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250

Visualising the Visibility Graph Analysis:

A Comparative Analysis of VGA Metrics Representation and Significance at Micro-Urban Scale

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ABSTRACT

Visibility Graph Analysis (VGA) demonstrated its potential in extracting intrinsic spatial characteristics and in interpreting social behaviour in micro-urban scale scenarios. Given its granularity, it tends to perform better in capturing pedestrian movement and visual-based patterns in irregular spaces, which are not well apprehended through Isovist-decomposition-based methods. Despite these potentialities, VGA still presents issues, associated with its dependence on a superimposed grid, which often leads to depth-based distortions; which require mathematical investigations towards value normalization. Still, another aspect that requires investigation, concerns visualization methods, as better fitting them to the data distribution can also improve the effectiveness of VGA Analysis. Considering this, this approach proposes a methodological discussion, confronting the default visualization method used in the Space Syntax framework (Equal Interval) and a data distribution method (Equal Count) that is better suited to represent ordinal-level data – often associated with network measures. The objective is to highlight how Space Syntax' VGA can visualise different micro-urban dynamics and how these visualisations inform the underlying system hierarchies, that are often unseen through the DepthMapX default data overview. VGA measures are statistically tested for normality, then histograms are constructed to visualize their data distributions, and set alongside respective spatializations. Discussions highlight patterns that emerge from each data distribution method. The study can then serve as a guide in selecting which representations for these metrics to use and how to interpret such *visual graphs, thus providing a tool for enhancing the effectiveness of VGA and understanding logics within urban environment at a micro-urban scale.*

KEYWORDS

Visual Graph Analysis, Micro-Urban Scale, Data Hierarchization, Through Vision, Multiscale Analysis.

1 INTRODUCTION

Since its conception, Visibility Graph Analysis (VGA) has shown its potential in understanding micro-urban social dynamics, such as pedestrian behaviour, co-presence in closed and open spaces and the logics of spatial control (Turner et al, 2001, Turner 2004; McElhinney et al. 2022). When compared to Axial and Angular Segment Analysis, its granular-field characteristics allow for a more detailed depiction of the spaces' visual components, capturing logics beyond the capabilities of these isovist line-based methods (Penn, Turner 2002, Lòpez, Baeza et al 2021).

Nevertheless, there are still some fundamental methodological challenges that remain to be addressed to improve the VGA's theoretical framework and results. First of all, VGA is calculated on a superimposed grid, meaning that the computed values are not just configurational-related, but influenced by pixels distribution and grid spacing instead (Dalton, et al 2022). Secondarily, given its higher granularity, VGA is usually used for architectural or micro-urban scale analysis, expecting for very detailed and precise analysis. Considering these expectations, the presence of any height differences in the analyzed area would significantly impact the outcome. Moreover, certain global measures such as Visual Integration share the same issue as their isovist-based counterparts, being dependent of system depth (Koutsolampros, 2019). In the other hand, certain local or semi-global metrics, such as Through Vision, Visual Control and Visual Controllability are less dependent or independent of depth yet have issues regarding their hierarchization. Lastly, another critical aspect is represented by the computation times of VGA, heavily influenced by grid-spacing and the extent of the analyzed environment.

All these factors undermine the effectiveness of VGA, and potential solutions such as normalization, grid spacing and form, plus pixel distribution are currently the focus of debate. Regardless of the necessary refinement of the methodological and operational procedure, it is also essential to discuss and evaluate the effectiveness of the data visualization within VGA maps in terms of hierarchisation, as it represents a critical aspect inherently present in urban form, as evidenced by studies based on road-circulation networks (Yamu, Van Nes, 2017)

Considering these points, the paper compares and discusses the data visualisation results that can be attained in each measure, analysing their uses and the information that can be derived from them, using the city centre of Pisa, Italy, as a case study. The objective is to highlight how Space Syntax' VGA can visualise different micro-urban dynamics and how these visualisations inform the underlying system hierarchies, that are often unseen through the DepthMapX default data overview. We address all the VGA-based measures, except for the angular and shortest-path ones, thus discussing global, semi-local and local measures. On this vein, the paper is structured as follows: Section 2 presents a glossary of the investigated measures, providing for the definition, a brief explanation and the references. Section 3 presents the datasets and methods, which aimed at lowering the impact of the critical aspects of VGA. Section 4 presents the results, qualitatively discussing the impact of data visualisation on configurational properties interpretations. Finally, Section 5 offers some concluding remarks and further developments insights.

2 A GLOSSARY OF VGA MEASURES

The evolution of VGA strands from the first definitions of the Isovist (Benedikt, 1979). Since 1979, and above all, following the extensive software development during the 2000-2010's (Turner et al, 2001; Turner, 2004; Turner, 2007; Varoudis, 2012; Varoudis, Penn, 2015) several VGA measures were incorporated into the Space Syntax framework, with the objective to model and describe the characteristics of enclosed spaces.

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Koutsolampros et al. (2019) categorized the VGA metrics according to their size and shape – denoting the form of the Isovists (Table 1); and the potentials to move and explore, with a focus on the measures related to wayfinding (Table 2). A third categorization can also be made, through the unification of measures that denote spatial control, configuration, or complexity (Table 3):

Table 1. VGA measures – Size & Shape

Measure	Extent	Definition	Reference
Isovist Area	Local	Expresses the area of all space visible from a point in the spatial plan.	Benedikt, 1979; Isovist.org, 2024
Connectivity	Local	Represent the number of connections among all points in the visual space. Is correlated to the Isovist Area	Turner, 2001; Isovist.org, 2024
Isovist Perimeter	Local	Expresses the length of the edge of all space visible from a location, or the geometric Isovist perimeter.	Benedikt, 1979; Isovist.org, 2024
Isovist Compactness	Local	Expresses the shape property (relative to a circle) of all space visible from a location. Compactness identifies the regions in which an observer's spatial experience is contiguously consistent.	Peponis, 1997; Isovist.org, 2024
Point First Moment	Local	First moment of inertia of the Isovist, it expresses a sort of inverse measure of compactness.	Koutsolampros et al., 2019
Point Second Moment	Local	Second moment of inertia of the Isovist, it expresses a sort of inverse measure of compactness.	
Isovist Min. Radial	Local	It is the minimum distance from the generating point to the obstacle that makes up the Isovist. Represents the shortest line of sight from the generating point.	
Isovist Max. Radial	Local	It is the maximum distance from the generating point to the obstacle that makes up the Isovist. Represents the longest line of sight from the generating point,	

Table 2. VGA measures – Potential to Move & Potential to Explore

Measure	Extent	Definition	Reference
Isovist Drift Angle	Local	Drift represents the vector from the generating point to the centre of gravity of the polygon. Isovist Drift Angle and Isovist Drift Magnitude metrics fully describe the Drift vector, which generally shows the direction towards the largest parts of an isovist as these largest paths would drag the centroid more.	Conroy 2001, Koutsolampros 2019
Isovist Drift Magnitude	Local		
Isovist Occlusivity	Local	Expresses the proportion of edges of an isovist that are not physically defined; Represents how previously unseen space may be revealed during movement, or the moments of dramatic visual change as a user passes between spaces.	Benedikt, 1979; Isovist.org, 2024
Through Vision	Local	Represents the number of lines of visibility passing through a location, highlighting locations that are crossed-over more often and then considered important for movement – related to *Choice*.	Hillier 2007; Turner 2007; Koutsolampros 2019
Visual Clustering Coefficient	Local	It is the ratio of the number of cells in an isovist that can see each other to the total possible connections that could exist between those cells. It gives a measure of compactness.	Turner et al 2001; Koutsolampros 2019

Table 3. VGA measures – Control, Configuration & Complexity

Measure	Extent	Definition	Reference
Visual Control	Semi-Global	It gives a measure of how much space is visible from a cell in comparison to other directly visible cells, expressing the potential of controlling surrounding areas.	Turner et al, 2001, Turner 2004, Koutsolampros et al 2019
Visual Controllability	Semi-Global	It is the ratio between the number of visible cells (immediate neighbours) and the sum of all the cells visible from the immediate neighbours, representing a measure of how controllable a location is.	Turner et al, 2001, Koutsolampros 2019
Visual Mean Depth	Global	It is the average number of visual steps required to reach every other cell in the system	Turner and Penn 1999, Koutsolampros 2019
Visual Integration (HH)	Global	It measures visual distance from all spaces to all others. These three measures depend on the normalization/calculation adopted to normalise depth.	Hillier 1996, Hillier 2007, Hillier Hanson 1984, Teklenburg et al. 1993, Turner et al, 2001, Turner 2004
Visual Integration (P-value)	Global		
Visual Integration (Tekl)	Global		
Visual Entropy	Global	It represents a measure of global complexity of a space without having to deal with its size. It increases in areas where there are many possible choices ahead.	Turner et al, 2001, Koutsolampros 2019
Visual Relativised Entropy	Global	Normalised version of the Visual Entropy, it takes into account the depth: deeper spaces will have higher entropy.	

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(University College London).

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3 DATASETS AND METHODS

The convex space used to create the Visual Fields for VGA is a representation of a 24,800m² micro-urban area set in the historical centre of Pisa, traced from the Regional Technical Charts (Regione Toscana, 2019).

This convex space is imported to DepthMapX 0.5 (2015), where a 0.375 spacing grid is set to create the Visual Field; the result comprised a graph of 71.843 points. While a 0.2 spacing is theoretically possible, tests indicated that 0.375m is the smallest spacing that can be modelled due to computational constrains; smaller grids consistently resulted in process time-outs. The modelled VGA measures are described in Tables 1-3; those required an aggregate processing time of 4 weeks to complete. Angular and shortest path measures (Koutsolampros et al. 2019), were excluded from the analysis, also due to computational constrains. All these methodological steps – highest granularity, micro-urban environment and flat terrain – were aimed at lowering the criticalities of VGA depicted below.

Results were exported from DepthMapX and converted into two formats: Geopackage (QGIS, 2024), to create the comparative visual analysis; and .csv, then imported to *R-Studio (2020)* for performing statistical analysis and the creation of value-distribution histograms. The statistical analysis comprises a normality test (Shapiro-Wilk, 1965), to verity if any of the VGA measures has a normal data distribution – which would fit the Equal Interval methods. The *null-hypothesis* for the test assume that if *P-Values* for the measures are below the established α (0.05), then the distribution is not normal. The histograms are constructed to inform the overall data distribution patterns for each VGA measure. Two scripts generate histograms to test the data "fitting", one that reproduces the Space Syntax default spatialization method, based on DepthMapX Equal Interval distribution (Turner, 2004); and another to represent the Equal Count (Quantile) method of data distribution (QGIS, 2024).

4 RESULTS

The results of the Shapiro-Wilk (1965) test indicate that none of the VGA measures have a normal distribution, as *P-Values* are much lower than the established α (0.05) (Table 4). This prompts the construction of histograms, so data distributions can be visually appraised.

Table 4. Shapiro test for three data subsets (15,000 points)

Measure	Variable	P-Value	P-Value	P-Value
Size & Shape	Isovist Area	1.92e-31	4.78e-31	3.59e-31
	Connectivity	2.91e-31	7.48e-31	5.05e-31
	Isovist Perimeter	2.42e-20	1.68e-21	7.43e-21
	Isovist Compactness	1.67e-55	3.05e-55	6.27e-56
	Point First Moment	5.20e-51	8.68e-51	2.01e-51
	Point Second Moment	2.27e-64	3.78e-64	1.85e-64
	Isovist Min. Radial	1.20e-50	1.10e-50	4.07e-51
	Isovist Max. Radial	8.98e-27	7.56e-26	9.70e-27
Potential to Explore & Move	Isovist Drift Angle	9.69e-38	7.62e-38	2.30e-37
	Isovist Drift Magnitude	5.42e-47	1.03e-46	2.95e-47
	Isovist Occlusivity	3.38e-32	1.33e-31	1.68e-31
	Through Vision	1.28e-64	1.24e-64	1.94e-64
	Visual Clustering Coefficient	2.74e-37	1.49e-36	1.38e-36
Control, Configuration & Complexity	Visual Control	1.00e-19	1.02e-18	1.37e-18
	Visual Controllability	4.32e-32	3.57e-32	2.18e-32
	Visual Mean Depth	6.35e-51	1.16e-50	1.01e-50
	Visual Integration (HH)	2.03e-25	7.77e-26	3.80e-26
	Visual Integration (P-value)	2.03e-25	7.77e-26	3.80e-26
	Visual Integration (Tekl)	4.40e-35	2.74e-35	1.61e-35
	Visual Entropy	5.19e-35	1.50e-34	3.77e-33
	Visual Relativised Entropy	3.35e-43	4.48e-43	5.38e-43

As visualized in data histograms (Figures 1, 2 and 3), most of the VGA measures present an irregular distribution that, in most cases, tends towards bimodality or multimodality. Few VGA measures possess other identifiable data distributions, that can be associated with certain known statistical patterns – as in example, the Isovist Drift Magnitude, which presents a clear log-based distribution; or the Through Vision, which is geometric, with characteristic heavy-tails, owning to its similarity with *Choice*.

In that regard, given this tendency to multimodal distributions, it is natural to assume that Equal Intervals tend to not usually fit well to the data. Slocum et al. (2022) state that the major disadvantage of Equal Interval distributions lies on the fact its fixed-class limits more than often fail to consider how data are distributed, thus, not being suitable for categorizing datasets which do not follow uniform or normal distributions. Analysing the histograms' data distribution unveils this limitation of Equal Intervals, when compared to the visualizations generated using an Equal Count (Quantile) method (Figures 1-3).

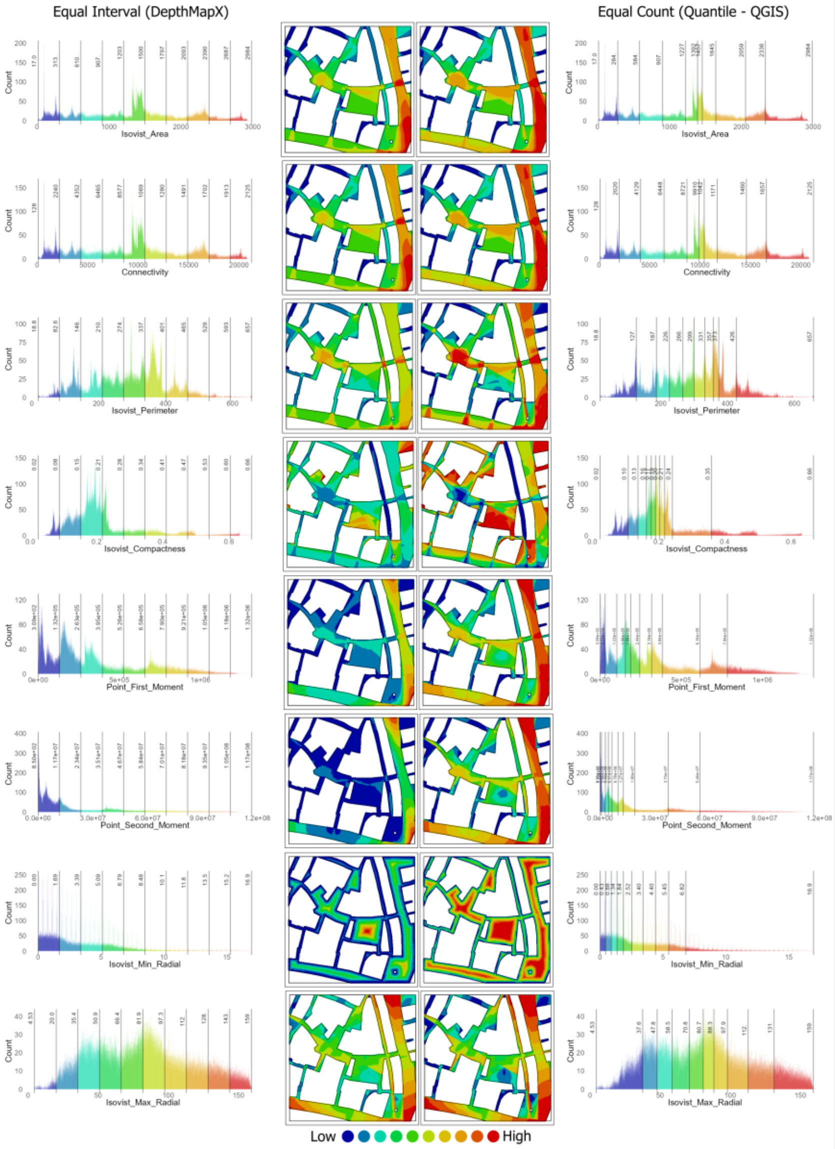

Figure 1. VGA measures – Size & Shape

Equal Count divides the classes based on the total number of points in each observation. According to Slocum et al, (2022), quantiles tend to better depict ordinal-level data – or data that is hierarchical – as captures within-class similarities and between-class dissimilarities. Therefore, it is a method that tends to better fit the multimodality of some VGA's data distributions, or those that have geometric distributions, unveiling spatial dynamics that remain previously hidden.

For instance, in Through Vision (Figure 2), patterns of cross-over among the central plazas become more evident, likewise those among the plazas and narrower streets; there is also a noticeable hierarchical difference between those narrower streets, which is invisible using Equal Intervals. Moreover, larger streets acquire more weight within the system. Point First Moment and Point Second Moment also have interesting visual improvements, as spatial patterns become more distinguishable as the inverse of Isovist Compactness (Figure 1). Isovist Occlusivity (Figure 2) is also improved, as visualizations now capture dramatic changes in passing through different spaces. Isovist Drift Magnitude (Figure 2), although a less significative VGA metric is the one that present most significant changes, as Equal Count captures the actual "centres of gravity" within and in-between the polygons that represent the space.

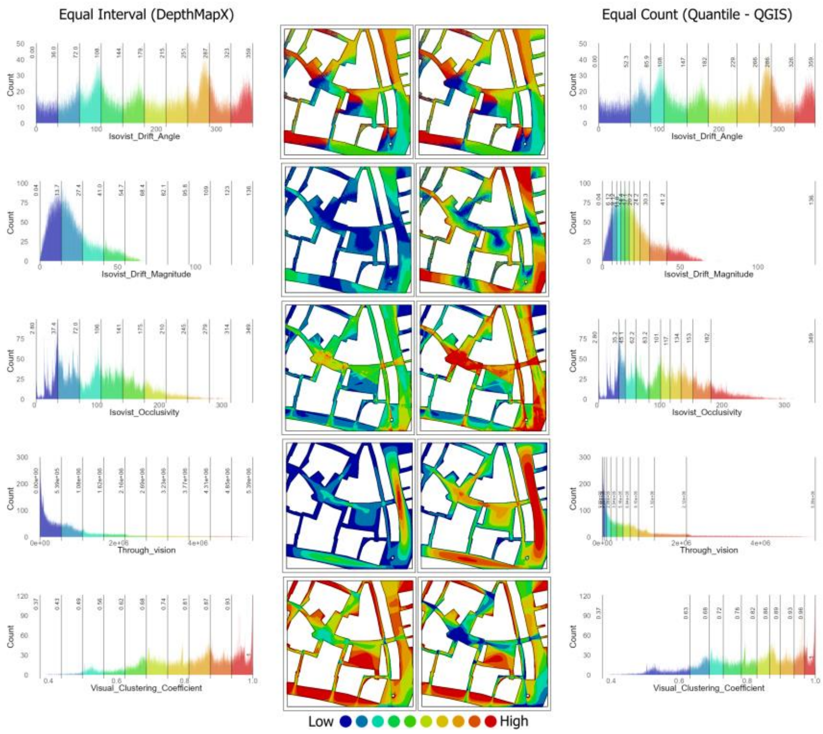

Figure 2. VGA measures – Potential to Move & Potential to Explore

Visual Control and Controllability (Figure 3) also demonstrate visualization improvements, which denote a clear distinction between cells with high and low potential of control. Moreover, the interesting fact is that Equal Intervals, in this case, also have explanative power, as the method tends to capture localized changes in Visual Control – a trait shared with Isovist Occlusivity (Figure 2), which merits further considerations.

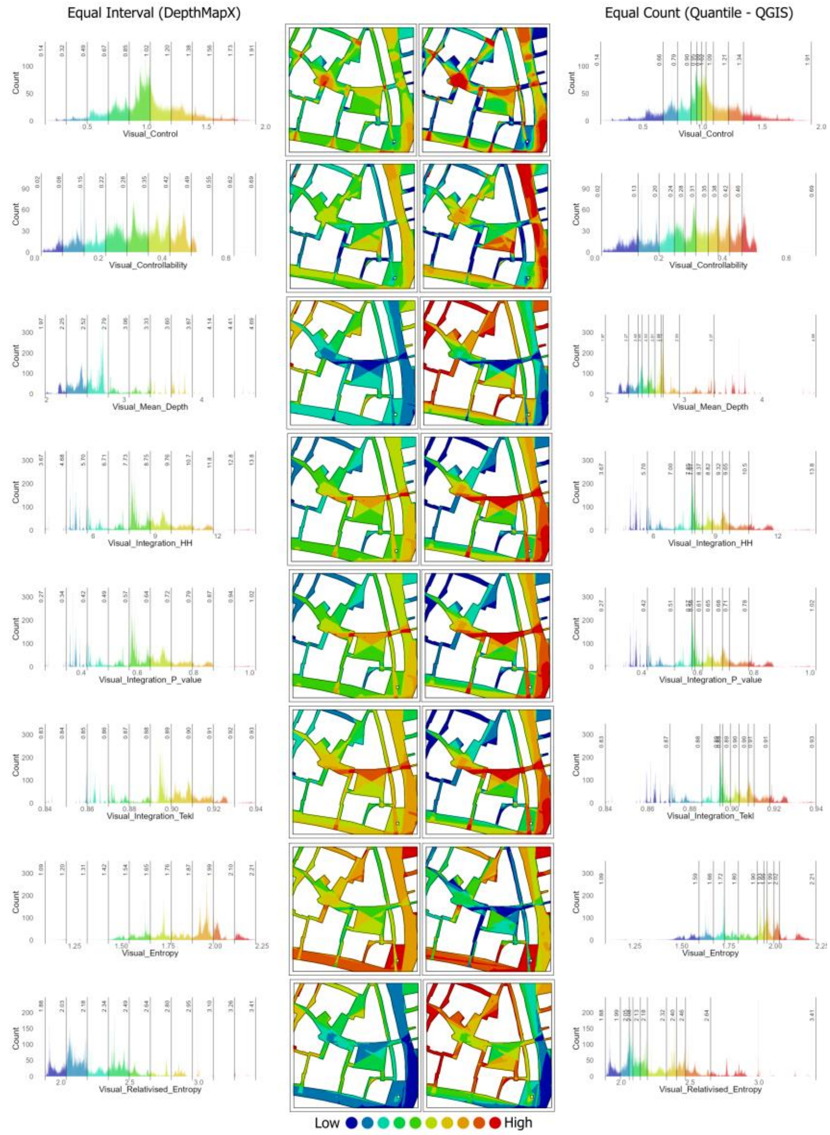

Table 3. VGA measures – Control, Configuration & Complexity

The different types of Visual Integration (Figure 3) also have improvements, as variations between visually integrated and *segregated* spaces are now more marked and defined. It is interesting to note, that emerging patterns in Equal Count (Quantile) are equal in all three modes of calculation, therefore, this distribution tends to function as a "visual normalization". The same can be said for the VGA metrics of Visual Entropy and Visual Relativised Entropy (Figure 3), as lower values are now distinguishable within the visualizations, informing the different patterns of complexity within the micro-urban spaces.

Overall results recommend avoiding using an Equal Interval-based visualization in most cases, due to the predominance of multimodal data distributions in VGA measures. Nevertheless, more studies are needed for addressing particular cases, such as the patterns found for Visual Control and Isovist Occlusivity, where Equal Intervals might inform useful local visual patterns.

5 CONCLUDING REMARKS

Although a natural approach for improving VGA measures explanative power lies on mathematical normalization and in the considerations regarding Visual Fields' pixel distribution (form) and grid spacing (size), this first exploration reiterates that is equally relevant adapting the numerical results to a fitting statistical distribution method for the purposes of visualizing data.

This investigation delved into the differences of data distribution within VGA measures, first unveiling the different statistical patterns within each metric. It was observed that most VGA metrics do not follow a normal – or even uniform – data distribution, as histograms reveal a predominance of multimodal distributions. This prompted to a comparison using both the default method for data visualization used in Space Syntax – the DepthMapX Equal Intervals, and the Equal Count (Quantile) method, widely used in Geographic Information Systems (GIS), and which tends to have a better fit with ordinal-level (hierarchical) data.

Results demonstrate that moving from the default data visualization used for Space Syntax (Equal Interval) to an Equal Count (Quantile) can contribute to unveil certain spatial patterns, providing important improvements in the VGA measures data visualization that may unveil to unanticipated spatial patterns – which are still rather unexplored. On this, punctual investigations could explore how/if specific data distributions (uniform, geometric, logarithmic, multimodal) may typically emerge from certain spatial configurations. Furthermore, studies are still needed, and could be oriented, to better understand the significance of the emerging patterns for some VGA measures.

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REFERENCES

Benedikt, M. L. (1979). To take hold of space: isovists and isovist fields. *Environment and Planning B: Planning and design*, *6*(1), 47-65.

Conroy, R. (2001). "Spatial Navigation in Immersive Virtual Environments". PhD thesis. UCL (University College London).

Dalton, N., Dalton, R., McElhinney, S., & Mavros, P. (2022). Upper bound projection and Stochastic isovists: a solution to the comparison of Visibility Graph Analysis systems. In Proceedings 13th International Space Syntax Symposium. Western Norway University of Applied Sciences, Department of Civil Engineering.

Hillier, B. (2007) Space is the Machine: A Configurational Theory of Architecture. Space Syntax Ltd.

Hillier, B., and J. Hanson. 1984. The Social Logic of Space. Reprint: Cambridge, UK: Cambridge University Press

Isovist.org (2024) User Guide. Available at: https://isovists.org/user-guide Accessed in 16 February, 2024.

Koutsolampros, P., Sailer, K., Varoudis, T., & Haslem, R. (2019). Dissecting Visibility Graph Analysis: The metrics and their role in understanding workplace human behaviour. In Proceedings of the 12th International Space Syntax Symposium, Beijing Jiaotong University, China.

Lopez Baeza, J., Carpio-Pinedo, J., Sievert, J., Landwehr, A., Preuner, P., Borgmann, K., ... & Noennig, J. R. (2021). Modeling pedestrian flows: Agent-based simulations

McElhinney, S., Conroy Dalton, R., Dalton, N., & Mavros, P. (2022). Detection of Intelligibility leaps using Isovist-waves: joining the dots to map potential 'aha moment' locations. In Proceedings 13th International Space Syntax Symposium. Western Norway University of Applied Sciences, Department of Civil Engineering.

Penn, A., & Turner, A. (2002). Space syntax based agent simulation. Springer-Verlag.

Peponis, J. (1997). Geometries of architectural description. In: Proceedings of the. *1st International Symposium Proceedings* (Vol. 2, p. 34), London, University College of London.

QGIS, Firenze, version 3.28.15 (2024) Available at: http://www.qgis.org/en/site/index.html

Regione Toscana (2019). Direzione Urbanistica e Politiche Abitative - Sistema Informativo Territoriale e Ambientale – SITA.: Carte Tecniche Regionali

RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

Shapiro, S. S.; Wilk, M. B. (1965). "An analysis of variance test for normality (complete samples)". Biometrika. 52 (3–4): 591–611. doi:10.1093/biomet/52.3-4.591. JSTOR 2333709. MR 0205384. p. 593

Slocum, T. A., McMaster, R. B., Kessler, F. C., & Howard, H. H. (2022). Thematic cartography and geovisualization. 4th edition. CRC Press.

Teklenburg, J. A. F., Timmermans, H. J. P., & Wagenberg, van, A. F. G. M. (1993). Space syntax : standardised integration measures and some simulations. Environment and Planning B: Planning and Design, 20(3), 347-357. https://doi.org/10.1068/b200347

Turner, A. (2001) Angular Analysis, in. In: Peponis J, et al. (eds.) Proceedings of the 3rd International Space Syntax Symposium. Atlanta, pp. 30.1-30.11.

Turner, A. (2004). *DepthMap4: A Researcher's Handbook*. http://www.vr.ucl.ac.uk/depthmap/depthmap4r1.pdf

Turner, A. (2007). “To Move through Space: Lines of Vision and Movement”. In: Proceedings, 6th International Space Syntax Symposium, 12 - 15 June, 2007. 6th International Space Syntax Symposium.

Turner, A., Doxa, M., O’Sullivan, D., and Penn, A. (2001) From Isovists to Visibility Graphs: A Methodology for the Analysis of Arcthiectural Space. Environment and Planning B: vol 28, 103-121. pp.108-109

Turner, A., Penn, A. (1999, March). Making isovists syntactic: isovist integration analysis. In *2nd International Symposium on Space Syntax, Brasilia* (pp. 103-121).

Varoudis, T (2012) depthmapX Multi-Platform Spatial Network Analysis Software’, Version 0.30 OpenSource. Avaialble at: http://varoudis.github.io/depthmapX

Varoudis, T., Penn, A. (2015). Visibility, accessibility and beyond: Next generation visibility graph analysis. In: Proceedings of the 10th International Space Syntax Symposium. University College of London, London, UK.

Yamu, C., & van Nes, A. (2017). An Integrated Modeling Approach Combining Multifractal Urban Planning with a Space Syntax Perspective. *Urban Science*, *1*(4), 37. https://doi.org/10.3390/urbansci1040037