the values assigned to each point of the cloud. This result in a parametric point-cloud equipped with a simple interface to define and edit relationships between its points. The relationships can be of a mathematical, geometrical or performative nature. The histogram interface includes a numerical and graphical representation of the data providing a rectangular map where each point in the histogram matrix is positioned according to its order in the point-cloud. The histogram matrix provides an abstract description of various relationships between points' properties in an ordered point-cloud.

For example, we can represent the height of every point in an unfolded histogram (Figure 4). The histogram has a numeric and graphic representation allowing a direct manipulation of the parameter represented. Various relationships can be defined between the points by simply assigning mathematical equations to the tabular data view or by applying a graphic rule often referred to as a law curve.

The histogram can be used for representing the relationships between two point-clouds or more of the same size. For example, by offsetting a point-cloud relative to its center point of gravity results in a dual point-cloud where the distance between a

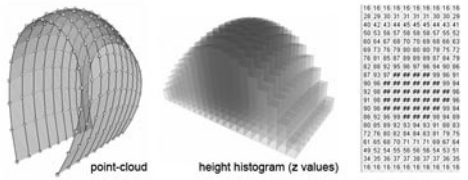


Figure 4
Altimetry histogram matrix.

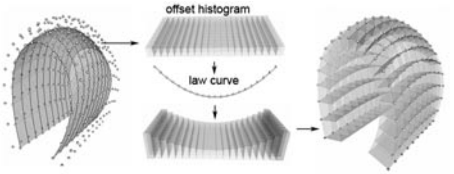


Figure 5
Using a histogram as a parametric design interface controlling the structural height of a ribs structure.

pair of corresponding points is defined by the offset magnitude. Unfolding the distance values as a histogram allows controlling the relationship between the two point-clouds. This provides a simple schematic design interface that can be used to alter the design model manually by changing the value of a specific pair of points or by introducing mathematical relationships numerically or graphically as law curves (Figure 5).

Parametric Histograms as Design Drivers

The following example shows various levels of parametric control that can be achieved using the proposed histogram-based design interface. We resample a given point-cloud model by projecting a grid through its points and finding the closest point to each of the grid points. The result is an ordered point-cloud matrix where each point has a location address that can be used for identification (Figure 6).

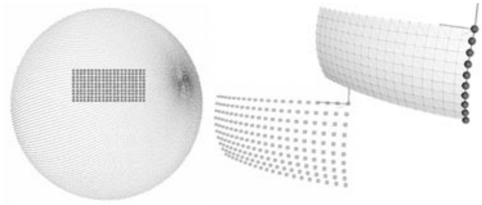


Figure 6
Grid-based point extraction.

The first level of parametric control is over the point-cloud geometry. The X, Y, and Z coordinates of each point can be documented in a tabular form following a sequential order. The coordinate values of each point can also be represented as three separate matrices providing the point location within the point-cloud. This way we can create mathematical or graphical relationships between the coordinate values and transform the point-cloud geometry parametrically. For example, we can introduce a parametric sine wave equation to the X-coordinate values and alter the design according to the amplitude and frequency parameters (Figure 7). We can also assign relationships to a selection set of points by simply identifying them in the unfolded schematic layout and change the values assigned. The histogram provides a simplified representation of the parameters values and allow for graphic manipulations that can be directly imposed on the spatial point-cloud.

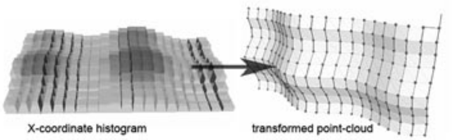


Figure 7
Transforming the point-cloud by editing the X-coordinates values represented as a histogram.

When populating the point-cloud model with cellular components, the points act as place holders defining the component size and orientation. A schematic layout of the components can be used to control the distribution pattern over the point-cloud geometry. Applying a numeric naming convention allows to create a histogram representation of the distribution pattern and to control it parametrically. For example, we can create a series of cladding panels and name them according to the opening ratio where "0" is a fully closed panel and "9" is a fully open panel (Figure 8). The schematic layout can be represented as a histogram where the numeric value defines which panel component is to be placed. This histogram can be used as an abstract design interface providing a schematic visual representation of the façade design (Figure 9). This method can also

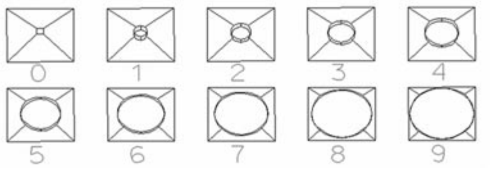


Figure 8
Components library.

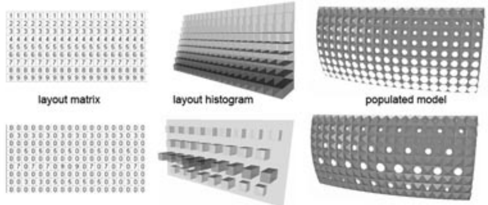
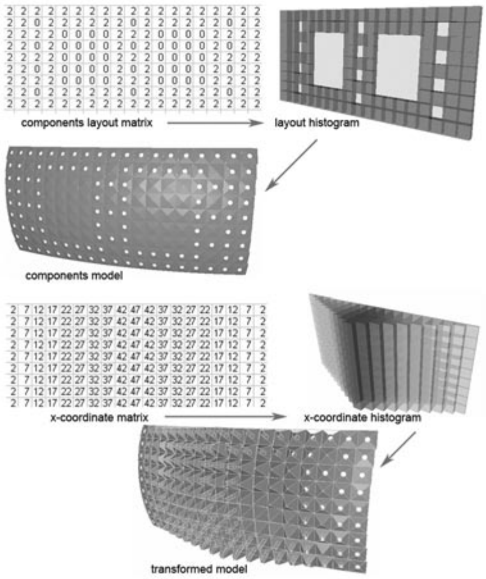


Figure 9
Populating the point-cloud geometry using histogram matrices.

be used as a framework for a performance driven design process. For example, we calculate the solar exposure of each panel and scaling the numeric results between 0-9. The rescaled solar exposure values can be used as a components distribution pattern populating the point-cloud geometry according to performance values.

When populating point-cloud geometry with components, the bounding-box of each component inherits its x-y size and its orientation from the point-cloud. Another layer of parametric control can be applied to the bounding box of the cellular-components. For instance, the z-scale values of each component can be represented schematically in a tabular form providing an unfolded histogram representation of the components height values. The histogram interface provides both uniform and non-uniform control over the height parameter of the components. By creating graphic or numeric relationships between the histogram values a uniform control can be achieved while changing an individual value results in a non-uniform transformation. This method simplifies the modeling process by providing a 2.5-dimensional interface for a complex design model (Figure 10).



2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	0	2	2	2	2	2	2	0	2	2	2	2	2	2	0	2	2
2	2	2	2	0	0	0	0	2	2	2	0	0	0	0	2	2	2	2
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2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

2	7	12	17	22	27	32	37	42	47	42	37	32	27	22	17	12	7	2
2	7	12	17	22	27	32	37	42	47	42	37	32	27	22	17	12	7	2
2	7	12	17	22	27	32	37	42	47	42	37	32	27	22	17	12	7	2
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2	7	12	17	22	27	32	37	42	47	42	37	32	27	22	17	12	7	2
2	7	12	17	22	27	32	37	42	47	42	37	32	27	22	17	12	7	2
2	7	12	17	22	27	32	37	42	47	42	37	32	27	22	17	12	7	2

Figure 10
Parametric components population using histogram matrices.

Conclusions

The application of CAD/CAM processes in architectural design and the growing use of digital fabrication introduced the need for creating elaborated 3-dimensional models of the overall design. Parametric constraint-based models allow direct manipulation of the design, but on the other hand limit its alterations. Geometric constraint modelers allow driving typological transformations and optimize the design model with great ease, but it requires remodeling in order to introduce a topological transformation. This paper presented how histograms can be used as parametric control interfaces that unfold and simplify the design complexity. This approach corresponds with the way complexity in general is captured by cognitive science as a multi-layered problem. The parametric relationships embedded within the design model are unfolded into a set of schematic histograms and tabular interfaces which allow handling each layer of the complex model separately. The first layer of the design model contains the point-cloud coordinates ordered in a tabular matrix. This matrix provides an unfolded representation of the design model and provides an identifier to drive direct manipulations of the 3-dimensional design model. Any parametric relationship assigned to the point-cloud model can be represented as an additional control-layer and unfolded into a tabular and histogram representation. This representation simplifies the interaction with the design model, making parametric design more accessible and reduces the need to operate the design model in 3D space. The histogram matrices provide an interface for direct manipulations of the design model in an unfolded schematic 2D representation of selected parameters.

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