From ‘Orthogonal’ Sprawl to ‘Curvilinear’ Dense: Assessing Accessibility Indices for Urban Networks of Social Housing in UAE

Khaled Galal Ahmed

Architectural Engineering Department, United Arab Emirates University, Al Ain, UAE
kgahmed@uaeu.ac.ae

Abstract. The shift towards designing more dense urban social housing neighbourhoods has started with the embracing of urban sustainability principles by the UAE government since the beginning of the 21st century. The assessment of the recent neighbourhoods designs still lacks concrete evidence about their expected performance especially for pedestrian mobility networks. This concern is gaining further significance with the noticeable tendency of most of the recent urban designs towards developing organic and curvilinear networks instead of the conventional orthogonal grids of the mobility networks that distinguished the traditionally designed neighbourhoods in the country. To bridge this gap, the research comparatively and quantitatively analysed the accessibility performance indicators of both of the traditional and the modern urban network designs. The research adopted the Case Study method with quantitative investigation tools that are fundamental to Urban Network Analysis, especially in relation to Accessibility. The simulation of the urban networks of two selected urban social housing neighbourhood forms, representing the networks of both the traditional urban orthogonal sprawl and the recent curvilinear dense one, were utilized employing the UNA toolbox. Three complementary Accessibility Indices were analysed including: Reach, Gravity and Straightness. Through this analysis, the aspects that affected the accessibility performance of the two urban form paradigms and the problems that have been associated with the designs of the urban networks of the new social housing projects, have been revealed. It became evident that the denser urban form was not sufficient in enabling more accessible facilities in the recent neighbourhood designs. The orthogonal grid, even with its very low Floor Area Ratio showed better performance of in the three accessibility indices especially the Straightness index, if compared with the much denser curvilinear grid with its ‘naturally longer’ pattern. The inefficient number and the inappropriate distribution locally provided facilities in relation to the pedestrian mobility networks have contributed to these disappointing results. So, it is essential to include this and/or similar urban network quantitative simulation tools to help develop genuinely sustainable urban forms for this significant type of urban development in the UAE cities.

1. Introduction

Social housing programs have started in the UAE since the establishment of the country by 1971. The early urban forms of the social housing neighbourhoods were distinguished with their sprawling urban spaces with generous areas of both the housing plots and urban spaces. The shift towards designing more densified urban forms of social housing neighbourhoods has started with the adoption of urban
sustainability principles by the UAE government since the beginning of the 21st century [1]. The recently designed versions of social housing projects are significantly denser with much higher Floor Area Ratios (FAR), if compared with the traditional social housing neighbourhoods. Currently, all local housing authorities in each Emirate in the United Arab Emirates (UAE), as well as the federal housing authorities in the country, are working remarkably hard to promote sustainable housing designs especially for social housing developments. To achieve this goal, some initiatives, guidelines and rating systems have been tailored to guide the development of this sector of housing towards sustainability. Examples include Estidama Pearl Community Rating System (PCRS) in Abu Dhabi [2], Al Sa’fat Green Building System in Dubai [3], the Barjeel Green Building Regulations in Ras Al Khaima [4] and Abu Dhabi National Housing Guidelines for Integrated Communities [5].

It is widely believed that the denser the urban development is, the more pedestrian-friendly its urban network will be [6]. Despite this recently adopted urban development approach, but actually there is no concrete evidence, that goes beyond the conventional mobility assessment tools such as measuring catchment distances, etc, about the expected performance of the pedestrian mobility networks in terms of their efficiency in enabling accessibility from houses to locally supplied facilities [7]. This concern is gaining further significance with the noticeable tendency in most of the recent designs of social housing neighbourhoods towards organic and ‘curvilinear’ networks, instead of the ‘orthogonal’ grid of the mobility networks in traditionally designed neighbourhoods. Accordingly, the research aims at comparatively analysing the accessibility performance of both of the traditional and the recent modern urban networks in social housing neighbourhoods. This would reveal the aspects that affect the accessibility performance of the two urban paradigms and hence highlight the problems, if any, that have been associated with the designs of the urban networks of the new social housing projects. It is envisaged that the interpretation of the results of these investigations could help devise some outcomes that enable the designers to enhance the accessibility of the urban networks towards achieving more sustainable social housing neighbourhoods in the UAE.

2. Research Method

The research adopts the Case Study method with quantitative investigation tools. The case study method was selected because it is the most suitable for addressing the research objective because it helps develop typological theories, or contingent generalizations on the different causal patterns leading to a particular outcome [8]. In addition, the quantitative tools are indeed fundamental to Urban Network Analysis, especially in relation to Accessibility. But this does not mean that the qualitative dimension of neighbourhood design does not matter. Rather, the reconciliation between both of the qualitative and quantitative tools is the ideal approach for urban mobility and accessibility investigations. As this research focuses on the simulation of urban networks in social housing neighbourhoods in the design phase, so, the quantitative tools were rationally utilized as detailed in the following subsection.

2.1. Urban Network Analysis

With the recent development of urban mobility and accessibility simulation tools, it is possible now to examine the predictable level of efficiency of the pedestrian mobility networks of urban systems while they are still in the design phase. Among the most important urban networks simulation tools is the Urban Network Analysis (UNA) toolbox. The UNA toolbox helps develop urban modelling that encompasses the urban form, land uses (including the housing units and the locally supplied facilities) and the mobility network grid. This allows the study of the physical layout of urban form designs and helps explain the ways in which they would function. The UNA toolbox has been recently developed by the ‘City Form Lab’ at Harvard University, School of Design. It enables the designers to assess accessibilities and encounters between people or places along the designed mobility networks. So, ultimately the UNA predicts how a specific urban network performs. Having said that, it should be also considered that the UNA toolbox and actually other similar urban network simulation tools are
not representing the urban reality. Still, such urban simulation techniques can significantly help designers to interpret urban development designs, and accordingly take decisions to enhance them.

For accessibility analysis, the UNA toolbox in Rhinoceros 6 compute program was utilized in this research to perform accessibility calculations between the urban network Origins (single family houses as the only designed house pattern) and the Destinations points (the provided facilities in the neighbourhood). Both of the Origin and Destination points were defined on the digital models developed on Rhinoceros 6 software for the urban networks of the two selected neighbourhoods. The UNA toolbox accessibility simulations include computing the scores of 3 different Accessibility Indices — Reach, Gravity, and Straightness [9]. Each of these 3 indices offers a unique and complementary way of analysing urban network accessibility relationships between the Origins (houses) and the Destination points (facilities) in an urban development design, explained by Sevtsuk [9] as follows:

**Reach:** The Reach index, also known as a “cumulative opportunities accessibility index” is the accessibility analysis score which results from counting the number of provided facilities of one or more types (Destinations), which can be reached from each house (Origin) in the neighbourhood, within a certain catchment distance (Search Radius) on the urban network. The attained scores in this analysis are “Positive Integers” where the Reach score of an Origin (house) describes the number of Destinations (facilities) that are reachable from the Origin at a shortest path distance of at most Search Radius. In the Reach analysis simulation, a walkshed is traced from each house in every direction on the urban network until the limiting radius is reached. To simplify computing the number of facilities reached from the houses within the defined Search Radius for each facility, the Destination weights value was set as Weight = Count. Accordingly, no weighting will be applied and only the count of facilities was considered.

**Gravity:** Unlike the Reach analysis that simply counts the number of facilities (Destinations) around each house (Origin) within a given catchment radius, the Gravity analysis considers ‘travel costs’ required to reach each of the facilities (Destinations). Gravity index assumes that accessibility at Origin is proportional to the attractiveness or weight of each Destination, and inversely proportional to the distance or travel cost between the Origin and Destinations. The four measures that control the Gravity index of the urban network in a neighbourhood are:

1. The distance between houses and facilities.
2. The number of existing/accessible facilities.
3. Attractiveness α* (the exponent that controls the weight of targeted Destinations based on their areas). The default value is set at “1” assuming that as Destination size increases, the Gravity index also increases in a linear manner.
4. Walking Sensitivity β* (the exponent that controls the “distance decay” effect depending on how sensitive the people are to walking in the region). The effect of distance is inversely proportional to the Gravity index and it decreases exponentially. As distance to Destinations grows, the Gravity index decreases. The exact distance decay rate is controlled with the exponent β. Since the beta values essentially approximate the likelihood to walk to particular Destinations, they also depend on Destination types. Beta and the corresponding distance decay are derived from the assumed mode of travel and Destination type where a higher beta value denotes a higher sensibility to walking distances. In harsh climates, such as in the UAE, beta values are usually adjusted around “0.004” for walking trips in meters.

**Straightness:** The Straightness index illustrates the extent to which the shortest paths from Origins (houses) to Destinations (facilities) resemble straight Euclidean paths. So, the Straightness metric records the positive deviations in travel distances that result from the geometric constraints of the network in comparison to straight-line distances in a featureless plane. Straightness index depicts how
much longer an actual walking paths from houses to facilities is, in comparison to as-a-crow-flies distance. So, this helps overcome the misleading appearance of some Destinations as seemingly close to Origins while they are actually inaccessible due to long travel detours. The results of the Straightness analysis to single destinations vary from 0 to 1. So, for example, a Straightness value of 0.75 indicates that an imaginary straight-line distance measured from the Origin to the Destination constitutes 75% of the shortest available network route to the same Destination, i.e., the network route requires a 25% detour compared to the line of sight between the Origin and Destination.

The UNA toolbox analysis for the 3 Accessibility Indices was performed for each single type of the provided facilities in the two selected neighbourhoods. So, for each index the analysis was frequently performed, each time for one type of the available facilities within the studied urban neighborhood (one time for retail, one time for school, and so on …). The Search Radius or catchment distance, that defines the radius in meters of the pedestrian mobility network used for computing the 3 accessibility indices, was defined based on the relevant local benchmark for the studied neighbourhoods. As per the local standards in Abu Dhabi Emirate, where the two case studies are located, the maximum walking distance between houses and facilities, ranges between 350 to 800 depending on the type of the facility (Table 1) (Abu Dhabi Urban Planning Council, 2014).

Table 1. Maximum Catchment Radius for each type of neighbourhood facilities.

| No | Facility Type | Maximum Distance |
|----|---------------|-----------------|
| 1  | Cafeteria     | 800             |
| 2  | Clinic        | 800             |
| 3  | Grocery       | 600             |
| 4  | Kindergarten  | 350             |
| 5  | Mosque        | 800             |
| 6  | Open Space    | 800             |
| 7  | Pharmacy      | 800             |
| 8  | Retails *     | 800             |
| 9  | School        | 800             |

* Including, but not limited to: ATM, Post Shelter, Laundry, Gents’ Saloon, Beauty Centre, Gardening Services, etc.

2.2. Selected Case Studies
Two case studies were selected to undertake the comparative Accessibility Indices analysis of their urban mobility networks. Al Dhaher Neighbourhood in Al Ain city and Watani 1 in Abu Dhabi city, both in Abu Dhabi Emirate, representing both the traditional sprawl and orthogonal urban form, and the recent modern compact and curvilinear urban form, respectively. Al Dhaher neighbourhood in Al Ain city has a typical urban form that was repeatedly developed in Abu Dhabi Emirate [Figure 1]. The neighbourhood accommodates 460 single family houses on two floors each. The ample areas of the standard square and rectangle-shaped housing plots are 45m×45m and 45m×60m, respectively. As low density was the norm for this traditional urban model, the Floor Area Ratio (FAR) of the neighbourhood reached to only 0.11. The orthogonal urban network of the neighbourhood serves housing clusters of 10, 12, 14, and 16 plots grouped around semi-public open spaces. The mobility network links the houses with the provided facilities that include 2 schools, 1 kindergarten, a clinic, 8 groceries, 7 cafeterias, 1 pharmacy, 9 mosques and some various retail shops distributed on both the longitudinal middle axial grid of the neighbourhood’s network and its outer axes.
Figure 1. The orthogonal urban form and the mobility network of Al Dhaher traditional neighbourhood in Al Ain City.

The recently developed Watani 1 social housing neighbourhood in Abu Dhabi city is the second comparative case study that is claimed to be designed as a sustainable urban community [Figure 2]. The 968 semi-detached houses neighbourhood was completed in 2015, with plot sizes of 25x28m and 20x25m. The degree of urban density, represented by the FAR, for this modern social housing case study reached to 0.41, which is almost 4 times higher than the traditional case study of Al Dhaher neighbourhood. The design of the urban morphology also adopts the idea of housing clustering but in a mainly curvilinear morphology around organic-shaped open spaces with various sizes. This organic street grid form has been repeated in several recent design models of urban neighbourhoods in the UAE. In this case the curvilinear mobility network connects the houses with the designed facilities that include 2 cafeterias, 3 groceries, 1 pharmacy, 1 retail outlet, 1 school, 1 kindergarten, and 1 mosque.

Figure 2. The curvilinear compact urban form and the mobility network of Watani 1 modern neighbourhood in Abu Dhabi city.
The accessibility indices of the urban network of each of the two case studies were comparatively analysed where the scores of Reach, Gravity, and Straightness were obtained and compared for each type of facilities.

3. Results and discussions

In this section, the results of the analysis of the 3 measures of the accessibility analysis: Reach, Gravity, and Straightness for the two neighbourhoods are graphically presented for the retail facilities only, as an example of the visual maps resulting from the analysis of each facility. Meanwhile, the overall results of each measure are represented, when applicable, in a table showing the normalized scores for the total number of houses in both of the neighbourhoods. For the accessibility analysis of the three indices, all houses have been considered as Origins and each type of facilities as a Destination. Search Radius was defined for each type of facilities according to the benchmark in Table 1, above. Through the normalization of the measures of each type of facilities (obtained by dividing all scores for all houses on the number of houses in each neighbourhood), the comparison could be done between the two case studies.

3.1 Reach Analysis

The Reach analysis was performed for all the provided facilities in the two studied neighbourhoods. Figures 3 and 4 below show the visual graphs for the Reach analysis results for the retail facilities in Al Dhaher and Watani 1, respectively. Table 2 represents the results attained from the normalized Reach scores for the total number of houses in each of the two neighbourhoods for all provided facilities except clinic that was not provided in Watani 1 neighbourhood.

![Figure 3. The Reach analysis for the retail facilities of Al Dhaher traditional neighbourhood.](image)

![Figure 4. The Reach analysis for the retail facilities of Watani 1 modern neighbourhood.](image)
Table 2. The comparative results for UNA Reach Analysis of the two case studies.

| No. | Analysis          | Neighbourhood       | FAR | No. of Houses | Normalized Reach Scores for the total number of houses |
|-----|-------------------|---------------------|-----|---------------|--------------------------------------------------------|
|     |                   |                     |     |               | Cafeteria      Clinic      Grocery      Kindergarten    Mosque      Open Space    Pharmacy      Retail      School |
| 1   | Al Dhaher (Al Ain)| 0.11                | 460 | 1.463         | 0.104         | 1.196         | 0.03         | 2.272         | 0.983         | 0.12         | 0.659         | 0.239         |
| 2   | Watani 1 (Abu Dhab) | 0.41               | 968 | 0.869         | NA            | 1.042         | 0.024        | 0.666         | 20.61         | 0.333        | 0.322         | 0.292         |

As shown in the Table, the normalized values for the Reach scores indicate that the orthogonal traditional urban network is performing better in 5 facilities types than that for the recent curvilinear urban network, even with the latter has much denser urban form. Actually, the Reach scores are much higher in Al Dhaher traditional neighbourhood than in Watani 1 modern one for Mosques (2.272 vs. 0.666), and moderately higher for Cafeterias (1.463 vs 0.869) and Retail (0.659 vs 0.322). Meanwhile, it was only slightly higher for Groceries (1.196 vs 1.042) and Kindergartens (0.03 vs 0.024). At the meantime, Watani 1 performed much better than Al Dhaher for the Reach score of Open Spaces (20.61 vs 0.983), moderately better for the Pharmacies (0.333 vs 0.12) and very slightly better for Schools (0.292 vs. 0.292). These Reach normalized scores reveal that Watani 1 is really performing less than anticipated as a dense urban form. Clearly, the inappropriate distribution of facilities and the longer curvilinear mobility paths have contributed to this shortcoming.

3.2 Gravity Analysis

Secondly, the Gravity analysis was conducted for all the provided facilities in the two studied neighbourhoods as well. Figures 5 and 6 below show the visual graphs for the retail facilities in both of them. Table 3 represents the results obtained from the normalized Gravity scores for each of the provided facilities considering the total number of houses in each of the two studied neighbourhoods.

Figure 5. The Gravity analysis for the retail facilities in Al Dhaher traditional neighbourhood.

As shown in Table 3, the normalized values for the Gravity scores affirmed the results from Reach analysis where the orthogonal traditional urban network performed better in the same 5 facilities types than the recent much denser curvilinear urban network. The Gravity scores were much higher in Al Dhaher traditional neighbourhood than in Watani 1 modern one in Mosques (0.438 vs. 0.113), and moderately higher for Cafeterias (0.255 vs 0.136), Groceries (0.382 vs 0.261), and Retail (0.174 vs 0.046). Meanwhile, it was only slightly higher for, Kindergartens (0.042 vs 0.037). On the other hand, Watani 1 performed much better than Al Dhaher for the Gravity score of Open Spaces (3.936 vs
0.179), moderately better for the Pharmacies (0.051 vs 0.017) and slightly better for Schools (0.043 vs. 0.034).

![Figure 6. The Gravity analysis for the retail facilities in Watani 1 modern neighbourhood.](image)

**Table 3.** The comparative results for UNA Gravity analysis of the two case studies.

| No. | Analysis  | FAR | No. of Houses | Cafeteria | Clinic | Grocery | Kindergarten | Mosque | Open Space | Pharmacy | Retail | School |
|-----|-----------|-----|---------------|-----------|--------|---------|--------------|--------|------------|----------|--------|--------|
| 1   | Al Dhaher (Al Ain) | 0.11 | 460          | 0.255     | 0.02   | 0.382   | 0.042        | 0.438  | 0.179      | 0.017    | 0.174  | 0.034  |
| 2   | Watani (Abu Dhabi) | 0.41 | 968          | 0.136     | NA     | 0.261   | 0.037        | 0.113  | 3.936      | 0.051    | 0.046  | 0.043  |

Again, these Gravity normalized scores confirms that Watani 1 is not performing as anticipated with its dense urban form. The reasons obviously include the inefficient number of facilities and their distribution in relation to the urban mobility network. Also, the longer curvilinear pedestrian pathways are seemingly contributing to these lower Gravity scores.

3.3 *Straightness Analysis*

The third analysed Accessibility Index is Straightness. Figures 7 and 8 below illustrate the visual graphs of the Straightness scores for the retail facilities in Al Dhaher and Watani 1 respectively, while Table 4 represents the comparative normalized Straightness results for all houses in the two case studies.

![Figure 7. The Straightness analysis for the retail facilities in Al Dhaher traditional neighbourhood.](image)
Figure 8. The Straightness analysis for the retail facilities in Watani 1 modern neighbourhood.

Table 4. The comparative results for UNA Straightness Analysis of the two case studies.

| No. | Analysis Neighbourhood | FAR No. of Houses | Cafeteria | Clinic | Grocery | Kindergarten | Mosque | Open Space | Pharmacy | Retail | School |
|-----|------------------------|-------------------|-----------|--------|---------|--------------|--------|------------|----------|--------|--------|
| 1   | Al Dhaher (Al Ain)     | 0.11              | 460       | 1.137  | 0.082   | 0.959        | 0.025  | 1.809      | 0.762    | 0.09   | 0.76   | 0.172  |
| 2   | Watani 1 (Abu Dhabi)   | 0.41              | 968       | 0.584  | NA      | 0.695        | 0.019  | 0.458      | 13.415   | 0.217  | 0.204  | 0.168  |

Except for Open Spaces, Pharmacy, and Retail facilities, the Straightness normalized values for all houses in Al Dhaher orthogonal sprawling neighbourhood were found higher for 6 facilities compared with Watani 1 with its denser urban form and curvilinear mobility grid. Almost similar to the normalized scores for the previous two indices - the Reach and Gravity - the Straightness normalized scores were much higher in Al Dhaher traditional neighbourhood than in Watani 1 modern one in Mosques (1.809 vs. 0.458) and Cafeterias (1.137 vs 0.584), and were moderately higher for Groceries (0.959 vs 0.695), and Retail (0.86 vs 0.204). Meanwhile, it was only slightly higher for, Kindergartens (0.025 vs 0.019) and Schools (0.172 vs. 0.168). At the meantime, Watani 1 performed much better than Al Dhaher for the Straightness normalized scores of Open Spaces (13.415 vs 0.762), moderately better for the Pharmacies (0.217 vs 0.09). Actually, these Straightness normalized scores were somehow expected because of the explicit longer curvilinear grid of the mobility network of Watani 1. Accordingly, besides the typology of the curvilinear grid, the inefficient number of the provided facilities and the inappropriate locational distribution of them in relation to the urban network grid are obviously having a negative impact on the Straightness index in Watani 1 modern neighbourhood.

4. Conclusions

With a rushed subjective perception when looking at the designs of both the conventional neighbourhood with its urban sprawling form and the modern much denser neighbourhood, one might envisage that the later would provide more accessible facilities, and hence, more sustainable built environment. But the quantitative analysis of the complementary 3 accessibility indices of the Urban Network Analysis; the Reach, Gravity, and Straightness, have enabled more in depth and accurate prediction and obviously different outcomes. With some exceptions, the normalized scores for the accessibility indices have revealed that Watani 1 is actually performing less than anticipated as a dense urban form.

So, it is evident through this analysis that being denser with even 4 times higher FAR than the urban forms of traditional social housing neighbourhoods is not sufficient in realizing more accessible
facilities in the recent neighbourhood designs. Besides the better performance of the orthogonal grid especially in the Straightness index, if compared with the curvilinear grid pattern with its longer lengths, the inefficient number and the inappropriate distribution of the locally provided facilities in relation to the pedestrian mobility networks have contributed to these unexpected results. It is important now to amend the process of the design and its approval or licensing for social housing neighbourhoods, by the concerned municipalities or housing authorities, to include this and/or similar urban network simulation quantitative analysis tools that would help reach to better designs and genuinely accessible and pedestrian-friendly urban forms for this significant type of urban development in the UAE cities.

Acknowledgment
The author wishes to acknowledge the funding for this research project from the Emirates Center for Happiness Research at the United Arab Emirates University, Grant Code G00003226. He also acknowledges the effort exerted by the Research Assistants from the University.

References
[1] K. Galal Ahmed, Designing Sustainable Urban Social Housing in the United Arab Emirates, Sustainability, Vol. 9, No. 1413; doi:10.3390/su9081413, 2017.
[2] Abu Dhabi Urban Planning Council, Abu Dhabi Community Facility Planning Standards, Standards Report. Version 1.0. ADUPC, Abu Dhabi, 2019.
[3] Dubai Government. Al Sa’fat Dubai Green Building System. Available online: https://www.dm.gov.ae/wp-content/uploads/2020/11/Safat-English.pdf, first accessed, 14 March 2020, 2020.
[4] Ras Al Khaimah Municipality, “Barjeel Ras Al Khaimah Building Regulations V1.1”, Available online: https://mun.rak.ae/Documents/Barjeel_Ras%20Al%20Khaimah%20Building%20Regulations%20V1.1.pdf, first accessed, 12 Dec. 2019.
[5] Abu Dhabi Housing Authority (ADHA), “Abu Dhabi National Housing Guidelines for Integrated Communities, Planning Guidelines. V 1.0”. Abu Dhabi: ADHA, 2016.
[6] URBACT, Densification beyond the city centre: urban transformation against sprawl. Available online: https://urbact.eu/densification-beyond-city-centre-urban-transformation-against-sprawl, First accessed 13 Dec. 2019.
[7] K. Galal Ahmed, “Sustainable Modes of Mobility in New Urban Neighborhoods in UAE: Assessing Walkability and Bikeability”, in Ahmed Al-Masri and Yousef Al-Assaf (Eds): Sustainable Development and Social Responsibility – Ch 33, Volume 2, pp 309-318, Springer, Cham. DOI: 10.1007/978-3-030-32902-0_33, 2020.
[8] A. Bennett, “Case Study: Methods and Analysis”, in Neil J. Smelser and Paul B. Baltes (eds.) International Encyclopedia of the Social & Behavioral Sciences, Elsevier Ltd, 2001.
[9] Andres Sevtsuk, “Urban Network Analysis for Rhinoceros 3D Tools for Modelling Pedestrian and Bicycle Trips in Cities”. USA: City Form Lab, Harvard University, 2018.