

VORONOI DIAGRAM VORO [SCHEMATA]: *Application of interactive weighted Voronoi diagrams as an alternate master-planning framework for business parks.*

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Abstract. This paper explores the application of Interactive Weighted Voronoi diagrams in business park master plans through site specific testing, derivation of zoning parameters and creation of an applet.

Keywords. Weighted Voronoi diagrams, 3D Voronoi grids, Alternative Planning frameworks for architectural design

1. Research Question

Can alternative planning frameworks such as a Voronoi (in comparison with generic planning grids) when applied for business park master plans satisfy the following requirements?

- i. Successfully fulfill master planning parameters such as zoning, parking and qualitative open space generation?
- ii. Generate spatial zoning that will reduce residual space, allow higher built up area, open space and FAR (Floor Area Ratio)?
- iii. Aid programmatic fit and spatial form generation of complex building projects?

2. Research Methodology

Our research methodology included:

- i. Background research on 2d and 3d Voronoi and weighted Voronoi diagrams for master planning application.
- ii. Comparison of Voronoi grid with Euclidean grids (with respect to generation of residual open space, built up areas, resultant FAR etc.).
- iii. Documentation & selection of MWC, Mahindra World City, Chennai as the Site for application and study of Voronoi weighted grid Business Park.
- iv. Application of Voronoi diagrams to MWC and arriving at required parameters for a Voronoi Applet.
- v. Creation of an Applet as an Interactive Weighted Voronoi Diagram.
- vi. Testing of applet in MWC to create a zoning diagram with Voronoi template.
- vii. Conclusion.

3. Background

3.1. INTRODUCTION: DEFINITION OF VORONOI DIAGRAMS

Consider a set S of N sites in a two dimensional Euclidean plane. A Voronoi diagram is a set of cells dividing the plane such that all the points in each cell are closer to their enclosed site than any other site in the plane.

By drawing lines to mark out Voronoi cells (or drawing areas in the shape of those cells), we divide up (or tile or tessellate) the drawing into regions. Every location within a Voronoi cell is closer to the point about which that cell is drawn than it is to any other point as shown in Figure 1. (Manifold System Release 8 User Manual: 2007).

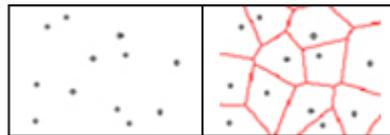


Figure 1. A Voronoi diagram generated from a set of randomly distributed points.

Voronoi Points are defined as the point objects at the intersections of the borders of the Voronoi cells. Voronoi Lines are the line objects at the border of each Voronoi cell. Voronoi Areas are the area objects for each Voronoi cell.

3.2. CONVEX HULL

The Convex Hull of a given set of points is a plot of the ‘skin’ of the set (Paul Herron,). This forms a unique polygon, where its vertices are the outside members of the set as shown in Figure 4 below.



Figure 4. Convex Hull of a given set of points

3.3. CONSTRUCTION OF 2D VORONOI DIAGRAMS

Given two sites s, t the perpendicular bisector $B(s, t)$ of s and t is the set of point’s p equidistant to s and t . Here s and t are called *Generators*. The Figure 2 below explains the steps of construction of a Voronoi diagram in a 2D plane.

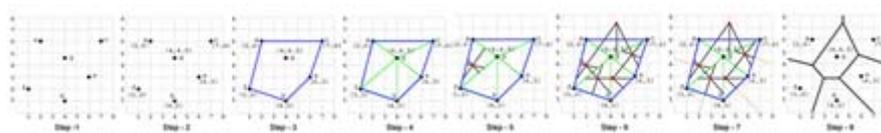


Figure 2. Steps to compute Voronoi diagram on a two dimensional plane.

Step1: Place 6 points a, b, c, d, e, f at random within a defined boundary.

Step2: Find the x, y co-ordinates of all points.

Step3: Draw the Convex Hull.

Step4: Triangulate the existing points to form a Delaunay triangulation.

Step5: Take each triangle and draw perpendicular bisectors of all the 3 sides that intersect at the circumcenter of the triangle. The circumcenter will be on the hypotenuse, within or outside the triangle if the type of the triangle is right, acute or obtuse angled triangle respectively,

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as shown in Figure 2 above. By using the circumcenter, find the intersection of the perpendicular bisectors of all the 3 sides of the triangle.

Step6: Similarly, find the circumcenter for all the other triangles; Join them to form the Voronoi cell.

Step7: Extend the perpendicular bisectors of the Convex Hull to the boundary to get the Voronoi diagram using the line Extension formula.

Step8: Calculate the area of the Voronoi Cell, using Polygonal area formula. (Geetha Ramesh, T. Vinoth Kumar: May, 2004)

3.4. THREE DIMENSIONAL VORONOIDIAGRAM

The Figure 3 below qualitatively illustrates the construction of 3D Voronoi diagram for 2 Activity spaces in 3 dimensions. Thus as can be seen from the diagram, the Voronoi bisectors in a 3D space are a plane surfaces. The same in 2D space are lines. (Figure 1)

The last diagram in the Figure 3 below, demonstrates how the shape of the plane dividing the sites areas gets curled up, when we increase the weight of one of the Sites.

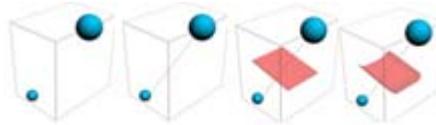
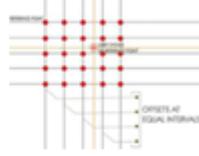
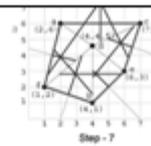
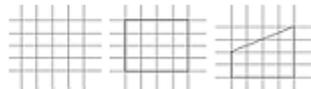


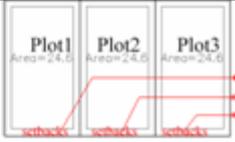
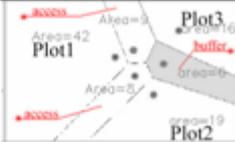
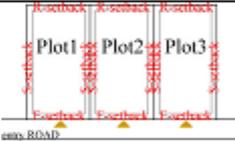
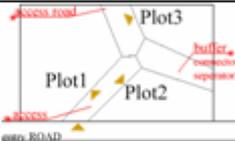
Figure 3. Illustration of steps to compute weighted Voronoi surface objects in 3D.

4. Comparison of Spatial Zoning generated by Euclidean Grid Iron planning and Weighted Voronoi diagrams

The following table compares Voronoi based planning with the traditional Grid Iron based planning.

TABLE 1. Comparison Of Voronoi with Euclidean Grid Iron for spatial zoning

Comparison	Grid iron	Voronoi
Construction of grid	 <p>Figure 5. Generation of Grid is by offset of lines with respect to User Choice of reference point.</p>	 <p>Figure 6. Generation of Voronoi is by drawing perpendicular bisectors between 2 reference points.</p>
Qualitative Area Comparison	 <p>Figure 7. A minimum cell has standardized area, Change in Location of site points does not affect site boundary and grid.</p>	 <p>Figure 8. Cell has customisable area. Changes in location site points / generators of a given site boundary results in variation of Voronoi diagram.</p>

<p>Quantitative Area Comparison</p>	 <p>Figure 9: Subdivision of site as a three plotted area using Grid Iron method. For a given plot of 100 m², Grid base planning gives: Usable area =73.9 m²Residual area =26.1 m²</p>	 <p>Figure 10: Subdivision of site as a three plotted area using Voronoi Diagram. Where for the same plot area of 100 m², Voronoi diagram gives: Usable area =77 m² Residual area =23 m²</p>
<p>Demarcation of access, open space, parking, zoning & other planning needs.</p>	 <p>Figure 11. Offsets are added all around Plot as Setbacks to give access, open space, parking and zoning.</p>	 <p>Figure 12. Buffer cells are added to give access, open space, parking and zoning.</p>
<p>Patterns & Residual Spaces.</p>	 <p>Figure 13. Residual Spaces with a Grid. Here, a minimum cell of standardized area gets repeated to form patterns. Unusable Residual spaces get locked up as setbacks in Individual plots.</p>	<p>There is less residual space, as prerequisites like lighting, open space, ventilation needs can be meaningfully created as buffers with a Voronoi diagram, instead of wasting area all around individuals plot as setbacks as in traditional planning. See Figure 14 below.</p>
<p>Surface formation.</p>	<p>Construction of grid is done by repetitive offsets in XY, YZ And, ZX planes of Euclidean space.</p>	<p>It follows Rules for Voronoi Bisectors in 3D. See Figure 3 above.</p>

4.1. THREE-POINT GENERATOR

Three Point Generator of a Voronoi diagram is similar to a site of 3 plots. Figure 14 below, illustrates in detail the logic planning sequence & possible design solutions for a given a site of 3 generators.

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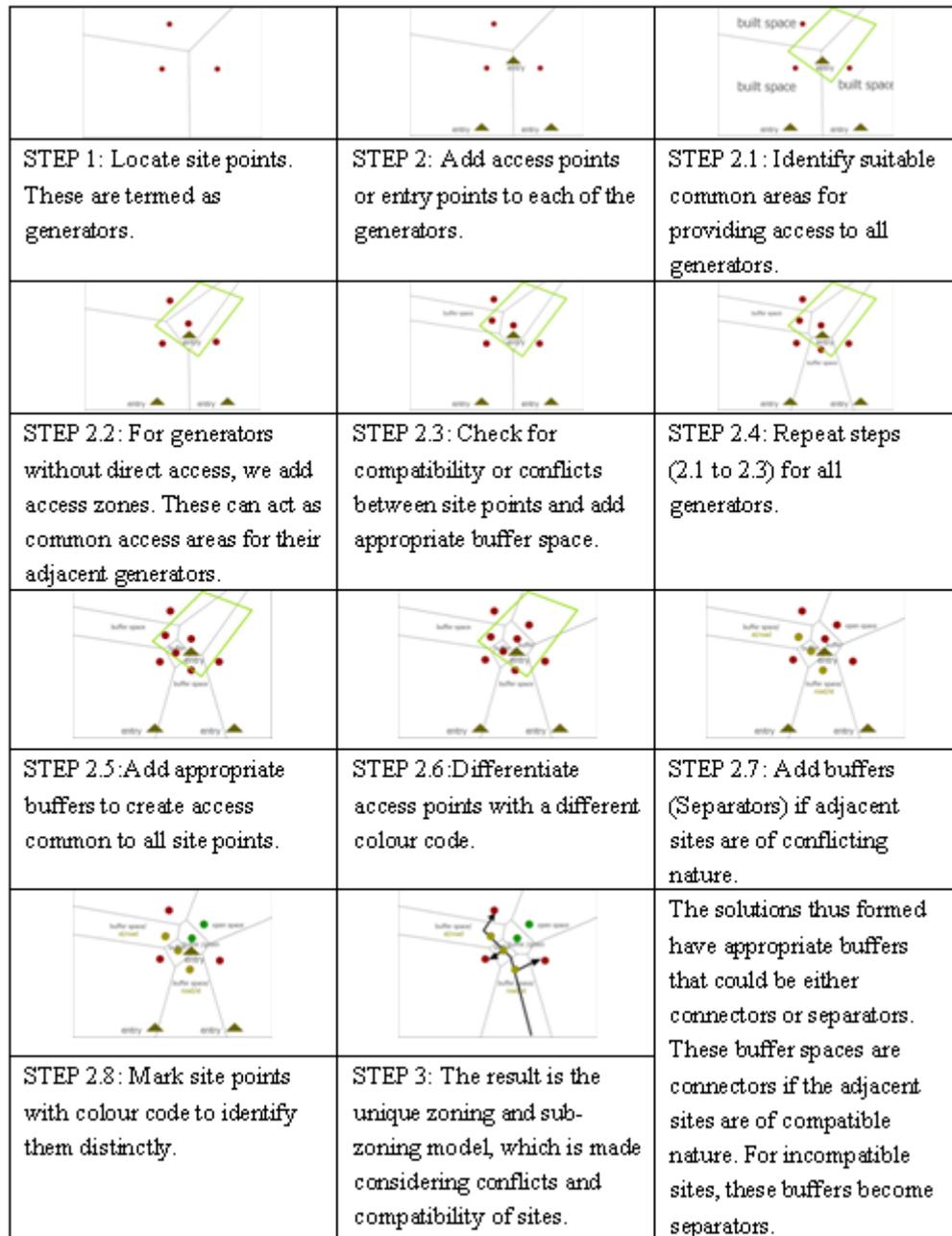


Figure 14. The above diagram illustrates the series of steps for adding access points, open space and demarcating built space using Voronoi diagram for spatial zoning.

5. Terminology used for Zoning using Voronoi Diagrams

Referring to Figure 14 above, addition of Zones in a Business Park Master Plan is analogous to addition of points in a Voronoi diagram. These Voronoi points are termed as Generators. They are of 2 types:

a) Attractors: Zones of compatible nature are termed as Attractors. Connectors are added between Attractors. For example, the possible connectors between zones of common interest are access areas, open space, parking and other similar buffers.

b) Repellers: Zones of conflicting types are termed as Repellers. Separators are added between Repellers. For example, the possible separators between zones of conflicting interests are screen walls, noise buffers etc.

6. Case Study of Mahindra World City (MWC) Business Park & Documentation of existing site features. (www.mahindravorldcity.com/chennai: Jan 2006)

Mahindra city was developed as an integrated business city, where business and lifestyles meet. The following Figure 15 gives the detailed Mapping of Mahindra World City (MWC).

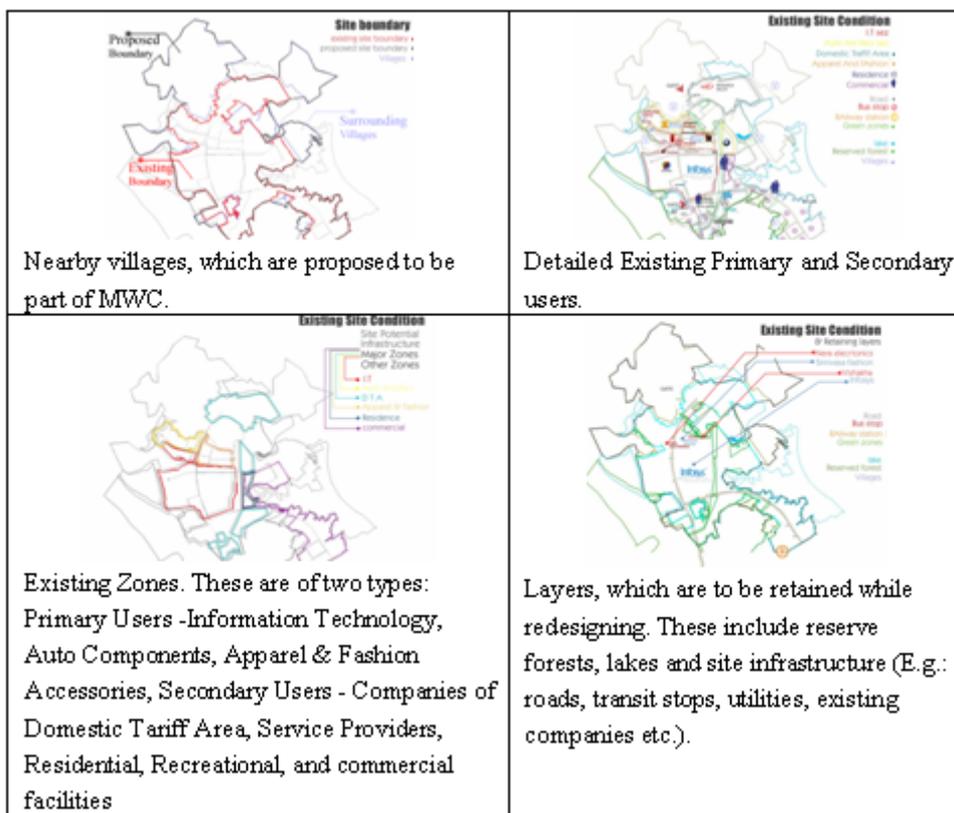


Figure 15. Gives the detailed Mapping of Mahindra World City (MWC).

6.1. DESIGN PROBLEMS EXISTING WITH MAHINDRA WORLD CITY (MWC).

The first phase of MWC layout includes 1200 Hectares of land, with the majority of its zoned sites having access to existing well developed road- rail network along the National Highway 45, and views of forests and lakes. In the second phase local villages at the rear of the existing phase will be acquired to create a SEZ (Special Economic Zone) of 2000 Hectares. The first phase MWC has to be rezoned to allow the second phase sites to take advantage of existing networks and other site potentials.

6.2. DESIGN SOLUTIONS FOR RE-ZONING:

The method used for Re-Zoning of MWC (Mahindra World City, Chennai) involved series of overlay, analysis and identification of the design flaws to different sectors within MWC.

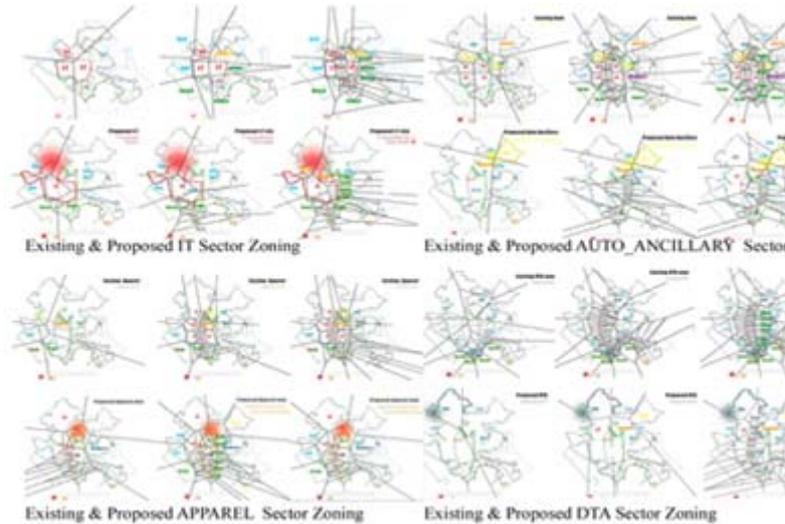


Figure 16. This figure above is a screen shot showing existing zoning & proposed re-zoning of all sectors using Voronoi.

6.2.1 Land Use Zoning of Primary and Secondary users.

The primary aims driving rezoning of primary and secondary users were targeted at minimizing conflicts between different land zones, designing for future Expansion, positioning of zones such that they are at accessible distance to transport areas and providing adequate buffers, open spaces and parking facility.

6.2.2 Land Use Zoning of social infrastructure: Residential, commercial, and recreational.

The key factors, which decide zoning structure for social infrastructure, were aimed at providing adequate buffers for noise & unpleasant views, providing amenities at walk able distance to all residents, ensuring safety, security and privacy and ensuring visibility and accessibility of commercial facilities.

Overlay of Voronoi on the existing site of MWC (Mahindra World City, Chennai) gave generic parameters for input to the Voronoi Applet. The Figure 17 below illustrates the Voronoi zones involved in the redesign of MWC.

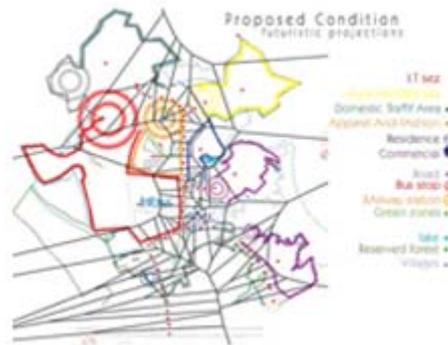


Figure 17. Proposed Re-Zoning of Mahindra city with Voronoi diagram for shortest distance and preferred nearest neighbours.

7. Creation of Applet “Voronoi Diagram Voro [Schemata.]” for generating Interactive Weighted Voronoi Diagrams (as Master Planning / Spatial Zoning templates)

Voro[Schemata] was developed from applet Voroadd. Voroadd applet Author: Oliver M nch: 2005 (www.geometrylab.de/VoroAdd/) was modified for academic thesis by Anuradha.V, Minal Sabnis with the following added features:

The research culminated in an applet integrating the following features:

1. A convex hull for the users to achieve architectural “fit” for the given site boundaries.
2. An interactive interface for the user to locate new program/building zone based on proximity and preferred neighbors.
3. Interactive user control of area intensity with weighted Voronoi integration.
4. Layering options to help users visualize spatial distribution of programs and activities within buildings. The following are the Modules developed in the Applet “Voronoi Diagram Voro [Schemata.]” to test Voronoi diagrams for spatial zoning.

TABLE 2: List of Modules in Voro [Schemata] Applet

Module 1	Add Site to add generators [G].
Module 2	Change Radius to change Area Intensity.
Module 3	Convex hull to demarcate site boundary.
Module 4	Layers to stack activity spaces one above the other.

8. Testing of applet in MWC (Mahindra World City, Chennai) for a Typical I.T., Information technology Building to create a zoning diagram with Voronoi template.

The following is a study of weighted Voronoi application in the design of an I.T., Information Technology office park housing 25,000 employees.

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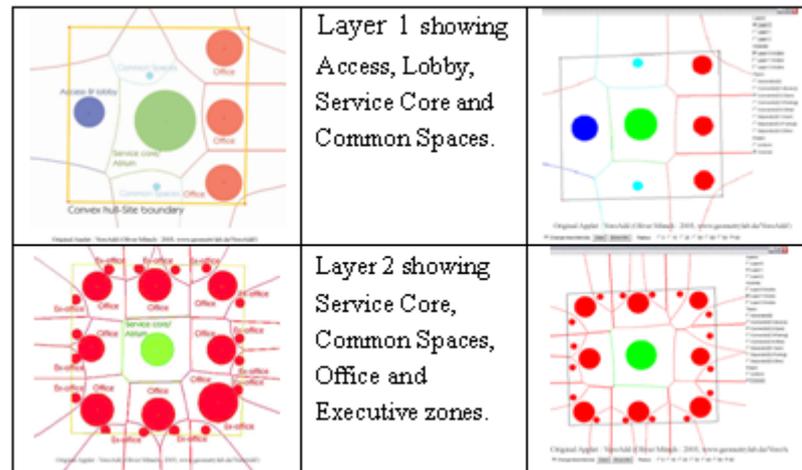


Figure 18. Overlay of layers in Voronoi [Schemata] Applet exploring zoning and area customisation possibilities

The Assumed zones for the design of an I.T. Building using Voronoi are: Access & Lobby areas, Common spaces (Recreation, Toilets, Restaurants), Service Core, Atrium (central zone), Office areas & Executive areas as shown in Figure 18 above. The above diagrams showcase Layers 1&2, which were created by the Voro [Schemata] Applet. Here the Site Boundary is created using Convex Hull and zones are located after checking for preferences, conflicts or compatibility among nearest neighbours. Voronoi areas are controlled using add weights feature of Voro [Schemata]. It also shows the overlay of layers, which helps understanding stacking of activity spaces one above the other.

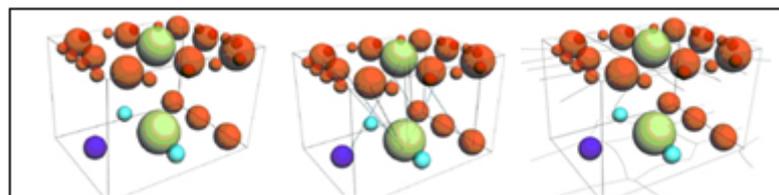


Figure 19. Map showing activity spaces / 3d nodes that are stacked as layers in 3D

9. Scope And Limitation

Our Applet “Voronoi Diagram Voro [Schemata.]”, allows users to interactively zone sites based on preferred network proximities and neighbours. In the next stage we propose to incorporate Voronoi diagram features such as shortest distances and nearest neighbours.

10. Conclusion

Our Voro [Schemata.] Applet application to MWC, Mahindra World City master plan led to the following conclusions:

Voronoi diagram overlays as alternate master planning tools are successful in addressing the basics of zoning & planning issues as compared to typical Euclidean grid planning.

With Voronoi diagram overlays in master plans we can create buffers (positive open spaces) as opposed to residual open space such as setbacks

Voronoi diagram overlays allow us to check for conflicts or compatibility among nearest neighbors and to assign appropriate preferred neighbors (as connectors or repellors).

Weighted Voronoi diagram overlays can be extended as 3D Voronoi for the design of a typical information technology office building. We found that the resultant 3D volumes form a continuous fold based on spatial distribution of programs and proximities defying distinct demarcation of built space as floors, walls, and ceiling.

Acknowledgement

Voro[Schemata] was developed from applet Voroadd. Voroadd applet Author: Oliver M nch: 2005 (www.geometrylab.de/VoroAdd/) was Modified for academic thesis by Anuradha.V, Minal Sabnis and programming help by Saravana Kumar Rathinam. Modifications made are as follows: Added layered Voronoi & Added layer types. Added convex hull (outer boundary) & Changed interface.

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