#81
VISUALIZING SPACE SYNTAX ANALYSES FOR DECISION MAKERS
Lessons from Israel

YOAV LERMAN
Hebrew University of Jerusalem, Jerusalem, Israel
yoavlerman@gmail.com

YONATAN LEBENDIGER
PlaNet Consultancy, Tel Aviv, Israel
yonatan.arch@gmail.com

ABSTRACT

Space syntax theory has been successfully incorporated into the urban planning field contributing to science-based urban design (Marcus et al., 2010; Karimi, 2012a; Lerman et al., 2014). While the theoretical foundations of space syntax require a thorough explanation (Hillier, 1996; Turner, 2007), its visualizations can be intuitive and serve as powerful tools in urban planning decisions.

To address the growing need of space syntax applicability this paper presents several visualization techniques employed in different planning projects to better communicate and discuss space syntax analyses. These techniques provide ways to clearly impart space syntax results to planners unfamiliar with this novel approach as well as to senior officials and other decision makers.

The case studies presented here are based in Israel and range from mixed-use brownfield development of a former airfield through a city centre revival plan to a municipality expecting massive growth on the fringe of a metropolitan area.

KEYWORDS

Geo-Visualization, Policy Making, Israel, Pedestrian Movement

1. INTRODUCTION

The space syntax discipline has come of age. Alongside recent improvements in GIS and the understanding of the complex nature of cities, space syntax is ready to take centre stage as one of the major fields that can improve decision making process in the face of growing challenges for cities all over the world (Karimi, 2016; Karimi, 2012b). This paper addresses the challenge of space syntax insemination which is central to this symposium (Heitor and Serra, 2016). This challenge refers to adding capabilities on top of space syntax analysis to increase its capacity and applicability. Specifically, this paper presents several geo-visualization methods used to better communicate space syntax analyses to decision makers in different planning context. The methods' descriptions are then followed by a discussion on their impact on the planning processes and outcomes.

Space syntax analyses may at times, do not fit in current urban planning process. This has been elaborated on, especially in the North American context (Raford, 2010; Major, 2015). While there is a rather well-established transport planning discipline (c.f. McNally, 2007) and plenty of planning work done on land use and building volumes, space syntax approach do not follow either of these disciplines. Furthermore, current transport planning deals mainly with vehicular transportation, while space syntax has a major strength in non-motorized transport planning

(Hillier et al., 1993; Lerman et al., 2014).In addition, space syntax analyses can inform decisions on land use distribution and especially retail and location of major live-centres (Hillier, 1996; Hillier, 1999), yet under current planning practices these decisions are (usually) not taken following centrality and location systematic analyses. Moreover, space syntax derived insights may collide with conventional vehicular transport planning and land use allocation decisions, putting barriers to the introduction and use of space syntax in the planning process.

Recent computational advances have made space syntax ready to hit the mainstream with relative ease compared to the past. The open nature of Depthmap alongside the QGIS space syntax toolkit (Varoudis, 2012; Gil et al., 2015) make it easy to export space syntax results in various ways and use the GIS capabilities to build new visualization techniques. These techniques can be easily shared and improved, possibly leading to a library of visualization techniques available for different contexts. Furthermore, the capacity of Depthmap to handle large scale data as demonstrated by recent studies (Serra and Pinho, 2013; Serra et al., 2015) makes space syntax ready to tackle a larger set of planning decisions.

The rest of this paper is organized in the following way: the next section presents several visualization techniques applied in actual planning projects done in different urban contexts in Israel. The section afterwards discusses the impact of space syntax in policy making based on the projects presented earlier and the final section concludes with several suggestions for making space syntax a common planning aid with an expanded visual language.

2. VISUALIZATION TECHNIQUES AND CASE STUDIES

Three visualization techniques are presented in this chapter. Each technique is accompanied by an example from an actual planning project it was used at. The projects themselves are long-term in their nature and involve a myriad of planners, architects and consultants as well as decision makers at different levels. The three projects are taken from different municipalities, which are all part of the growing Tel Aviv Metropolitan Area: The city of Tel Aviv itself, the city of Rishon Letzion and the municipality of Binyamina. In the city of Tel Aviv space syntax analysis was applied in the planning of a new mixed-use quarter on brownfield land; in Rishon Letzion it was used in an urban regeneration plan; and in Binyamina it was applied in assessing new proposed regional roads necessity.

2.1 SPATIAL POTENTIAL IDENTIFICATION – TEL AVIV, DOV AIRFIELD PLAN

The visualization technique shown here uses space syntax analysis in order to identify a possible urban core inside a proposed project. This identification helps in recommending specific locations (i.e., street segments and intersections) where further planning considerations may be needed.

This specific projects deals with an existing airfield in the northern section of the city of Tel Aviv. As the airfield prepares to be shut down the land is ready for an urban development in an area just to the north of the intensive city core. Since the proposed project will become concrete only in the future there was a need for to identify the most significant new streets and intersections inside the project boundaries. An important street is a street that has a relatively high spatial potential compared to other streets inside the project, while an important intersection is an intersection where important streets meet. For the specific analysis in this case an axial map of the city of Tel Aviv was used in order to evaluate the spatial potential of the axial lines that are completely inside the project or cross its boundaries. Each of these axial lines was graded according to its spatial potential using a single measure going up from zero (least spatial potential) to five (highest spatial potential).

To quantify the spatial potential, several space syntax axial measures were used based on the literature regarding correlations between pedestrian movement volume and space syntax measures. These measures were: Global Integration, Local Integration (with r=3), Global Choice, Local Choice (with r=3) and Connectivity (for relevant literature please see: (Hillier et al., 1993; Baran et al., 2008; Lerman and Omer, 2013; Lee and Seo, 2013; Özer and Kubat, 2014).

Specifically, this was done in the following way: initially all lines were given the value of zero as their spatial potential value. A point was added for the spatial potential value for each line that had a relatively high value in one of the five axial measures (in this specific example for the top ten percent values for each axial measure). Thus, each time an axial line had a specific space syntax measure valued at the top ten percent (among all lines inside the project), a point was added to its spatial potential value. Hence, an axial line that had relatively high values in all of the five measures got the maximum five points, while a line that had a high value only in a single measure got only one point. An axial line that did not appear in any of the top ten percent of the specified measures got a value of zero as its spatial potential. A short Python script, which does this calculation, available for QGIS, can be found online. This technique allows for a single map to reflect the spatial importance of all the axial lines inside the project area.

Overall, the Dov Airfield project consists of 121 axial lines (including lines that are fully or partially inside the project area). Figure 1 shows the Dov Airfield addition to the axial map of Tel Aviv. Presented in this map is the value of local integration (r=3). Table 1 presents the analysis of the axial lines according to this technique. As can be seen in Table 1, less than twenty percent of the axial lines have a spatial potential value which is greater than zero. This means that most of the axial lines do not exhibit relative high values at even a single measure. Out of the axial lines that do have a spatial potential value greater than zero (twenty one lines in all) a third have the maximum value of five (seven axial lines), meaning that they are the part of the top ten percent in each of the five axial indices mentioned previously.

A map which visualizes the application of this technique for Dov Airfield is shown in Figure 2. Presenting this map to decision makers enabled focusing further efforts on the urban design of intersections where two important axial lines meet (where each line had high spatial potential). This technique proved valuable in highlighting the most important streets and intersections in this project, where improvements to the public realm would have the highest influence and where complex transport planning decisions are needed to be made.

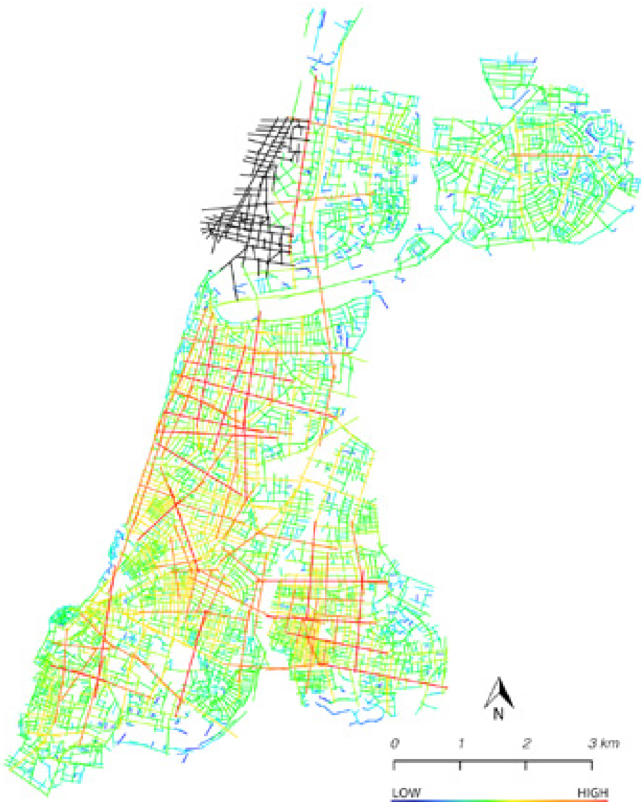

Figure 1 - Local integration (R=3) of Tel-Aviv with the proposed Dov Airfield project (in black).

	No. of Axial Lines	Percentage
Value of 5 (max)	7	5.79%
Value of 4	2	1.65%
Value of 3	2	1.65%
Value of 2	3	2.48%
Value of 1	7	5.79%
Value of 0 (min)	100	82.64%
All	121	100.00%

Table 1 - Axial lines values according to the spatial potential technique in Dov Airfield project.

Figure 2 - Application of 'spatial potential identification' for the Dov Airfield project. The white circles mark the intersections with the highest spatial potential inside the project.

2.2 HEAD/TAIL PEDESTRIAN MOVEMENT VISUALIZATION – RISHON LETZION URBAN REGENERATION PLAN

The visualization technique shown here applies space syntax analyses to emphasize the pedestrian movement core of an existing urban centre based on an empirically calibrated pedestrian movement model. This visualization provides a clear map of the street segments where high pedestrian volume is expected and where the potential for urban revitalization is at its highest. The demonstrated project itself deals with urban revival and intensification of the centre of the city of Rishon Letzion. The project encompasses 162 hectares where currently there are 42,000 inhabitants. The city aims to intensify its centre with additional 130,000 square meters for offices and commerce as well as additional 5,000 housing units.

In order for the regeneration plan to take place, a multi-modal transportation plan was conceived, which enables central streets to serve their role as urban places and carry different kinds of traffic with efficiency and minimal friction among different road users. As part of this transportation plan space syntax analysis was used to create a pedestrian movement model (as previously done in other cases such as: Lerman et al., 2014). This model assesses the expected pedestrian movement volume for each road segment. The pedestrian movement model was used as a reference for city regeneration actions such as streets improvements, allocations of building rights and land use changes.

To allow for all stakeholders to easily relate to the pedestrian movement model a clear and simple map had to be provided. For this a straightforward visualization based on head/tail breaks proposed by Jiang (2013) was used. This algorithm breaks a heavy-tailed distribution in a deterministic fashion and captures the underlying hierarchy of the data. This is done by partitioning all the data values around the mean into two parts (head and tail) and continuing the process iteratively for the head values (above the mean) until the remaining head part do not exhibit a heavy-tailed distribution. Since pedestrian movement is not distributed evenly and many streets carry low volume of movement compared to the few that carry high volume of movement (Jiang, 2009), the head/tail breaks provide a fitting categorization for visualization of this movement distribution.

First, a pedestrian movement survey took place at 75 points using the gate count method on a sunny spring weekday. The survey was conducted for eight hours (From 10 AM till 1 PM and from 3 PM till 8 PM) in which for every hour ten minutes were observed at each survey point. The pedestrian survey itself also exhibited a heavy-tailed distribution with a low number of survey points having high volume of pedestrian movement and most survey points having relatively low volumes of pedestrian movement.

Thus, the 75 survey points were divided into the following three categories (shown in Figure 3):

1. High pedestrian movement volume (over 548 pedestrians per hour, on average) — 8 points which account for 11% of the survey.
2. Medium pedestrian movement volume (less than 548, but more than 240 pedestrians per hour, on average) — 15 points which account for 20% of the survey.
3. Low pedestrian movement volume (less than 240 pedestrians per hour, on average) — 52 points which account for 69% of the survey.

Out of the empirical survey a pedestrian movement model was created using statistical correlations in a similar fashion to other studies2 (Raford and Ragland, 2006; Lerman et al., 2014). The movement model itself reflects the nature of urban movement, with a high number of road segments carrying relatively low movement volumes and a low number of road segments who are subject to high movement volumes (Jiang, 2009). Therefore, the head/tail breaks algorithm (Jiang, 2013) was used to visualize the survey results.

The city centre itself comprises 1,280 road segments, which were divided into the following categories (shown in Figure 4a):

1. High volume of pedestrian movement expected (over 300 pedestrians per hour on average) – 97 segments which account for 7.6% of the city centre.
2. Medium volume of pedestrian movement expected (less than 300 and over 121 pedestrians per hour on average) – 200 segments which account for 15.6% of the city centre.
3. Low volume of pedestrian movement expected (Less than 121 pedestrians per hour on average) – 983 segments which account for 76.8% of the city centre

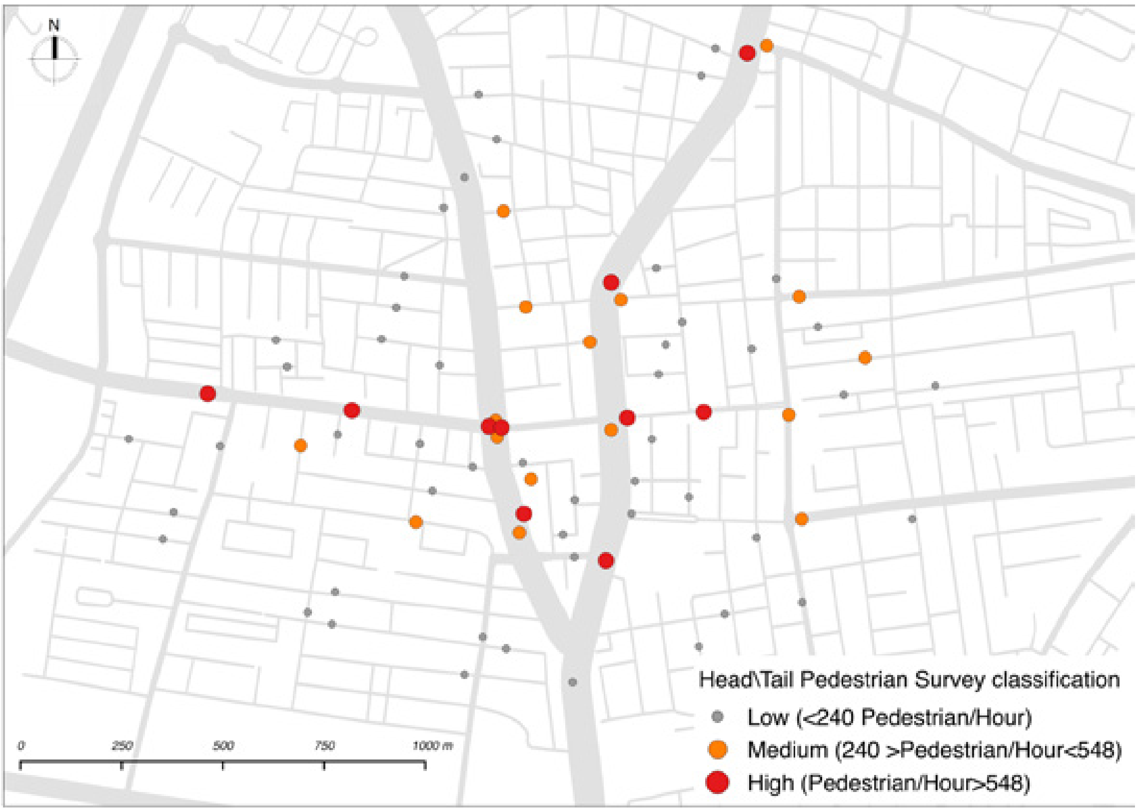

Figure 3 - Pedestrian survey results in Rishon Letzion. The area of intervention is marked in blue.

Figure 4 shows the pedestrian movement volume model visualization under the head/tail breaks (Figure 4a) and under the standard space syntax colour scheme (Figure 4b). Finally, in order to present a clear and comprehensive model map which can be used easily by policymakers a manual cleaning process took place for which the results are shown in figure 5. This refinement process removed isolated segments and added others to create a continuous and coherent network map. This map contains the city centre road network divided into the most important pedestrian core network segments, the secondary pedestrian road network and the background road network. The pedestrian core network segments are where most of the "tough" planning decisions are needed and where public space improvements carry the most benefits. The map shown in Figure 5 is not the correct model map, yet for practical decision making is makes more sense than the map in Figure 4a. This map can serve as reference point for different stakeholders since the segments in it are continuous, and fit the infrastructural decisions that this map can be used for (for a discussion on the benefits of clear and simple models in policymaking see: Givoni et al., 2016).

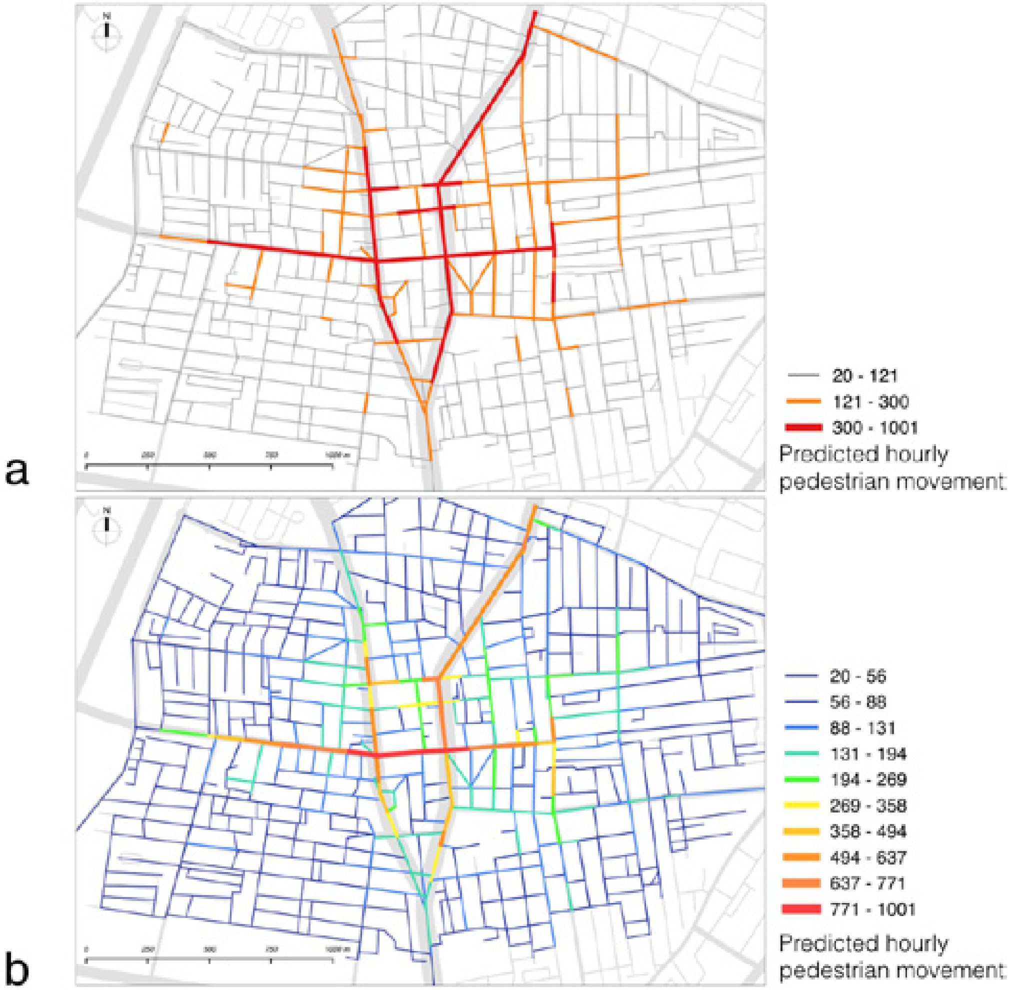

Figure 4 - Pedestrian movement volume model for Rishon Letzion Centre: (a) shows the model after visualizing according to head/tail breaks; (b) shows the model visualization using classic space syntax colour scheme.

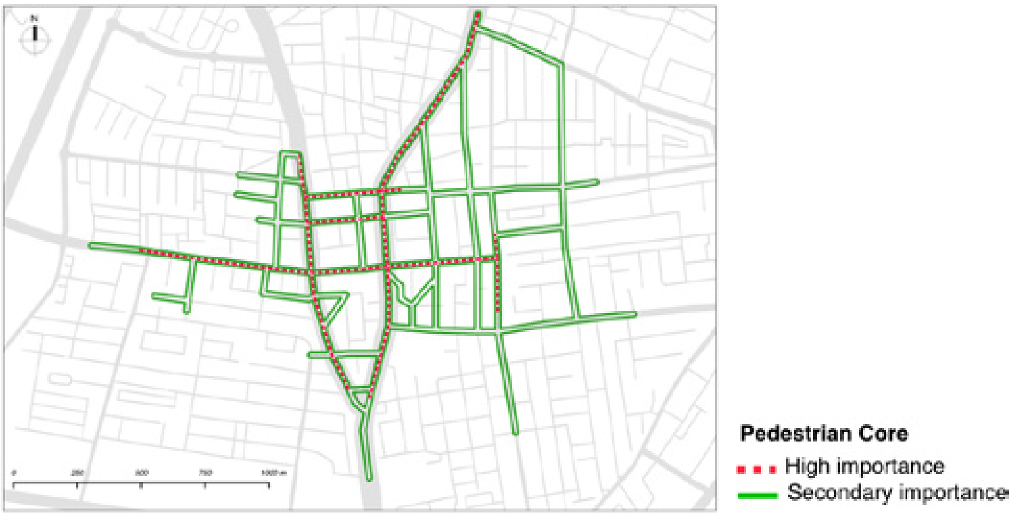

Figure 5 - The pedestrian movement model results provided for decision makers after a manual clean-up intended to produce a more coherent map.

In this case, the space syntax analysis contributed to changing the way the decision makers and the rest of the planning team looked at the regeneration project in its entirety. Space syntax analysis helped create a plan that directs the intensification and improvements to the most important street segments in the city centre (in terms of pedestrian movement and vitality) by focusing efforts on public space and road sections changes along these segments.

2.3 CHOICE IMPACT FOR ASSESSMENT – BINYAMINA OUTLINE PLAN

The visualization technique shown here applies space syntax analyses to assess vehicular movement patterns and to evaluate possible changes due to the introduction of new regional roads.

The demonstrated project in this instance deals with vehicular transportation planning in a growing community. The municipality of Binyamina is located at the fringe of Tel Aviv Metropolitan Area and is expecting significant growth in the coming years. The size of the municipality is 2,400 hectares with 15,000 inhabitants, expecting to grow to about 30,000 by 2040. In line with the expected growth there are plans to add new regional roads. Besides the conventional transportation assessments using the four-step model (McNally, 2007), space syntax analysis was used to assess the new roads relevance and impact on vehicular flow changes. Space syntax analyses afforded a quick way to assess the impact of new regional roads on existing roads inside and outside the municipality. The current vehicular conventional models use traffic analysis zones and do not have the resolution to analyse specific urban segments that may act as critical movement sections.

In order to assess potential vehicular flows this analysis focused on angular choice measures (Turner, 2007) as the choice measure reflects the through-movement potential of a given segment in the network. In addition, the analysis was applied at different radii reflecting different regimes for movements that occur at different distances – from medium vehicular distances (5 km) to longer trips (20 km and beyond).

The visualization technique presented here shows the relative impact on angular choice values following proposed changes to the road network. Specifically, it was done separately for potential shorter trips (5 km up to 10 km) and potential longer trips (20 km up to 75 km). This technique focuses on the relative change in the choice value on a given road segment and not the absolute choice values. The specific steps used for this visualization are describes below:

1. Analyse the existing and planned road network at different radii. In this case we considered ranges of 5-10 km for local trips and 20-75 km for longer trips.
2. Normalise Choice variables by dividing at the max value for each radii resulting in values between zero and one.
3. Divide the planned network's normalised choice values by the existing network's values for each radius under consideration, for all overlapping segments. Values that are higher than one represent choice value increase (signifying probable higher motorized demand for the road segment under future conditions), while values that are lower than one represent choice value decrease (signifying probable lower motorized demand for the road segment under future conditions).
4. Visualize the choice increases and decreases in the clearest way possible. In the case presented here we used equal breaks separately for the increased and decreased value and then superimposed them together.

This method has several drawbacks such as that it does not take the size and speed of the roads into account. If the trip distribution is known (for example how many trips are shorter than 20 km and how many are longer than 20km), the super-imposed map can be tuned to reflect this actual distribution. Preliminary results show merit for using the choice variable as a proxy for vehicular movement at different radii but further work needs to be carried out.

Figures 6 and 7 present the superposition of choice impact analysis at different radii. Figure 6 shows this analysis for long radii of between 20 km and 75 km (intended to capture longer trips) made out of specific analysis at radii 20 km, 40 km and 75 km. This figure shows that a new road (dashed green line) would increase the number of long trips using the eastern highway (Highway 6), while lowering the number of long trips using the western highway (Highway 4). Figure 7 shows the same for shorter radii of between 5 km and 10 km (intended to capture local trips) made out of specific analysis at radii of 5 km, 7.5 km and 10 km. This figure shows that the proposed new road would enlarge the number of short trips using road 653.

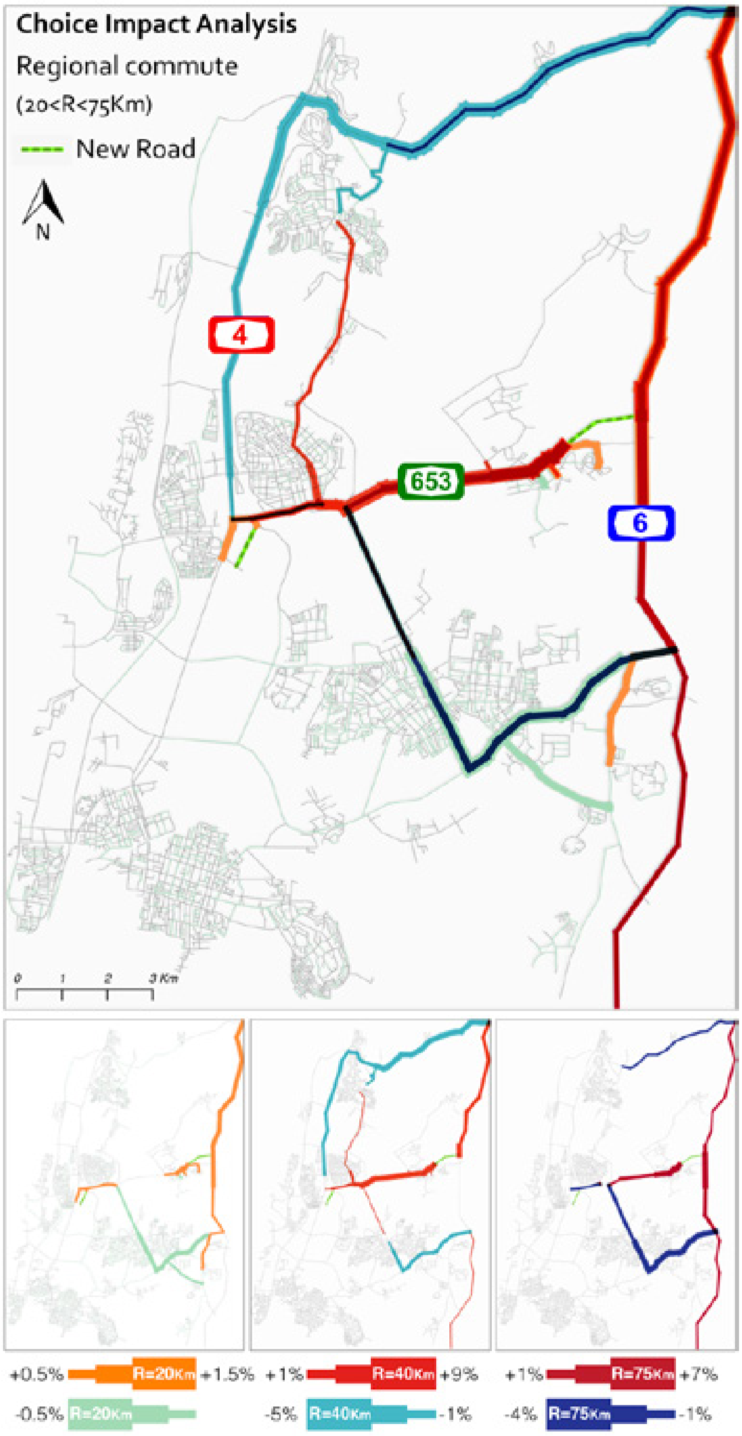

Figure 6 - Choice impact analysis for longer distances (20 km up to 75 km) for Binyamina regional roads.

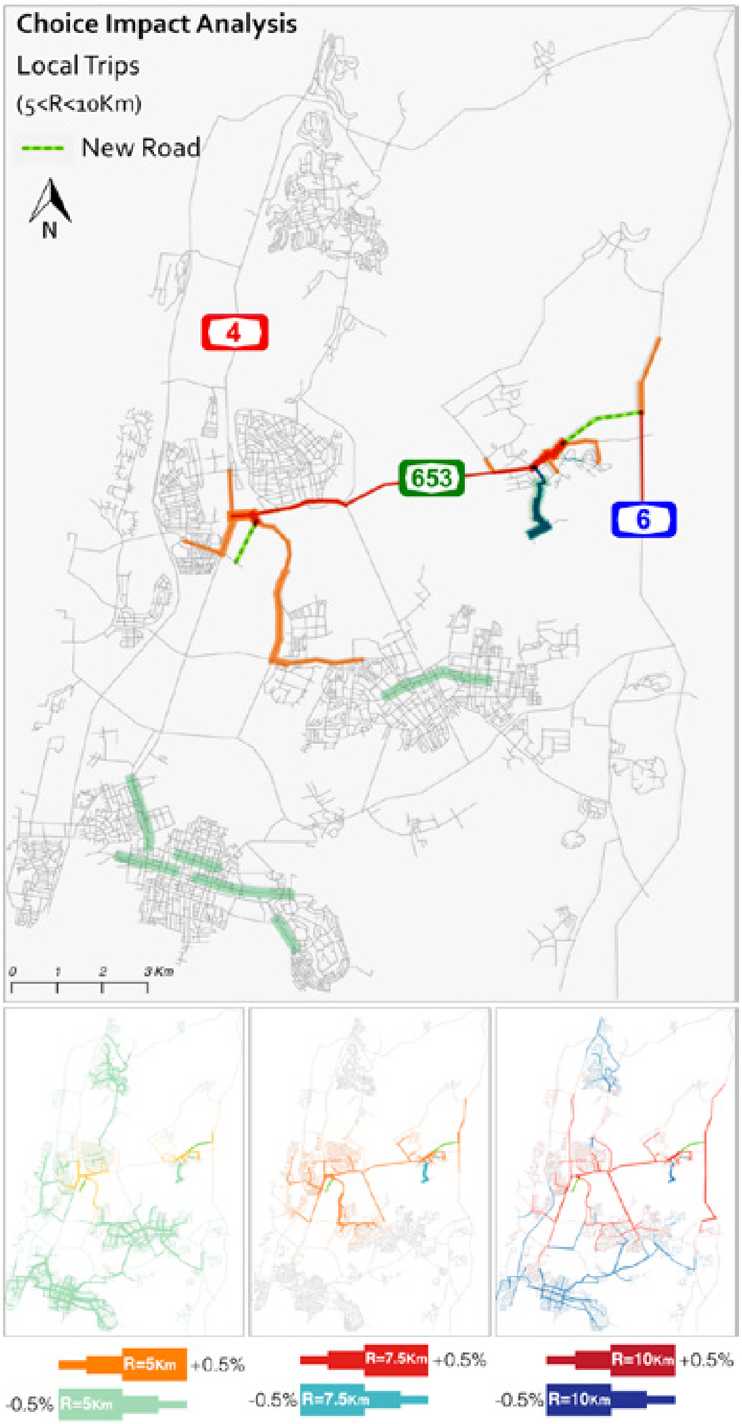

Figure 7 - Choice impact analysis for shorter distances (5 km up to 10 km) for Binyamina regional roads.

The analysis applied in this project proved especially effective both in understanding whether the new roads may cause current roads to be bypassed (i.e. actually changing congestion patterns) and to understand the combined impact of the new roads together.

3. RESULTS – IMPLICATIONS FOR POLICY MAKING

In all three cases described above the major impact of using space syntax as part of the planning process was to focus the planners' attention on the importance of the road network structure and its impact on the other planning decisions needed to be made (changes to street sections, land use distribution, multi-modal transportation and so forth).

Except for the third example (Binyamina) where the decisions were already centred on possible changes to the regional road network, the other two examples helped to change significant parts of the principal discussions to the road network structure itself. Furthermore, this new focus offered the ability to analyse possible changes to the road networks and their implications regarding transportation, land use and so forth3.

As far as these particular projects show, the planning community (at least in Israel) is ready to embrace network planning as part of the planning process itself. It can be considered as a step toward making the urban planning profession an evidence-based one (Marshall, 2012). Applying space syntax as part of the planning process adds an analytical component, which helps in focusing the planners' attention on the vital importance of the road network structure.

4. CONCLUSIONS

To summarize, in the studies presented in this paper, the attention to the road network's impact on urban dynamics helped planning teams get back to the traditional way of urban planning. That is to say that road network planning (connectivity and right of way allocation) comes before decisions on land uses, buildings and interiors are made and not the other way around.

Several limitations in the work presented here include the fact that these visualization techniques are experimental in their nature and have not been developed through consistent usage. The different visualization techniques themselves were used in a somewhat arbitrary way. Further work is needed to assess the visualization techniques proposed here in a systematic way.

Another recurrent challenge in the application of space syntax is the almost unavoidable friction with (conventional) traffic engineers. The current use of the four-step model (McNally, 2007) reigns supreme when discussing and predicting vehicular scenarios. Space syntax has not been used to a significant degree for vehicular transport planning, even though it seems to be of great potential (Pereira et al., 2012). Further research should assess space syntax accuracy versus that of the conventional transportation models and look to reduce the current friction between the two approaches. The possible application of space syntax in the most traditional transportation planning context may help spread it further and faster.

Finally, several other challenges come to mind when considering the potential of space syntax and the contribution of the space syntax community. A current state-of-the-art practice compendium may well be due. This proposed compendium should provide guidelines on best practice of space syntax with regards to transport planning, land use, urban regeneration and so forth. Another possible venue may be to create an open visualization scripts library which will enable consistent space syntax analyses in different kind of projects and contexts besides the Depthmap related visualizations.

Easy, fast, consistent and reproducible visualizations based on space syntax analyses would open the way for space syntax to be in a considerable greater use than is currently done. Also, at times, planning projects require adhering to a strict timeline that is rather short and insufficient for a rigorous and thorough research. This is another point where consistent visualization tools can help in reducing the amount of time and effort needed to communicate space syntax results. Right now, space syntax is more often than not used for the most complex of projects (Marcus et al., 2010), where traditional design tools have significant limitations. It can and should be used much more frequently in planning decisions in order to facilitate the move to evidence-based design (Marshall, 2012; Karimi, 2012a).

In conclusion, this paper presents additional capacities and capabilities for space syntax usage in urban planning in different contexts. Overcoming the insemination challenge (Heitor and Serra, 2016) would require further work, yet the simplicity and elegance of space syntax shows promise for a highly useful method for urban planning.

ACKNOWLEDGEMENTS

We gladly acknowledge the cooperation with Ari Cohen Architects and Urban Planners, Irit Solzi and Dror Gershon Architects and Urban Planners and Viaplan Ltd. in the work presented here. We also recognize the pioneering efforts of Tel Aviv Municipality, Rishon Letzion Municipality and Binyamina-Givat Ada Municipality in improving and changing planning processes.

NOTES

Please see: https://github.com/ylerman/Top20

[2] Applying a stepwise regression resulted in an R-square of 0.69 compared to the observed pedestrian movement volume (with $p<0.01$). The model needed only two variables – an angular integration with radius of 1,000 m (which had a correlation coefficient of 0.59 to observed pedestrian movement volume) and commercial fronts distribution variable (which has a value of 0 for no commerce, 1 for partial commerce and 2 for two-sided commercial street segments). For further details on statistical correlations and movement model please see: Lerman et al., 2014. The model equation itself for the log value of hourly pedestrian movement model is as follows:

2.755913+0.009*(angular integration at 1,000 m radius)+0.514*(commercial fronts)

[3] Since the discussion of future changes to the road network involves sensitive propositions which are still being deliberated by the cities' officials themselves we are unable to share them in this paper. However, we have used the same techniques described in this paper to evaluate and visualise the impact of hypothetical changes to the road network in each of the cases.

REFERENCES

Baran, P. K., Rodríguez, D. a., and Khattak, A. J. (2008). "Space Syntax and Walking in a New Urbanist and Suburban Neighbourhoods." *Journal of Urban Design*, 13(1),pp. 5–28.

Gil, J., Varoudis, T., Karimi, K., and Penn, A. (2015). "The Space Syntax Toolkit : integrating depthmapX and exploratory spatial analysis workflows in QGIS." In *Proceedings of the Tenth Space Syntax Symposium*, 148:1-12, edited by K. Karimi, L. Vaughan, G. Palaiologou and T. Bolton. London: Space Syntax Laboratory, University College London.

Givoni, M., Beyazit, E., and Shiftan, Y. (2016). "The use of state-of-the-art transport models by policymakers – beauty in simplicity ?" *Planning Theory & Practice*, 17(3), pp. 385–404.

Heitor, T., and Serra, M. (2016). "Lisbon's 11th International Space Syntax Symposium – challenges and prospects for the space syntax field." *Journal of Space Syntax*, 6(2), pp. 279–282.

Hillier, B. (1996). "Cities as movement economies." *URBAN DESIGN International*, 1(1), pp. 41–60.

Hillier, B. (1999). "Centrality as a process: accounting for attraction inequalities in de- formed grids." *URBAN DESIGN International*, 4(3), pp. 107–127.

Hillier, B., A. Penn, J. Hanson, T. Grajewski, and J. Xu. (1993). "Natural Movement: Or, Configuration and Attraction in Urban Pedestrian Movement." *Environment and Planning B: Planning and Design*, 20(1), pp. 29–66.

Jiang, B. (2009b). "Street Hierarchies: A Minority of Streets Account for A Majority of Traffic Flow." *International Journal of Geographical Information Science*, 23(8), pp. 1033–1048.

Jiang, B. (2013). "Head/Tail Breaks: A New Classification Scheme for Data with a Heavy-Tailed Distribution." *Professional Geographer*, 65(3), pp. 482–494.

Karimi, K. (2012a). "A configurational approach to analytical urban design: "Space syntax" methodology." *URBAN DESIGN International*, 17(4), pp. 297–318.

Karimi, K. (2012b). "Special issue: Evidence-informed and analytical methods in urban design." *URBAN DESIGN International*, 17(4), pp. 253–256.

Karimi, K. (2016). "The shifting paradigm of space syntax research and its future prospects: A reflection on the 10th International Space Syntax Symposium in London, 2015." *Journal of Space Syntax*, 6(2), pp. 275–278.

Lee, S., and Seo, K. W. (2013). "Combining Space Syntax With GIS-Based Built Environment Measures in Pedestrian Walking Activity." In: Kim Y. O., Park H. T., and Seo K. W. (eds) *Proceedings of the 9th International Space Syntax Symposium*, 98:1-14. Seoul: Sejong University.

Lerman, Y., and Omer, I. (2013). "The Effects of Configurational and Functional Factors on the Spatial Distribution of Pedestrians." In: D. Vandenbroucke, B. Bucher and J. Crompvoets (eds.), *Geographic Information Science at the Heart of Europe*, Springer. Heidelberg, Germany, pp.: 383-398.

Lerman, Y., Rofè, Y., and Omer, I. (2014). "Using Space Syntax to Model Pedestrian Movement in Urban Transportation Planning." *Geographical Analysis*, 46(4), pp. 392–410.

Major, M. D. (2015). "The hidden corruption of American regular grids: Why space syntax doesn't work in the United States , when it looks like it should." In *Proceedings of the Tenth Space Syntax Symposium*, 75:1-12, edited by K. Karimi, L. Vaughan, G. Palaiologou and T. Bolton. London: Space Syntax Laboratory, University College London.

Marcus, L., Stahle, A., and Dahlhielm, M. (2010). "Architectural Knowledge and Complex Urban Space Analysis of Five Proposals for Slussen in Stockholm." *Journal of Space Syntax*, 1(1), pp. 177-198.

Marshall, S. (2012). "Science, pseudo-science and urban design." *URBAN DESIGN International*, 17(4), pp. 257–271.

McNally, M.G. (2007). "The Four-Step Model." in D. A. Hensher and K. J. Button (eds.) *Handbook on Transport Modelling* (Handbooks in Transport, Volume 1), pp. 35-53.

Özer, Ö., and Kubat, A. S. (2014). "Walkability: Perceived and measured qualities in action." *ITU Journal of the Faculty of Architecture*, 11(2), pp. 101–117.

Pereira, R., F. Holand, V. Medeiros, and A. Barros. (2012). "The Use of Space Syntax in Urban Transport Analysis: Limits and Potentials." *Proceedings of the Eighth International Space Syntax Symposium*, 8214: 1–25. Santiago de Chile, 3–6 January 2012.

Raford, N. (2010). "Social and Technical Challenges to the Adoption of Space Syntax Methodologies as a Planning Support System (PSS) in American Urban Design." *Journal of Space Syntax*, 1(1), pp. 230-245.

Raford, N., and Ragland, D.R. (2006). "Pedestrian volume modelling for traffic safety and exposure analysis: Case of Boston, Massachusetts." *Transportation Research Board 85th Annual Meeting Compendium of Papers* (Paper #06–1326 (CD-ROM)).

Serra, M., Hillier, B., and Karimi, K. (2015). "Exploring countrywide spatial systems: Spatio-structural correlates at the regional and national scales." In *Proceedings of the Tenth Space Syntax Symposium*, 84:1-18, edited by K. Karimi, L. Vaughan, G. Palaiologou and T. Bolton. London: Space Syntax Laboratory, University College London.

Serra, M., and Pinho, P. (2013). "Tackling the structure of very large spatial systems - Space syntax and the analysis of metropolitan form." *Journal of Space Syntax*, 4(2), pp. 179–196.

Turner, A. (2007). "From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis." *Environment and Planning B: Planning and Design*, 34(3), pp. 539–555.

Varoudis T. (2012). "DepthmapX Multi-Platform Spatial Network Analysis Software, Version 0.30 Open Source." Available at: http://varoudis.github.io/depthmapX/