

The Second-order Voronoi of Roundabout Cairo Since 1867

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Abstract: *The deterioration problem of the roundabout network in Downtown Cairo concentrates on the physical characteristics of the area without recognizing the spatial structure for future conservation. In this regard, the overlay of second-order voronoi tessellation of roundabout generators on Cairo in 1867 signifies Haussmann's original concept of spatial structure in the area with the extended logic of space syntax.*

The essence of fiber process adjusts the second-order edges of the roundabout structure at the two poles of 'Tahrir' and 'Ezbekia Garden' to articulate the extended boulevards of enlarged Cairo. The former projects over the Giza Nile and Pyramids with boulevard realization, while the latter superimposes on old Cairo up to the historical monuments of Azhar, Sultan Hasan and Citadel extents. Meanwhile, the second-order voronoi of the most integrative roundabout centrality of 'Abdean Palace' interconnects the socioeconomic hub of 'Ezbekia Garden' with the royal quarter of 'Tahrir' along the Nile. Nevertheless, the interactive fiber process of the first and second orders determines the rectilinear network from 'Tahrir' to 'Ezbekia' poles with the emphasized public integrity of the central 'Hippodrome' over Cairo at large. Further interaction of ordered fiber process superimposes the gridiron street pattern of patchwork areas beyond the primary radial pattern, while revitalizing the landmarks of old Cairo with new analogical royal establishments. In summary, the symbolic structure of the second-order voronoi syntaxes Parisian Cairo in one spatial layout of all times for future conservation.

Keywords: *Cairo, Roundabout, Second-order Voronoi, Space Syntax, Spatial Structure*

1. Introduction

The second-order of voronoi diagram shifts the spatial structure from the single generators of the first-order to the binary sets of the convex hull. The consecutive tessellation of the first-order into the second explores the spatial context of the convex cells with the network of voronoi edges [4]. The voronoi's condition of spatial convexity validates the interdisciplinary engagement with space syntax of convex hull foundation as well [5]. The cross-analysis of geometrical voronoi diagram with topological space syntax benefits the future cognitive structure of space in universal scopes. In this regard, the methodological initiative investigates the pilot study of roundabout Cairo through the construction of the second-order voronoi with the logical space syntax of integral and control measurements to identify the layout structure for conceptual conservation in the future. The case of Cairo in 1867 realizes French urbanism according to the worldwide trend of 'Haussmannization' planning. The Egyptian royalty invited Haussmann himself to plan modern Cairo on his Parisian model of roundabout structure, which was part of the ceremonial plan to inaugurate the Suez Canal navigation with the attendance of many monarchies around the world [1]. The plan of Haussmann's Cairo was implemented under the direction of the other French engineer 'Le Grand' with the endorsement of the Egyptian royalty to meet the 1867 event. The new survey map of Cairo was published officially in 1874, which details Haussmann's roundabout structure with the boulevard network of enlarged Cairo. Overtime the cornerstone of radial network had influenced the latter expansions of roundabout Cairo up to the national revolution in 1952, which changed the further development of the city. The importance of Haussmannized Cairo represents a modern cultural heritage of Egypt, which includes

the foundation of 'Tahrir Roundabout' with symbolic dimensions for future development after being the focus of massive national demonstrations of prospective reforms for a better future [9].

This study investigates the first chapter of Haussmann's original plan for Cairo, to be followed by the chronological chapters of Cairo during the British colony and the independence stages up to the current situation. The previous studies date back in 1889 with the extensive twenty-volume document of 'Khetat' meaning 'plans' in Arabic. The historian and head of Public Works Department of Egypt, A. Mubarak, authored the publication on the status-quo of detailed royal plans to modernize Egypt during the 19th century [3]. Meanwhile, the earlier 'Description De L'Egypte' encyclopaedia of the 1798 Napoleonic expedition on Egypt had stimulated the modernization plans of the country [6]. While the latter document portrays Egypt through an unparalleled artistic description, the former also describes the royal plans through an unparalleled literature as well. Although both documents would enrich any library with extensive material on modern Egypt, they limit to being only descriptive without emphasis on the conceptual plan. On the other hand, the recent studies address the historical values of the 19th century European Quarters in Egypt for conservation [for example 8], with the exclusive demonstration of special architecture in Haussmann's roundabout Cairo that corresponds to the downtown of Cairo at present [7]. Further studies address the deteriorated condition of buildings and open spaces in the historical quarter [2], in addition to the current governmental attempts to revitalize the special merits of the downtown heritage area with visual enhancements [10]. Nevertheless, the empirical approach of this pilot study for universal practices attempts to determine the conceptual structure of space through the methodological innovation of 'voronoi-syntax' with extractive strategy towards the future conservation of Haussmann's Cairo.

2. Analysis of the Second-order Voronoi

The extended spatial tessellation of voronoi diagram subdivides the convex hull into higher orders of generator sets. The packing of two generators per convex space re-divides the first-order voronoi polygons with regard to the fiber-process of voronoi edges. The second-order voronoi of Cairo's Haussmannization plan delineates the convex spaces in binary sets of every two adjacent generators "Fig. 1". The superimposed second-order of fiber process on the initial first-order voronoi tessellation may position any of the corresponding generators away from the convex space boundaries. Despite the possibility of being apart, the contents of each convex polygon measure the nearest distance to the probable outside location of its generator with respect to others. The analytical technique overlays the voronoi edges of fiber-process in first and second voronoi orders on the detailed map of roundabout Cairo. The layers of spatial data determine the relationship of urban structure between the network of voronoi fiber-process and the realized plan characteristics. The sieve-map of transparent layers reveals Haussmann's conceptual plan in terms of street network, land use and building characteristics. Meanwhile, the convex hull of ordered voronoi diagram measures the asymmetry of spatial integration and the distributiveness of spatial control for the layout syntax of roundabout Cairo. Overview of the cognitive structure correlates the image of shaped voronoi edges and polygons with their spatial measurements of space syntax.

The most symbolic observation of the second-order voronoi tessellation projects the overlapping edge of 'Tahrir' roundabout to cut through the plateau of Giza Pyramids "Fig. 2". This optimizes the precision of the underlying first-order containment of the Pyramids plateau with the sweet-spot of unobstructed breadth over the Giza Nile. Moreover, the second order voronoi merges the adjacent polygons with 'Tahrir' in absolute dominance over the Nile course. Thus, the generative fibre-process of second-order voronoi of 'Tahrir' symbolizes Egypt in universal context. This extraordinary cognitive structure of 'Tahrir' roundabout had been later realized through the planned boulevard of 'The Pyramids' with tram-line, which closely follows the striking course of the second-order 'Tahrir' edge "Fig. 3". The opposite pole of clustered generators around the 'Ezbekia Garden' observes another outstanding correlation between the overlapping edge of the second-order polygons of generators {6,5} and {6,7}, which coincides with 'Boulevard Neuve' of commercial spine up to the historical landmark Mosque of 'Azhar' complex. The same fiber-process of 'generator-6' projects the second-order edge of {4,6} binary set in extension to the first-order edging, which defines 'Boulevard Sultan Hasan' towards the consecutive roundabouts

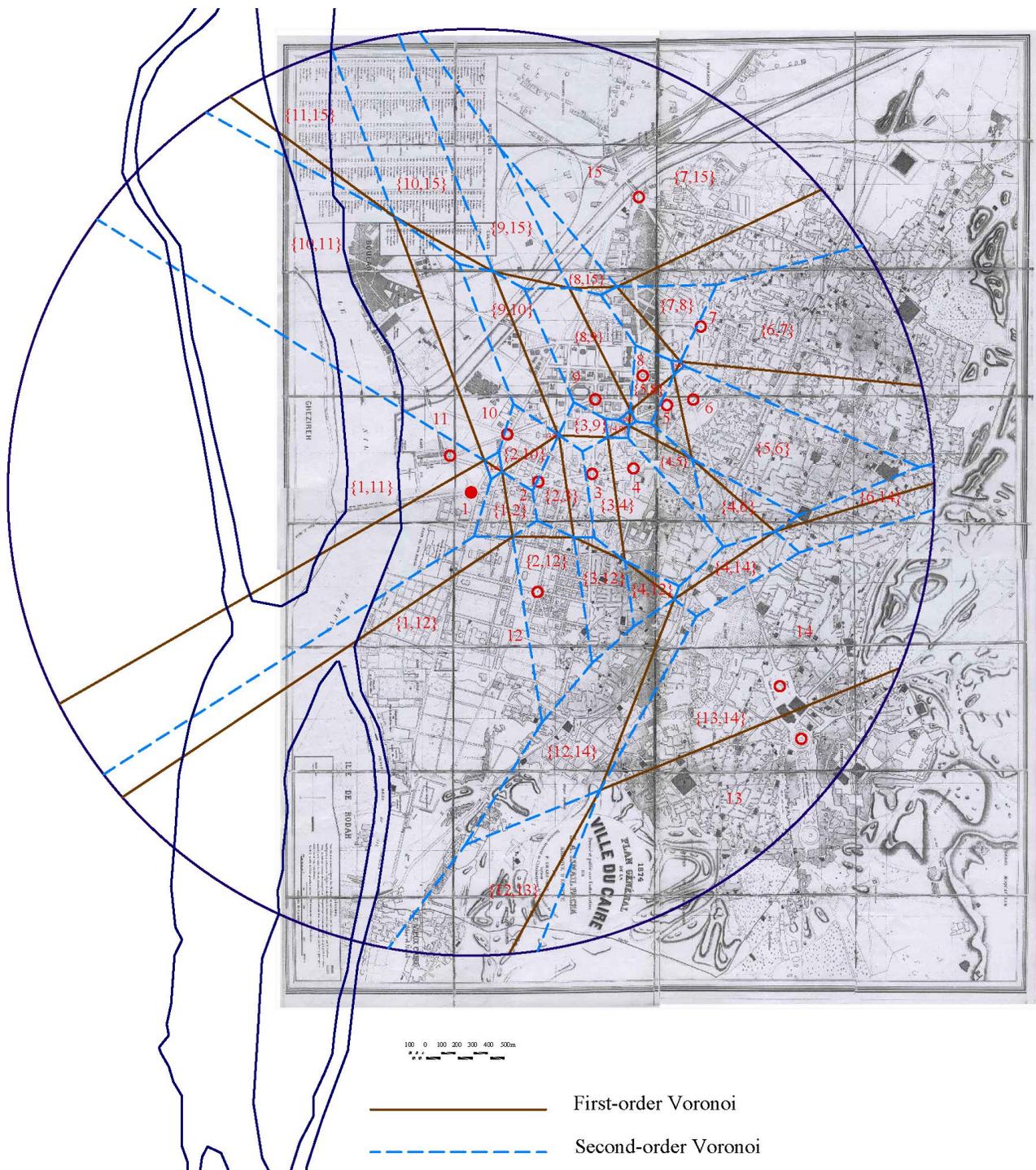


Fig. 1: Overlay of Second-order Voronoi on Cairo in 1867

'13 & 14' of the historical monuments of 'Sultan Hasan Mosque & Cairo Citadel' respectively. The unique structure of this boulevard measures the longest among Haussmann's radial plan with extensive land reclamation of the irregular urban fabric of old Cairo. Haussmann's original fibre process has influenced the later expansions of Cairo's network at the city level. For example, the two arteries of 'Ramses Street' and the recent 'May Bridge' are set in parallel to the first order edges of 'generator-15' where 'Cairo Station' locates. The same roundabout sets the order-two edges in line with the crossing 'Shanan' street. Meanwhile, the second order of 'generator-11' overlaps with generators '1 & 10' towards the distant 'Urabe' street of later suburban extends on the western bank of the Nile. Nevertheless, the second-order union of generators '10 & 15' articulates the Nile course.

This latter pattern of diagonal links defines the orientation of a regular grid at the detailed resolution of backstreets. Overview of the rectilinear networking interlocks the mechanism of realized roundabout structure with the voronoi fiber process of superimposed grids to form primary radial skeleton and secondary patchwork areas of gridiron pattern at different angular rotations.

The land use of second-order observes the spatial structure of roundabout Cairo at the building resolution in relationship to the zoomed out convex hull of the first-order. The polygonal zoning distributes royal establishments towards the 'Tahrir' pole along the Nile, public and commercial activities at the hub of 'Ezbekia Garden', in addition to the miscellaneous functions of traditional Cairo down to the 'Citadel' pole. Nevertheless, the detailed second-order contents of the generator set {5, 6} structures the landmarks of the 'Mixed Tribunal, Azhar & Zewela town gate' at the exact corners of the voronoi polygon. The adjacent set of generators {5, 8} zooms into the cultural landmark of 'L'Opera' building. The comparable set of generators {6, 7} structures 'Le Bourse' landmark in axial line with the 'Nasr town gate' of Cairo, which emphasizes the infinite polygon. The neighboring set of generators {7, 8} adjusts into the landmarks of 'Ezbekia Garden, Hotel Shepherds & Hotel Grand Continental' buildings without generative roundabouts however. To the back of 'Ezbekia Garden' polygon, the spacious 'polygon-9' centralizes the 'Hippodrome' with central roundabout structure. Meanwhile, the first order of 'generator-15' corresponds to the 'Cairo Station' with the widest unbound polygon towards the northern 'Choubra' suburbs along the Nile. The same infinite generator readjusts at the second-order to exclude the contents of all the polygonal adjacencies, except 'generator-7' with the direct access through 'Boulevard Claude Bey' towards the 'Ezbekia Garden' pole. The connection of 'Cairo Station' with 'Ezbekia Garden' structures another arcaded spine of commercial activities. Overtime the socioeconomic landmarks clustered at the polygons of 'Ezbekia Garden' such as theatres, banking foundations, hotels, cafés, shops and offices in neo-renaissance styled building façades. From 'Ezbekia' also spread the multi-storey commercial/residential 'Okelle' building type of eclectic architecture between the Italian Galleria and the Arabic Wekala of courtyard structure, which stretched up to the 'Azhar' area along the structured spine of 'Boulevard Neuve' inside old Cairo.

The opposite pole of 'Tahrir' observes the royal structure of land use. The second-order set of generators {1, 11} structures the symmetrical axis of 'Kasr El Nile Bridge' between the two royal palaces of 'Dubara & Kasr El Nile'. However, their first-order resets the polygonal contents into the respective palaces in separate. The radial boulevards of 'Tahrir' roundabout correspond to the three landmarks of royal palaces and the Nile Bridge itself. The further adjustment of second-order 'Tahrir' with 'polygon-12' juxtaposes the palaces of the royal family with the continuous promenade along the Nile frontage. The second-order polygons of 'generator-12' exclude the miscellaneous zones of old Cairo, which emphasizes its royal identity with 'Tahrir' structure of land use. The extended definition of royal land use structures the binary set of generators {11, 10} in correspondence to 'Beaulac Quarter' of royal workshops and public works. At the border between 'Beaulac' and the order-two polygon of generators {1, 11} founded the first 'Egyptian Museum', which adds to the symbolic structure of the royal land use structure. Meanwhile, the shared edge of first-order voronoi between 'Tahrir' and 'polygon-12' passes through the Royal School with its surrounding gardens. Also the Royal Hospital of 'Kasr El Aini' occupies the southern tip of 'polygon-12'. Apart from the 'Royal Quarter' along the Nile, the central convex hull generates '3 & 4' roundabouts to encompass the most prestigious royal palace of 'Abdean' in Cairo. Despite the location inside traditional Cairo, the extraordinary structure of second-order generators {3, 4} readjusted the fibre process to cut-off the old Cairo from the royal palace with its front plaza. The adjusted polygon of standalone palace in the geometric center of Cairo forms a unique royal symbol along the crossways of Cairo poles. The elite society ties with the royalty in prestigious 'châteaux' housing around the royal establishments with spacious private gardens. Nevertheless, the suburban housing on the 'Garden City' concept gained potential towards the northern and western environs of 'Choubra & Giza', in addition to the 'Roda & Gezira' royal islands.

Although different, the irregular pattern of old Cairo implants the roundabout generators '13 & 14' with curious structure. The royal new monumental mosque of 'Refae' in similar style as the adjacent historical mosque

of 'Sultan Hasan' are emphasized through the common cross-sectional voronoi edge passing through the interior of the two mosques, with unique duality of roundabout interface from both sides of the twin mosques. Nevertheless, the union set of generators {13, 14} reunite the two mosques in one infinite polygon with the inclusion of the other Cairo's historical monument of 'Salah El Din Citadel' of elevated topography with the new royal complex of 'Gawhara Palace' and the impressive mosque of 'M. Ali' on top of the citadel plateau. Furthermore, the hybrid voronoi tessellation of first and second orders of the same generators '13 & 14' readjusts the royal structure into the demarcation of the other prestigious 'Helmia Palace' of spacious gardens in the heart of old Cairo. This voronoi structure has been made possible through the second order buffers of generators '14, 12 & 4', which adjusts the interface of medieval Cairo with the new royal plans. The generated interface between the selective symbols of medieval Cairo and the new royal expansions adds time dimension to the roundabout structure.

The convex hull of voronoi diagram observes the second-order of fiber process in correlation to the spatial measurements of integration and control, which merges the voronoi structure of roundabout Cairo with the logic of space syntax morphology "Table 1". The second-order boulevard articulation towards the largest public facility of the 'Hippodrome' corresponds to the most integral structure of the roundabout generators. Meanwhile, the second-order connectivity of 'Abdean Palace' with 'Tahrir Square' through the joint structure of 'generator-12' measures as high as the public 'Hippodrome' integrity, in addition to the highest control of the roundabout scheme. In this regard, the royal structure of roundabouts with the largest public representation symbolizes the universal integrity of the layout with the privileged royal control. Meanwhile, the unique structure of 'Abdean Palace & Hippodrome' are the only generators which interact with both of 'Tahrir & Ezbekia' poles simultaneously through their joint second-order generators of '6-12 & 10-8' respectively. Furthermore, the two distinctive landmarks are set in direct adjacency at the first-order voronoi with the distant poles of 'Cairo Citadel & Cairo Station' respectively. Therefore, the dual royal and public generators of the layout optimize the symbolic structure of the voronoi-syntax according to the spatial measurements and fiber processing as well.

The contrasting structure, however, of the second-order interaction with old Cairo measures the least integral and control dimensions of the roundabout spatial system. The superimposed generators '13 & 14' of revitalizing old into new Cairo observes the monumental emphasis of visibility space syntax to overcome the topographic and urban tissue characteristics. The extended verticality of 'M. Ali Mosque' on the top topography of 'Cairo Citadel' shifts the concept of space syntax from two to three dimensional measures of infinite spatial structure. Meanwhile, the monumental 'Refae Mosque' next to the precedence of 'Sultan Hasan' emphasizes the new vista of old Cairo along 'Boulevard Sultan Hasan' with the logic of least integral or control alteration to the irregular pattern. Comparable logic excludes the integration of 'generator-11' due to the second-order correspondence of royal workshops with the least interest of space syntax, while being located at the royal quarter along the Nile. This has been treated at the second-order voronoi to separate the royal workshops of the generator set {10, 11} from the royal place of 'Kasr El Nile' of the generator set {1, 11}. The opposite generators of 'Ezbekia Garden' control the interface with old Cairo in correlation to the second-order structure, thus filtering old from new Cairo.

3. Conclusion

The second-order voronoi of roundabout Cairo in 1867 with the space syntax of integral and control measurements determines the Haussmannization concept of spatial structure as follows:

1. The symbolic structure of 'Tahrir' roundabout adjusts the second-order voronoi to cut through the Pyramids plateau with the dominance over the breadth and width of the Nile stream, which is also realized through the

TABLE 1: Spatial Measurements

Gen.	RA	Control
1	0.1538	0.9
2	0.1208	1.0095
3	0.1318	0.6761
4	0.0989	1.2595
5	0.1428	0.7095
6	0.1428	1.2
7	0.1758	0.6
8	0.1318	1.1261
9	0.0879	1.5
10	0.1318	1.1261
11	0.1868	0.65
12	0.1208	1.6166
13	0.2197	0.4166
14	0.1428	1.0333
15	0.1428	1.2095
Ave.	0.1421	1.0021

'Boulevard of the Pyramids' with the direct bridging of the Nile at the global context of enlarged Cairo. Meanwhile, the opposite pole of 'Ezbekia Garden' superimposes the roundabouts' second-order voronoi in correspondence to the radial boulevards of 'Neuve & Sultan Hasan' towards the respective polar monuments of 'Azhar Mosque & Cairo Citadel' all through the irregular pattern of old Cairo.

2. The street network of enlarged Cairo observes the correlated structure with the fiber process of first- and second-order voronoi. The global resolution of primary radial pattern had structured the first-order bisectors with rectilinear connections along the second-order voronoi. The detailed resolution of the second-order realizes the superimposed orthogonal grid pattern with rotational angles towards the roundabout backstreets. The same fiber process had influenced the later orientation of the street network overtime, with branching mechanism from the forefront of radial layout to the squared patchwork areas.
3. The contrast of superimposed roundabouts on the irregular fabric of old Cairo emphasizes the analogical model of new Cairo. The historical monuments of 'Salah El Din Citadel & Sultan Hasan Mosque' observe their generative revivalism of voronoi's fiber process in time dimension. The two orders of voronoi spatial tessellation are set interactively to highlight the new monumental mosques and royal complexes in connection to the two old monuments. In one structure, the fiber process assembles the globally revived model, while in the other tessellates into selective interaction of distinct revivals.
4. The adjoined spatial measurements of integral and control syntax to the detailed second-order voronoi of the roundabout structure concludes the conceptual logic of Haussmannized Cairo. The second-order boulevard articulation of the royal 'Abdean Palace' and the public 'Hippodrome' corresponds to the most integrative roundabouts. Meanwhile, the second-order integration of the same 'Abdean Palace' with the generators of royal quarter along the Nile structures the optimal control syntax. Thus, the second-order concept of voronoi syntax symbolizes the royal dominance of the layout structure with the public integrity.

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5. References

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