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On Spatial Mechanisms of Social Equity: Exploring the Associations between Street Networks, Urban Compactness, and Social Equity

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Abstract: In several publications between 1998 and 2003, Elizabeth Burton examined whether urban compactness promotes social equity. Based on an extensive literature review, Burton developed numerous urban compactness and social equity measures. Using a sample of 25 free-standing English cities of different sizes, her studies found that urban compactness measures are often statistically correlated with social equity measures in these cities. Extending Burton's studies, this study explores the correlations between the measures of street networks, urban compactness, and social equity in the same 25 cities that Burton studied. Correlational analyses revealed that street network measures are correlated differently with different urban compactness and social equity measures. Some street network measures are not statistically correlated with social equity and urban compactness measures. Some are statistically correlated with urban compactness measures, but not with social equity measures. Yet others are statistically correlated with social equity measures, but not with urban compactness. Still others are statistically correlated with both social equity and urban compactness measures. Therefore, it was concluded that spatial mechanisms may work differently for different aspects of social equity. The implications of these findings are discussed.

Keywords: urban compactness; urban density; mixed use; social equity; topological accessibility; space syntax

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1. Introduction: Burton's Publications on Urban Compactness and Social Equity

The objective of Burton's research, first presented in her PhD dissertation [1] and then in several subsequent publications [2–6], was to examine whether urban compactness promotes social equity and justice (which she used interchangeably). Her studies were designed as a comparative investigation involving many cities to allow differences in the effects of different levels and types of urban compactness on social equity to become discernible at the city-wide level. She focused her study at the city-wide level rather than on smaller neighborhoods, because many alleged effects of compactness appear to occur at that level. Her focus on the city-wide scale was also dictated by the fact that it is not easy to identify examples of distinctly compact and non-compact cities, encompassing all aspects of compactness. Therefore, instead of examining whether the "compact city"—as a distinct phenomenon—promotes social equity, her studies sought to explore whether greater compactness measured at the city-wide level is associated with social equity measured at that level [2] (p. 1976).

Burton [4] defined urban compactness along three dimensions—*density*, *mix-of-use*, and *intensification*. She provided several indicators describing each dimension. For describing density, she used two indicators for *gross density*; four indicators for *net density*; one indicator for *population-weighted density*; three indicators for the *density of sub-centers*; and four indicators for *housing density*. Altogether, she used 14 individual density indicators. For describing *mix-of-use*, she used three indicators for the *provision of facilities*; six indicators for *horizontal mix-of-use*; and two indicators for *vertical mix-of-use*. Altogether, she used

11 individual *mix-of-use* indicators. For describing intensification, she used six indicators for the *increase in density*; one indicator for the *increase in sub-center density*; two indicators for the *increase in population (re-urbanization)*; and seven indicators for the *increase in development*. Altogether, she used 16 individual intensification indicators. She also used six composite compactness indicators combining the density, mix-of-use, and intensification indicators. Altogether, she used 47 indicators to measure urban compactness.

To study the effects of density on social equity, Burton [2] defined social equity at the city-wide level using the following indicators: three indicators for *access to retail facilities*; three indicators for *access to green space*; four indicators for *access to job*; two indicators for *access to public transport*; four indicators for *opportunities for walking and cycling*; seven indicators for *the availability of domestic living space*; two indicators for *health risks*; three indicators for *crime*; eleven indicators for *the degree of social segregation*; and five indicators for *the availability of affordable housing*. Altogether, she included 44 individual social equity indicators. Burton also used the averages of the indicators in each of the ten categories of social equity. In addition, she used three composite social equity indicators: *average of all social equity indicators*, *average of all segregation indicators*, and *average of all housing affordability indicators*. Altogether, she used 57 indicators measuring social equity.

Burton [2] recognized that her indicators have many limitations. She wrote:

> No indicator is a perfect reflection of the dimension it is designed to measure. However, the importance of the indicators for this research lies in their consistency: the values were used only in a relative sense, across all the different cities, not as absolute values in their own right. The significance of the research findings generated by this methodology was assessed in the light of its limitations. The main area of concern, perhaps, is the validity of the indicators, particularly those used to measure social equity. Both urban density and social equity are difficult concepts to quantify—one of the main reasons for lack of empirical evidence to support the compact city debate. The difficulties are threefold: first, only readily quantifiable aspects of the two phenomena could be used; secondly, the indicators may not be an accurate reflection of the dimensions of compactness or social equity which they are designed to measure; and, thirdly, the methods and sources used to measure each indicator may not produce accurate values. [2] (p. 1977)

In her study, Burton used data from 25 cities selected from English administrative districts (Table 1 and Figure 1). Cities with major discrepancies between the district boundary and the edge of the built-up area (that is, a difference of over 25 per cent between the population of the administrative and urban areas in 1981) were omitted from the sample. Only medium-sized cities (those with urban populations between 80,000 and 220,000) were selected to help control for the influence of external factors. The selected cities were also relatively "freestanding", reducing the complex effects of compactness, where cities merge into one another. Any city sharing more than 10% of its boundary with another city was excluded from the sample.

Table 1. The sample of 25 English cities used in Burton's studies, divided based on the local authority categories.

Large Non-Metropolitan Cities	Small Non-Metropolitan Cities	Industrial	Districts with New Towns	Resort and Retirement
Derby Southampton	Bath Cambridge Cheltenham Exeter Gloucester Lincoln Oxford Worcester York	Great Grimsby Luton Ipswich Scunthorpe Slough	Crawley Harlow Northampton Stevenage	Blackpool Eastbourne Hastings Southend-on-Sea Worthing

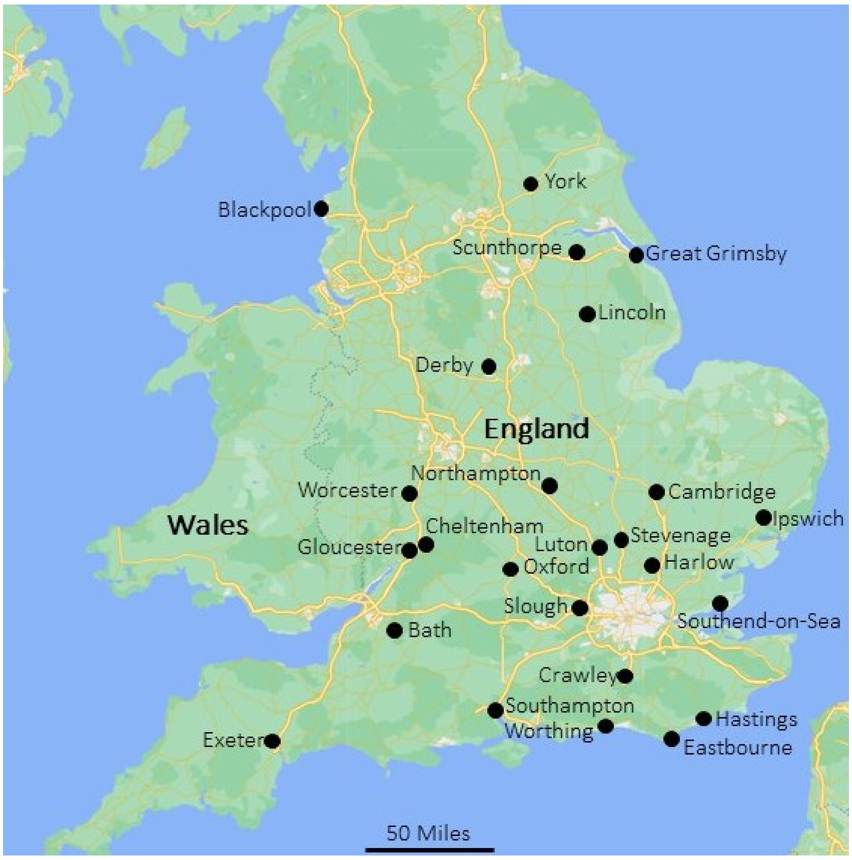

Figure 1. The locations of the 25 cities used in Burton's studies on a partial map of the UK.

Burton [4] ranked her 25 cities from high to low based on the density, mix-of-use, and intensification indicators, as well as based on the composite indicators of these three dimensions of urban compactness. She found that there are differences between the three categories of indicators for the towns scoring high and low. In other words, a compact city is unlikely to exhibit high levels of density, mix-of-use, and intensification at the same time. She also found that scores for individual rather than composite measures of compactness generally exhibited greater contrasts between cities. Therefore, Burton suggested that fine-grain measures can be more useful than overall measures of compactness for studying distinctions between cities.

Based on her statistical analysis of the urban compactness and social equity measures of the 25 cities, collected from a variety of sources, Burton [2] reported the following findings:

- The evidence was weak, but tended to support the claim that high densities increase *access to facilities* and *access to green spaces*, improving social equity.
- The evidence was ambiguous concerning the claim that high densities increase *job accessibility*, improving social equity.
- The evidence supported the claim that high densities increase *public transport use*, improving social equity.
- The evidence contradicted the claim that high densities increase *opportunities for walking and cycling*, improving social equity.
- In some cases, the evidence tended to support, and in other cases, it tended to contradict the claims that high densities increase the amount of *domestic living space*, improving social equity, and that high densities are associated with poorer *health*, reducing social equity.
- The evidence contradicted the claim that high densities reduce *crime*, improving social equity.

- Finally, the evidence supported the claims that high densities reduce *social segregation*, improving social equity, and that high densities reduce the amount of *affordable housing*, reducing social equity.

The impact of Burton's research involving the 25 English cities was significant. According to Google Scholar, at the time when this study was being conducted, Burton's research in [2] had received 763 citations; Burton's research in [3] had received 117 citations; Burton's research in [4] had received 326 citations; Burton's research in [5] had received 131 citations; and Burton's research in [6] had received 72 citations. Given the significance of Burton's studies, a study extending the theoretical and empirical foundations of her studies seems appropriate.

2. Research Problems

Despite Burton's reported findings on the associations between urban compactness and social equity measures in some English cities, many basic questions on these topics have remained unanswered. For example, it is not clear how and why urban compactness should occur in the first place. Most often, they seem to occur naturally overtime through complex physical, social, economic, and political processes. In very few cases, urban designers, planners, developers, and planning authorities have tried to emulate such natural processes, but with very little success. It is often hard to artificially generate and sustain the kind of social, cultural, and economic diversity that urban compactness requires. Conversely, it is also hard to design urban compactness that helps generate and sustain social, cultural, and economic diversity [7]. In general, urban compactness seems to co-evolve with social, cultural, and economic diversity in cities.

Along with a lack of theoretical clarity, measuring urban compactness has remained a problem. Several dimensions of urban compactness are often metrically defined. Important in this regard is that humans are generally poor at metrical-spatial operations. Their abilities to perform metrical operations are also highly variable. Many amongst us often do not understand such complex concepts as urban compactness. Those of us who understand them may not always understand and use them in the same way, because there is no unique definition of urban compactness [8–10]. It is also true that social resources cannot always be metrically defined. The fact that urban compactness should affect such sustainability factors as energy use makes sense, because energy use often depends on the length, area, volume, mass, and functions of buildings, infrastructures, and cities [11]. However, it does not make any immediate sense why urban compactness should also affect social equity and justice.

Then, one should note that subjective perceptions of compactness may contrast markedly with its metrically defined measures. Urban compactness is a perceived experience, affected by social and cultural values [12]. Various studies, for example, have confirmed that empirically derived measurements often do not represent perceived urban density, or compactness [13]. Open spaces, height-to-space ratios, artificial light levels, traffic levels, private gardens and entrances, the absence of nonresidential uses nearby, and social homogeneity may all affect perceived urban density [14], as well as urban compactness. This may be due to the fact that humans develop their understanding of the environment based on immediate information. Therefore, they are easily deceived concerning the overall density if the immediate information suggests otherwise. According to Alexander, "density is a complex concept involving the interaction of perceptions with the concrete realities of the built environment" [15] (p. 182).

Concerning the usefulness of metrically defined concepts such as urban compactness in everyday practice, one should also note that humans are much better at mentally performing topological-spatial operations than metrical-spatial operations. It has been known for a while now in psychology literature that children learn to perform topological operations before they learn to perform metric operations [16]. Therefore, one wonders how the primacy of topological relations over metric relations might be related to Burton's findings on the statistical associations between urban compactness and the distribution of key urban resources such as superstores, green spaces, housing, and jobs that give rise to social equity or inequity. In this regard, several scenarios can be tested:

- In Scenario 1, we may find no statistical association of topological measures describing urban form and structure with urban compactness and social equity measures. Still, statistical associations between urban compactness and social equity measures may exist.
- In Scenario 2, we may find no statistical association of topological measures with social equity measures. Still, statistical associations between topological and urban compactness measures, and those between urban compactness and social equity measures, may exist.
- In Scenario 3, we may find statistical associations of topological measures with social equity measures, but not with urban compactness measures. Still, statistical associations between urban compactness and social equity measures may exist.
- In Scenario 4, topological measures of urban form and structure, urban compactness measures, and social equity measures may all be associated with each other.

These scenarios are presented in Figure 2. The purpose of this study was to explore the validity of these scenarios or mechanisms describing the relationships between topological spatial relations, urban compactness, and social equity. For its purpose, the study used the data provided by Burton in [1,2,4] along with several topological measures of street network properties generated specifically for this study.

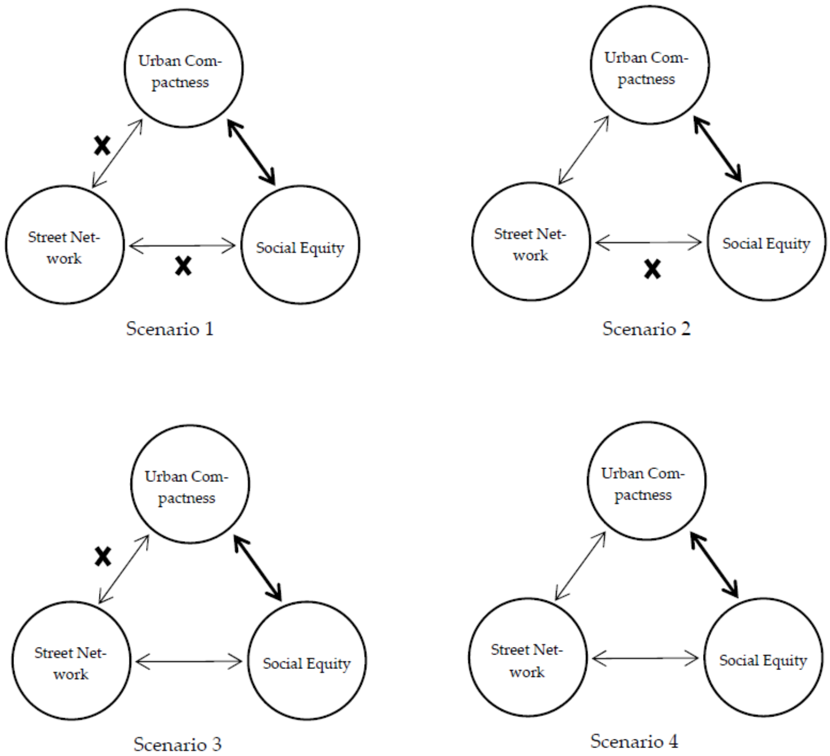

Figure 2. Different scenarios showing how topological accessibility, urban compactness, and social equity or inequity may be related to one another. Based on Burton's findings, it is assumed that associations between urban compactness and social equity measures exist in all scenarios.

3. Methods

Among many topological spatial relations between urban form and structure, the study used only the measures of topological distance and accessibility in street networks. These are different from metric distance and accessibility. Metric accessibility depends on linear distance, while topological accessibility depends on connections or turns. For example, we can say that A and B are x miles apart. Conversely, we can also say that A and B are *n* turns away. Though different, topological and metric accessibilities are also complementary. When combined, they provide a better description of accessibility. For example, the accessibility between A and B if they are ten miles apart, but require no changes in directions, would be different from the accessibility if they are ten miles apart, but require many changes in directions. Additionally, humans often understand and appreciate topological accessibility more easily than metric accessibility. Furthermore, topological accessibility is more robust than metric accessibility. In many cases where precise metric accessibility is hard to determine, topological accessibility can still be determined because its level of precision can vary depending on the task at hand. Therefore, investigations on the associations between urban compactness and topological accessibility can be useful for understanding social equity.

It should be noted here that Burton (cited above) used metric accessibility in her studies to define the properties relevant to social equity, but they are not city-level measures in the way that her density and compactness measures are. For example, the number of persons per hectare and the number of households per hectare are gross density measures that can be applied to the whole city, even though such a measure may not be a true description of how things are distributed in space. Burton herself acknowledges this limitation when she writes, "Most of the indicators [in my studies] measure overall density, and may hide internal distributions of density that are more significant in determining different outcomes" [4] (p. 245). In contrast, Burton's accessibility measures, such as the average distance to the nearest superstores from a set of origins, are more a property of superstores than of the city itself. To put differently, it is possible to change the average distance to superstores by adding or taking out a superstore, without making any changes to the overall accessibility of a city. Therefore, whether defined metrically or topologically, the overall accessibility of a city is a different property than the overall accessibility of facilities within the city.

Therefore, the goal of this study was to explore the statistical associations of the overall topological accessibility of the city with its density, compactness, and provisions for urban facilities to understand social equity, while testing the validity of the scenarios presented in Figure 2. The study was conducted in three stages. First, it described various street network properties of Burton's 25 cities using topological measures. Then, it explored whether Burton's measures of urban density and compactness are correlated with the topological measures of street networks. Finally, it explored whether Burton's measures of social equity are correlated with the topological measures of street networks.

4. Space Syntax

To measure the topological accessibility in Burton's cities, the methods of "space syntax" were used in this study. More generally, space syntax refers to a body of theory, methods, techniques, and measures that can be used in the study of buildings and cities based on the "hidden" structures of perception, use, and experience (for an early theoretical and methodological introduction to space syntax, see [17,18]). Since the 1970s, a substantial body of research has used space syntax to measure street network properties and their effects on social, economic, cultural, and historical processes [19,20].

Space syntax often uses the phrase "spatial configuration", referring to how individual spatial units are related to each other and to the whole in a spatial system. In urban studies, these spatial units generally include *axial lines*, representing straight lines of movement and visibility, and *segments*, representing the parts of axial lines that are broken at the points of intersections with other axial lines. Space syntax provides rigorous techniques to represent a street system as configurations using axial lines and segments, which are called the axial map and the segment map, respectively. It also provides techniques for analyzing the intersecting patterns of these axial lines or segments using different topological and topo-metric measures. Additionally, space syntax allows users to color the map based on the values of a measure of individual units.

One key syntactic measure of space syntax is *integration*. The integration value of an axial line or segment indicates how well the line is connected to all the other lines in a linear map, or how close the line is to all the other lines in the map. A higher integration value of a line indicates a stronger connection of the line to the network of lines. The integration value is also relativized to allow for a direct comparison between networks of different sizes [18]. The integration value of a map as a whole is given by the mean of the integration values of the lines in the map. The other key syntactic measure of space syntax is *choice*. While integration is about closeness, choice is about betweenness. Unlike integration, choice gives the degree to which a line lies on the simplest paths from one line to another line in the network. The choice value of a given line is determined by dividing the number of the shortest paths between any two lines in the map containing the given line, divided by all the shortest paths between any two lines in the map [21]. In simple words, integration measures how easy it is to go from one line to all the other lines of a network, thus indicating the potential of a line for to-movement. In contrast, choice measures how likely it is for a line to be chosen on paths from one line to another in a network, indicating its potential for through-movement [22].

Using space syntax techniques, it is possible to compute the integration and choice values of lines or segments at different radii. For example, the integration or choice value at radius 3 of a line or segment uses only those lines that are three steps away from the given line or segment; the integration or choice value at radius 5 uses only those lines or segments that are five steps away from the given line; and so on. The integration or choice value at radius n of a line or segment considers n steps needed to cover all the lines or segments in the system. Therefore, an integration or choice value computed at a lower radius describes a more local syntactic property than that computed at a higher radius. Note, however, that the most local of any syntactic property of a line is its connectivity value, which is the number of lines directly connected to the line.

Using its methods, techniques, and measures, space syntax is able to describe how axial lines and segments of a street network are connected to each other at different scales, defining accessibility and visibility, as well as how they are associated with social processes of long and short durations (for a review of some of these studies, see [23–26]). Relevant to the present study is the fact that, by using space syntax, many recent studies have looked at issues directly and indirectly related to social equity, such as density and diversity [27,28], land use [29,30], income distribution [30,31], and urban segregation [32–34]. However, none of these studies considered as many cities as did Burton's study. They have usually been limited to one city and/or areas within a city. They also have not considered the multidimensionality of an urban social phenomenon such as social equity as thoroughly as did Burton. Additionally, they have failed to acknowledge that the metric and topological measures of urban form and structure may affect urban social phenomena differently. Therefore, studies involving topological measures of street networks defined using space syntax techniques, urban compactness measures, and social equity measures are warranted.

5. Findings

5.1. Street Network Measures and Burton's Sample of English Cities

The axial and segment map analyses of the 25 cities in the study sample were performed using DepthmapX [35] to determine various street network measures. These measures included axial connectivity, axial integration R3, axial integration R5, and axial integration Rn; axial choice R3, axial choice R5, and axial choice Rn; segment integration R3, segment integration R5, and segment integration Rn; and segment choice R3, segment choice R5, and segment choice Rn.

As noted, space syntax software programs can color the axial lines or the segments of a map using their values for any of its network measures. The colors generally range from red for high values to blue for low values of a network measure. By showing how the values of a network measure are distributed, these colored maps help represent the syntactic structure of a city. There are remarkable differences in the syntactic structures of the 25 cities of this study, as illustrated by their segment maps colored using integration Rn values (Figure 3). Therefore, it would be interesting to see how the network measures of space syntax are related to the compactness and social equity measures in these cities.

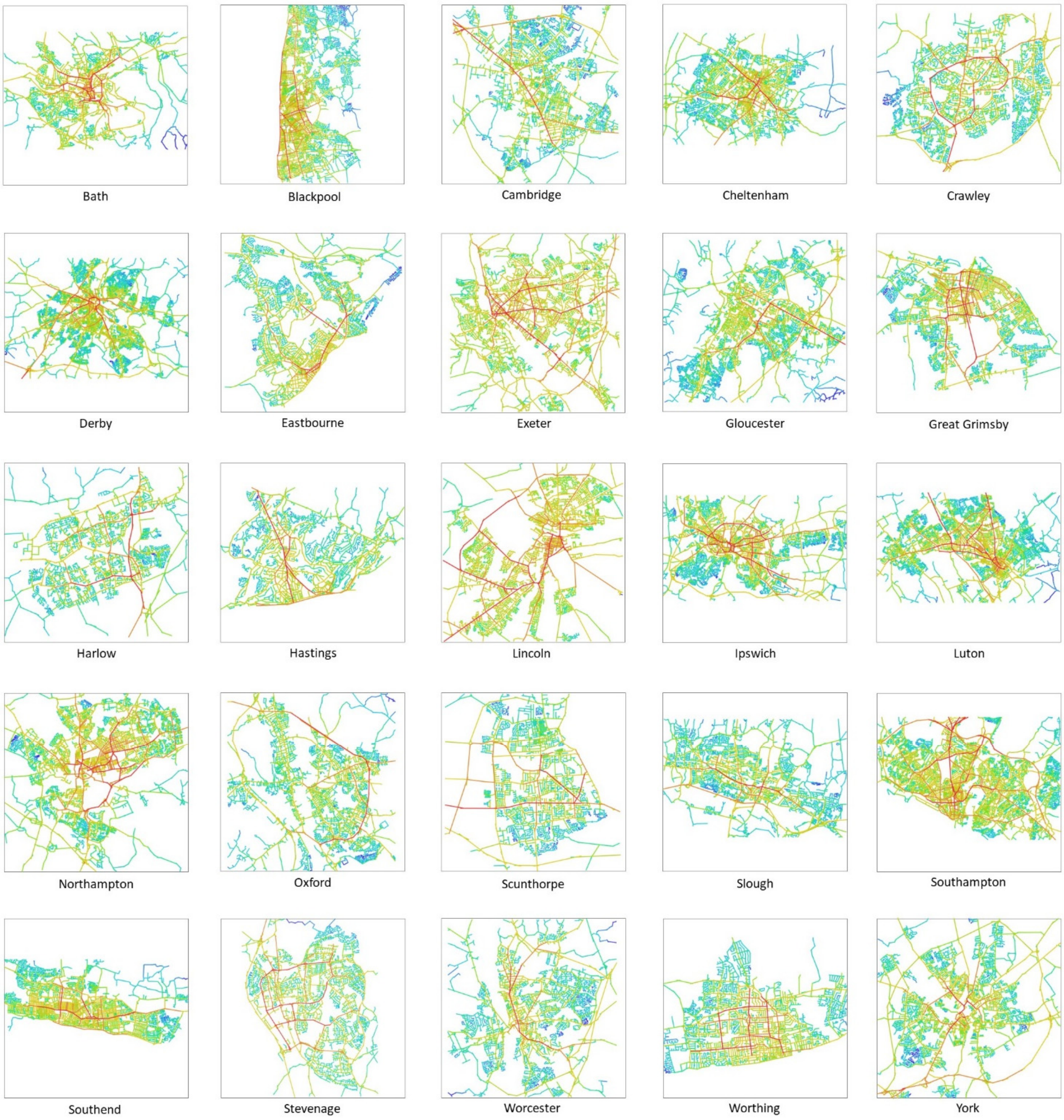

Figure 3. The segment maps of the 25 cities in the study sample colored using integration Rn. The colors range from red, for segments with high integration values, to blue, for segments with low integration values. The distribution of the most integrated segments in these maps shows linear patterns (e.g., Cambridge, Worcester), radial patterns (e.g., Derby, Exeter), deformed grid-like patterns (e.g., Stevenage, Worthing), deformed grid-like patterns with radiating lines (e.g., Ipswich, Lincoln), and so on. These differences indicate different patterns of accessibility and movement in these cities.

5.2. Street Network Measures and Composite Compactness Indicators

The bivariate correlational analyses of this study were performed in IBM SSPS Statistics 24 [36]. The significant results of the correlational analysis for Burton's composite compactness indicators and street network measures are shown in Table 2 (for all the results, see Supplementary Table S1).

Table 2. The table shows only the significant correlations between street network measures and composite compactness indicators, and those between street network measures and individual density, mix-of-use, and intensification indicators.

	A-Conn	AC-Rn	AC-R5	AC-R3	AI-Rn	AI-R5	AI-R3	SC-Rn	SC-R5	SC-R3	SI-Rn	SI-R5	SI-R3
Composite Compactness Indicators													
Average of all compactness indicators	**0.408 ***		**0.416 ***	**0.453 ***					**0.568 ****	**0.585 ****	**0.401 ***	**0.565 ****	**0.585 ****
Average of all density indicators	**0.419 ***		**0.422 ***	**0.447 ***		**0.412 ***	**0.427 ***	**0.413 ***	**0.518 ****	**0.514 ****	**0.431 ***	**0.539 ****	**0.533 ****
Average of all mix-of-uses indicators			**0.417 ***	**0.440 ***									
Individual Density Indicators													
Gross Density													
Persons per hectare	**0.423 ***		**0.468 ***	**0.496 ***		**0.479 ***	**0.499 ***	**0.464 ***	**0.484 ***	**0.479 ***	**0.441 ***	**0.510 ****	**0.506 ****
Households per hectare	**0.503 ***		**0.535 ****	**0.574 ****		**0.565 ****	**0.588 ****	**0.465 ***	**0.542 ****	**0.554 ****	**0.436 ***	**0.571 ****	**0.589 ****
Net Density													
Persons per hectare in built-up area		**0.494 ***						**0.646 ****	**0.535 ****	**0.522 ****	**0.633 ****	**0.552 ****	**0.533 ****
Households per hectare in built-up area	**0.476 ***	**0.420 ***	**0.420 ***	**0.466 ***		**0.451 ***	**0.479 ***	**0.610 ****	**0.584 ****	**0.599 ****	**0.587 ****	**0.603 ****	**0.621 ****
Persons per hectare in residential built-up area		**0.498 ***						**0.649 ****	**0.530 ****	**0.514 ****	**0.637 ****	**0.545 ****	**0.524 ****
Households per hectare in residential built-up area	**0.468 ***	**0.425 ***	**0.413 ***	**0.458 ***		**0.441 ***	**0.470 ***	**0.615 ****	**0.580 ****	**0.592 ****	**0.593 ****	**0.598 ****	**0.612 ****
Population-Weighted Density													
Average of ward densities, measured in terms of persons per hectare	**0.435 ***		**0.551 ****	**0.564 ****		**0.513 ****	**0.519 ****	**0.470 ***	**0.563 ****	**0.546 ****	**0.476 ***	**0.582 ****	**0.558 ****
Density of Sub-centers													
Average density of four most-dense wards, measured in persons per hectare	**0.479 ***		**0.600 ****	**0.604 ****		**0.528 ****	**0.521 ***		**0.542 ****	**0.554 ****		**0.568 ****	**0.584 ****
IndividualMix-Of-Use Indicators													
Living over the shop: area of retail space that is used for accommodation, as a percentage of total retail space									**0.437 ***	**0.486 ***		**0.439 ***	**0.509 ***
Mixed commercial or residential uses: number of purpose-built flats in commercial buildings, as a percentage of all purpose-built flats	**0.578 ****		**0.562 ****	**0.625 ****		**0.542 ****	**0.606 ****		**0.557 ****	**0.604 ****		**0.561 ****	**0.631 ****
IndividualIntensification Indicators													
Number of dwellings completed between 1980 and 1991 for every 1000 households.			**−0.462 ***	**−0.450 ***	**−0.496 ***	**−0.489 ***	**−0.461 ***						
Number of dwellings completed per hectare (gross area of district) between 1980 and 1991					**−0.515 ****								
Number of dwellings completed per hectare (residential built-up area of district) between 1980 and 1991		**0.407 ***	**−0.399 ***		**−0.645 ****	**−0.408 ***							
Derelict land reclaimed as a percentage of total residential built-up area between 1980 and 1991	**0.553 ****		**0.716 ****	**0.719 ****		**0.593 ****	**0.594 ****		**0.592 ****	**0.597 ****		**0.594 ****	**0.588 ****
Average number of planning applications granted annually for every 1000 residents between 1980 and 1991		**−0.701 ****						**−0.646 ****	**−0.554 ****	**−0.544 ****	**−0.625 ****	**−0.553 ****	**−0.540 ****

**: Significant at the 0.01 level (2-tailed). *: Significant at the 0.05 level (2-tailed). A-Conn: axial connectivity; AC: axial choice; AI: axial integration; SC: segment choice; SI: segment integration; Rn: radius n; R5: radius 5; R3: radius 3.

Burton's *average of all compactness indicators* showed somewhat significant and moderately strong positive correlations with axial connectivity, axial choice R5, and axial choice R3. It showed significant and strong positive correlations with segment choice R5 and segment choice R3, and a somewhat significant and weak positive correlation with segment integration Rn, but significant and strong positive correlations with segment integration R5 and segment integration R3. These findings indicate that urban compactness may be affected more by local than global integration and choice values, and that urban compactness may increase with an increase in local integration and choice values. These findings also indicate that street networks with better to-movement and through-movement potentials at local levels may help increase urban compactness.

Burton's *average of all density indicators* showed somewhat significant and moderately strong positive correlations with axial connectivity, axial choice R5, axial choice R3, axial integration R5, and axial integration R3. It showed a somewhat significant and moderately strong positive correlation with segment choice Rn; significant and strong positive correlations with segment choice R5 and segment choice R3; and a somewhat significant and moderately strong positive correlation with segment integration Rn, but significant and strong positive correlations with segment integration R5 and segment integration R3. These findings indicate that, as with urban compactness, urban density may be affected more by local than global integration and choice values, and that urban density may increase with an increase in local integration and choice values. Therefore, by extending our previous suggestion, these findings suggest that street networks with better to-movement and through-movement potentials at local levels may help increase urban densities.

Burton's *average of all mix-of-use indicators* showed some correlations with two local network measures only, which included somewhat significant and moderately strong positive correlations with axial choice R5 and axial choice R3. These findings indicate that mix-of-use may be marginally affected by some local street network measures. Again, extending our earlier observations, these findings suggest that street networks with better to-movement potentials at local levels may help increase not only urban compactness and density, but also urban mix-of-use.

Burton's *average of all intensification indicators*, *average of all population intensification indicators*, and *average of all built-form intensification indicators* did not show any significant correlations with street network measures, indicating that these urban intensification phenomena may not be associated with street network measures (Supplementary Table S1).

5.3. Street Network Measures and Individual Density Indicators

The statistically significant results of the correlational analysis between the street network measures and the individual density indicators are shown in Table 2 (for all the results, see Supplementary Table S2). Both the gross-density indicators—*persons per hectare* and *households per hectare*—showed several correlations with street network measures. These correlations were fewer and weaker for axial measures than segment measures. Two of the four net density indicators—*persons per hectare in built-up areas* and *persons per hectare in residential built-up areas*—showed several correlations with street network measures. Again, these correlations were fewer and weaker for axial measures than segment measures. The other two net density indicators—*households per hectare in built-up area* and *households per hectare in residential built-up area*—showed an almost similar number of correlations with axial and segment measures. Once again, these correlations were weaker for axial measures. The population-weighted density indicator—*average ward density*—showed fewer correlations with axial measures than segment measures, and its correlations with both axial and segment measures were often significant and strong. Only one of the three indicators for the density of sub-centers showed serval correlations with axial and segment measures, which were often significant and strong. The other two indicators showed no correlations. The four indicators for housing density, the six indicators for the increase in density, and one indicator for the increase in sub-center density showed no correlations with street network measures (Supplementary Table S3).

According to the findings, street networks with higher integration and choice values may help increase gross, net, and population-weighted densities. In this regard, segment integration and choice values generally showed stronger associations than did axial integration and choice values. In contrast, axial and segment integration and choice values showed minimal effect on the density of sub-centers, housing density, increase in density, and increase in sub-center density.

5.4. Street Network Measures and Individual Mix-of-Use Indicators

Out of Burton's 11 mix-of-use indicators, only two indicators showed significant correlations with street network measures as shown in Table 2 (for all the results, see Supplementary Table S3). These were *living over the shop* and *mixed commercial or residential uses*. The former showed somewhat significant and moderately strong positive correlations with four local segment measures. The latter showed at least nine significant and strong positive correlations with local axial and segment measures. The findings indicate that higher values of local segment network measures may improve living over shops, and that higher values of local axial and segment network measures may improve mixed residential or commercial uses.

5.5. Street Network Measures and Individual Intensification Indicators

Out of Burton's nine intensification indicators, five showed several significant correlations with axial and segment network measures, as shown in Table 2 (for all the results, see Supplementary Table S4). Out of these five indicators, each of the following three indicators—*number of dwellings completed between 1980 and 1991 for every 1000 households*; *number of dwellings completed, 1980–91, per hectare (gross area of district)*; and *number of dwellings completed, 1980–91, per hectare (residential built-up area of district)*—showed only a few correlations with axial network measures. These correlations were generally negative, somewhat significant, and moderately strong. It remains unclear why the correlation of the *number of dwellings completed* with *axial choice Rn* was positive, but was negative with either *axial choice R5* or *axial integration Rn*.

Two indicators—*derelict land reclaimed, 1982–93, as a percentage of total residential built-up area* and *average number of planning applications granted annually, 1981–91, for every 1000 residents*—consistently showed significant and strong to very strong correlations with both axial and segment network measures. The correlations were positive for the former, indicating that the *derelict land reclaimed* measure increased with an increase in axial and segment network measures. This may have occurred because derelict lands are rarely reclaimed without better network accessibility. The correlations were negative for the latter, indicating that the *average number of planning applications granted annually* decreased with an increase in axial and segment network measures. This may have occurred because cities with higher axial and segment network measures may already have high compactness and density, therefore reducing *average number of planning applications*.

5.6. Street Network Measures and Composite Social Equity Indicators

According to correlational analyses, Burton's composite social equity indicators—*average of all social equity indicators*, *average of all segregation indicators*, and *average of all housing affordability indicators*—were not associated with the local and global network measures of space syntax (for all the results, see Supplementary Table S5).

5.7. Street Network Measures and Average Social Equity Indicators

Among Burton's *averages of social equity indicators* in ten categories, only two *averages* showed a few significant correlations with network measures, as shown in Table 3 (for all the results, see Supplementary Table S5). One of the two *averages*—*average distance to nearest green space, from all wards, most-deprived ward, and difference for most- and least-deprived wards*—showed significant negative correlations with axial network measures. The findings appear to suggest that as local axial network measures increase, the *average distance to nearest green space* seems to decrease.

Table 3. The table shows only the significant correlations between street network measures and averages of individual social equity indicators by category, and those between street network measures and individual social equity indicators.

	A-Conn	AC-Rn	AC-R5	AC-R3	AI-Rn	AI-R5	AI-R3	SC-Rn	SC-R5	SC-R3	SI-Rn	SI-R5	SI-R3
Average of Social Equity Indicators													
Average distance to nearest green space, from all wards, most-deprived ward, and difference for most- and least-deprived wards			**−0.444 ***	**−0.499 ***		**−0.547 ****	**−0.547 ****						
Death rate from mental illness (suicide rate) and respiratory disease		**−0.448 ***						**−0.419 ***			**−0.424 ***		
Individual Social Equity Indicators													
Access to Superstores													
Difference in distance to the nearest superstore for the most- and least-deprived wards							**−0.397 ***						
Access to Green Space													
Average distance to the nearest open green space (from the central point of each ward)	**0.537 ****		**0.772 ****	**0.787 ****	**0.421 ***	**0.785 ****	**0.750 ****		**0.572 ****	**0.606 ****		**0.615 ****	**0.658 ****
Job Accessibility													
Percentage change (1981–1991) in relative proportion of low-income employees/self-employed persons working outside district			**0.551 ****	**0.581 ****		**0.466 ***	**0.472 ***		**0.425 ***	**0.429 ***		**0.433 ***	**0.436 ***
Public Transport Use													
Percentage of low-income employees/self-employed persons who travel to work by public transport (1991)		**0.418 ***			**−0.403 ***								
Extent of Walking and Cycling													
Percentage change (1981–1991) in proportion of low-income employees/self-employed persons who travel to work on foot or bicycle	**0.452 ***		**0.523 ****	**0.563 ****		**0.578 ****	**0.573 ****						**0.419 ***
Amount of Domestic Living Space													
Percentage change (1981–91) in average number of rooms per household								**−0.459 ***			**−0.473 ***		
Percentage of low-income (that is, social renting) three-person households with small homes (1–3 rooms) in 1991									**0.401 ***	**0.414 ***		**0.414 ***	**0.431 ***
Health													
Deaths from mental illness, as a percentage of all deaths (1991)					**−0.447 ***								
Crime													
Highest home content insurance premiums (1995)		**0.421 ***						**0.415 ***			**0.420 ***		
Variation in the cost of home content insurance (1995): difference between highest and lowest premium		**0.519 ****						**0.403***			**0.401 ***		
Percentage change (1981–1991) in segregation of car-less households, by ward	**−0.573 ****					**−0.517 ****	**−0.568 ****						**−0.399 ***

**: Significant at the 0.01 level (2-tailed). *: Significant at the 0.05 level (2-tailed). A-Conn: axial connectivity; AC: axial choice; AI: axial integration; SC: segment choice; SI: segment integration; Rn: radius n; R5: radius 5; R3: radius 3.

The other *average—death rate from mental illness (suicide rate) and respiratory disease—* showed significant negative correlations with axial choice Rn, segment choice Rn, and segment integration Rn. These findings appear to suggest that as global network measures increase, the *death rate from mental illness (suicide rate) and respiratory disease* seem to decrease.

5.8. Street Network Measures and Individual Social Equity Indicators

Only the significant correlations between street network measures and individual social equity indicators are shown in Table 3 (for all the results, see Supplementary Table S6). Only one of the three indicators of *access to superstores* showed one somewhat significant and weak negative correlation with street network measures. One of the three indicators of *access to green spaces* showed several significant and strong to very strong positive correlations with street network measures. One of the four indicators of *job accessibility* showed several somewhat significant to significant, and moderately strong to strong, positive correlations with street network measures. One of the two indicators of *public transport use* showed only one somewhat significant and positive correlation with axial choice Rn, and the other showed somewhat significant negative correlations with axial integration Rn. One of the four indicators of *extent of cycling and walking* showed several somewhat significant to significant, and moderately strong to strong, positive correlations with street network measures. One of the seven indicators of *amount of domestic living space* showed two somewhat significant and moderately strong negative correlations with street network measures, and another showed four somewhat significant and moderately strong positive correlations with street network measures. One of the two indicators of *health—death from mental illness*—showed only one somewhat significant and moderately strong negative correlation with street network measures. Two of the three indicators of *crime* showed several somewhat significant and moderately strong to strong positive correlations with street network measures. Only one of the eleven indicators of *social segregation—percentage change, 1981–91, in segregation of car-less households, by ward*—showed one somewhat significant to significant, and moderately strong to strong, negative correlations with street network measures. Only one of the four indicators of *housing affordability* showed one somewhat significant and strong positive correlations with street network measures. Overall, 11 out of 44 individual social equity indictors showed some correlation with street network measures.

6. Discussion and Conclusions

Overall, the study found that street network measures are significantly correlated with composite urban compactness measures in many instances, showing possible alignment with Scenario 2, Scenario 4, or both as shown in Figure 2. However, among the composite indicators of the three dimensions of urban compactness—density, mix-of-use, and intensification—*the average of all density indicators* appeared to be the most associated with network measures. This was followed by *the average of mix-of-use indicators*. *The average of all intensification indicators* appeared to be the least associated with network measures.

These findings may suggest that we choose to build more densely at locations that possess better topological accessibility. Because of an increase in urban density, mix-of-use may increase, encouraging urban intensification. The findings may also suggest that we rarely choose to prioritize mix-of-use developments at less-accessible locations, because profit in urban economy depends on the agglomeration of functions at easily accessible locations. Based on the existing density and mix-of-use, we then decide to intensify urban developments at any given location only if such an action would enhance profit, which can affect social equity.

The study also finds that urban density measures are usually more strongly correlated with local than global street network measures. Put another way, the density of an urban area may depend less on how the area is connected to the city. Instead, it may depend more on how the area is connected to other local areas. In other words, better global topological accessibility of an area may help generate more movement in the area, as space syntax studies generally show [37–39], but any increase in movement may not translate into urban density if the area under consideration is not easily accessible locally.

Additionally, the study found that not all individual density measures are similarly correlated with street network measures. Among the individual density measures, the gross, net, and population-weighted densities were better correlated with street network measures than the density of sub-centers, housing density, increase in density, and increase in sub-center density. Put another way, street network measures are better correlated with generalized density measures than they are with density measures describing specific features, such as sub-centers and housing.

It is interesting to note here that even though *the average of all mix-of-use indicators* showed at least two correlations with street network measures, only two out of eleven individual mix-of-use indicators showed correlations with street network measures. In contrast, even though *the average of all intensification indicators* showed no correlation with street network measures, five out of nine individual intensification indicators showed several correlations with street network measures. Such findings may show a possible alignment with Scenario 1, Scenario 3, or both, and may suggest that Burton's use of averages or z-scores to aggregate a set of indicators into composite indicators might not have been appropriate. The findings may also suggest that the relationships between individual and composite indicators may not be straightforward. Therefore, in the future, it may be useful to reduce the number of indicators along more relevant principal components or dimensions using factor analysis.

Finally, Burton's composite social equity indicators did not show any correlations with street network measures, showing a possible alignment with Scenario 1, Scenario 2, or both. However, at least two of the ten average social equity indicators and 12 of the 44 individual social equity indicators showed some correlations with street network measures, showing a possible alignment with Scenario 3, Scenario 4, or both. These findings indicate that the relationships between street network measures and social equity may be more nuanced than what aggregate measures suggest. This is in line with Burton's observation that, concerning urban compactness and social equity, it is better to focus more on individual indicators emphasizing fine-grain distinctions and less on composite indicators emphasizing global distinctions.

Based on the findings of the study, it can be suggested that the relationships between topological accessibility, urban compactness, and social equity in cities are complex and that these relationships may occur in different ways. However, due to their statistically significant associations with many aspects of urban compactness and social equity, topological accessibility may play a rather fundamental role in the spatial mechanisms of social equity.

7. Implications of the Study

The implications of this study can be described in relation to the studies conducted by Burton and the space syntax community, as well as in relation to urban planning and policy issues of social equity.

The study extends Burton's work by adding street network measures to urban compactness and social equity measures. It also extends Burton's work by showing that street network and urban compactness measures can affect social equity differently.

By applying space syntax techniques to a sample of 25 cities, the study contributes to the space syntax literature that generally reports studies on issues related to social equity in a city or for areas within a city. The study also includes many more measures of street networks, urban compactness, and social equity than any previous space syntax studies, providing a comprehensive understanding of how these measures may be related to each other.

The urban planning and policy implications of the findings of this study are numerous. First, street network and urban compactness measures should be considered carefully and differently, because they can affect social equity differently.

Second, street networks require careful considerations by urban planners and policy makers because of their direct and indirect associations with social equity. Direct associations indicate that street network measures can affect social equity measures. In contrast, indirect associations indicate that street network measures can affect urban compactness, which in turn can affect social equity.

Third, urban planning and policy must help promote the ease of movement and access to resources, both at the local and global levels of street networks to improve social equity, either directly or indirectly through a compact urban form. As indicated by the findings of the study, the associations of street network measures with urban compactness and social equity measures seem to vary based on the levels and types of analyses. For example, in many instances, the integration and choice values show stronger associations with urban compactness, density, and mix-of-use at local levels than at global levels. In many other instances, the segment integration and choice values show stronger associations with gross, net, and population-weighted densities than do axial integration and choice values.

Fourth, as reported here, urban intensification generally slows down in areas with ease of movement and access to resources, for they tend to have high compactness and density. This may indicate that urban planners and policy makers may want to focus on intensification in areas lacking ease of movement and access to resources, because these areas can potentially create social inequity through uncontrolled intensification and undesirable compactness and density.

Finally, as discussed in the "research problems" and "methods" sections of the paper, the topological properties of street networks, such as closeness (*integration*) and betweenness (*choice*), have many cognitive as well as descriptive advantages over the metric properties of urban forms, such as compactness and density. By showing how street networks can affect social equity, the findings of this study suggest a new line of exploration into the issues of social equity that is more directly relevant to human behavior and perception.

To end this paper, it should be noted that among many topological properties of urban form and structure, the study used only some, which were defined using space syntax techniques. In addition to paying attention to those space syntax measures that were not utilized in this study [19,20], urban planners and policy makers will also need to pay attention to many other topological properties of urban form and structure [40–46] in future studies to enhance our understanding of the spatial mechanisms of social equity.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/urbansci6030052/s1, Supplementary Table S1: Pearson product-moment correlation coefficient (r) values and their level of significance (*p*-values) for the correlations between street network measures and composite compactness indicators; Supplementary Table S2: Pearson product-moment correlation coefficient (r) values and their level of significance (*p*-values) for the correlations between street network measures and individual density indicators; Supplementary Table S3: Pearson product-moment correlation coefficient (r) values and their level of significance (*p*-values) for the correlations between street network measures and individual mix-of-use indicators; Supplementary Table S4: Pearson product-moment correlation coefficient (r) values and their level of significance (*p*-values) for the correlations between street network measures and individual intensification indicators; Supplementary Table S5: Pearson product-moment correlation coefficient (r) values and their level of significance (*p*-values) for the correlations between street network measures and averages of individual social equity indicators by category; Supplementary Table S6: Pearson product-moment correlation coefficient (r) values and their level of significance (*p*-values) for the correlations between street network measures and individual social equity indicators.

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