This is the peer reviewed author accepted manuscript (post print) version of a published work that appeared in final form in:

Soltani, Sahar, Gu, Ning, Ochoa Paniagua, Jorge, Sivam, Alpana 2022 'The role of spatial configuration in moderating the relationship between social sustainability and urban density', Cities, vol. 121, article no. 103519, pp. 1-20

This output may not exactly replicate the final published authoritative version for which the publisher owns copyright. It is not the copy of record. This output may be used for non-commercial purposes. This version is licensed under a Creative Commons CC-BY-NC-ND 4.0 license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

The final definitive published version (version of record) is available at: https://doi.org/10.1016/j.cities.2021.103519

Persistent link to the UniSA Research Outputs Repository: https://researchoutputs.unisa.edu.au/11541.2/26548

General Rights

Copyright and moral rights for the publications made accessible in the UniSA Research Outputs Repository are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognize and abide by the legal requirements associated with these rights.

- Users may download and print one copy for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the persistent link identifying the publication in the UniSA Research Outputs Repository

If you believe that this document breaches copyright, please contact us and provide details. We will remove access to the work immediately and investigate your claim.

Abstract

Spatial configuration is an important element of a neighborhood design due to its impact on social behavior, density, and physical arrangement. However, current studies usually overlook this aspect when exploring the impact of densification on the social sustainability indicators, including safety, social interaction, sense of place, community stability, and community participation. Therefore, this study undertakes two interrelated case studies i) to identify the patterns of interaction between spatial configuration factors, density, and social sustainability indicators using the first case study, and ii) to examine and validate these patterns in a different context using the second case study. Computational analysis has been conducted to extract the spatial configuration followed by statistical analysis to explore the potential social patterns. The outcomes confirm the integral role of spatial configuration on social sustainability in finding strong associations between safety, sense of place, and social interaction with spatial configuration measurements. Community participation and community stability have not been strongly affected by spatial configuration, but they helped in explaining the contextual impact. The outcomes of this study can assist planners, policy makers, and designers to strategically prioritize social sustainability in their urban densification development plans by considering spatial configuration.

Keywords: Spatial Configuration, Social Sustainability, Urban Density, Spatial Network Analysis, Socio-spatial Relationships

1. Introduction

As the world's urban population continues to grow, the shift towards higher density urban areas seems inevitable in most countries (Hernández-Palacio, 2017). Even though past studies have shown the great impact of urban density on social sustainability (Kyttä and Broberg, 2014, Bramley and Power, 2009), very little is known about the role of neighborhood design, and spatial configuration in this trade-off. Research shows spatial configuration can influence both social behavior and density distribution (Zerouati and Bellal, 2019). This configuration, which is essentially represented through the street layout, has a social function by offering potential for movement, interaction, and mobility, while giving information about reaching the desired places (Lynch, 1960, Hansen, 1959). Overlooking these aspects would undermine the objectives of urban sustainability plans from achieving effective socially sustainable neighborhoods, as an essential precondition to preserve sustainability changes, while improving the living quality of residents (Vallance et al., 2011).

The dilemma of the compact city and its social impacts triggers the necessity to explore the design role in improving the quality of life of residents while considering this mainstream urban strategy. Despite its importance, the current literature does not adequately explore the role of the spatial configuration on density and social sustainability in an integrated manner. Therefore, we argue for utilizing a more design-focused investigation of density through spatial analysis to take advantage of the socio-spatial interpretations. Consequently, this study examines the impact of spatial configuration as a potential moderator on the relationship between social sustainability and density. An integrated computational approach has been developed in this study by employing a complementary set of spatial analysis methods through space syntax (Hillier and Hanson, 1984) and Urban Network Analysis (UNA) (Sevtsuk and Mekonnen, 2012) to target both street and building networks, incorporated with social sustainability outcomes using statistical analysis.

In the following sections, we first explore the social impact of urban density as reported by other empirical studies, and then, inspect the challenges of the current density measurements to justify the suitability of spatial analysis in studying density. Next, we discuss the effectiveness of spatial analysis in defining socio-spatial patterns.

1.1 Social impact of urban density

While the compact city is becoming the dominant urban strategy because of its environmental and economic benefits, its impacts on residents, however, are open to controversy. Some scholars claim that compact city is not only an inevitable scenario for today's growing global urbanization and population, but can also contribute to the citizen's well-being and health (Lee and Kaufman, 2020), quality of life (Wang and Shaw, 2018), and livability (McCrea and Walters, 2012, Walton et al., 2008) through the provision of social sustainability conditions (Laatikainen et al., 2015, Quastel et al., 2012, Steemers, 2003). Various studies provide evidence for the positive impact of urban density on some aspects of social sustainability. For instance, a study of twenty-five medium-sized UK cities confirmed the positive role of high-density housing on social equity (Burton, 2003). Some believe the opportunity for social interaction and access to activities can be enhanced in denser areas, which contributes to the improvement of well-being (Kyttä et al., 2016). Similarly, Yang (2008) found that neighborhood satisfaction in high-density areas in Portland, Oregon (US) was higher than the same-density neighborhoods in Charlotte, North Carolina (US). However, studies conducted in various parts of the world indicate that the exact link between aspects of social sustainability in correlation with density and design configuration is complicated, fragmented and seemingly contradictory. A nonlinear relationship between social sustainability and density was found by Raman (2010) in his study on six neighborhoods in the UK. This nonlinear relationship was also found by Walton et al. (2008) in their studies on three ranges of different population densities in Auckland, New Zealand. Studies on developing countries emphasize the contextual differences in patterns of impact. Dave (2011) conducted a study on eleven neighborhoods of various densities in Mumbai, India. She demonstrated that perceived density, which is defined by the built form, design, layout and mix of land use, as well as socio-demographic characteristics, have more impacts on social sustainability dimensions than physical density.

Several studies report undesirable impact of high density on some aspects of social sustainability. The results of a study conducted in the UK show that although denser areas facilitate environmental and social equity by providing better accessibility to services and facilities, they have negative effects on the sustainability of community by reducing perceived safety, social interaction and group participation. Such characteristics lead to a lack of community stability and sense of place (Dempsey et al., 2012, Bramley et al., 2009b). The same outcomes were extracted in a study on other cases in some small towns of Helsinki, Finland (Kyttä et al., 2011), whereas the results on the urban areas were contradictory (Kyttä and Broberg, 2014). Kytta et al. (2016) found that the correlation between density and social sustainability is rather complex and context dependent. Similar to previous studies, they demonstrate that high density areas support better accessibility in both urban and suburban neighborhoods. Contrary to urban areas, better accessibility does not support perceived environmental quality by residents in suburban areas which also induces poor well-being conditions. The authors believe that this contradiction is a result of misinterpreting the outcomes without considering specific contextual conditions.

However, such studies remain narrow in focus only dealing with density to refer to the urban form, and generally overlook the role of the other aspects of the built environment design. Furthermore, the same population density can be manifested in a quite different dwelling and built form configuration, layout, and design, which can lead to different types of accessibility and physical proximity (Neuman, 2005, Raman, 2010). In urban studies, density has remained a complex concept that has been defined in many ways, from physical forms of density to non-physical aspects, referring to various scales, from street level to metropolitan scale (Pafka, 2020). A lack of methodology exists in studying density in close association with various design aspects of the built form (Peponis et al., 2007, Grosvenor and O'Neill, 2014). Numerous design factors can be influential in defining density, such as morphological characteristics of individual buildings, block types and design attributes of street networks, etc. Many researchers agree that for density to be an effective measurement, it needs to integrate aspects of the built environment such as distribution of land use, services, and attraction points (Pafka, 2020, Berghauser Pont et al., 2017). Furthermore, the existing methods that try to integrate design aspects with density merely focus on the mathematical measurements of the buildings and plots (Ramaina et al., 2014). This will lead to disregarding the benefits that density can produce through the arrangement of the street and building form (Zainol and Elsawa, 2018). Therefore, we focus the density measurements on the spatial network to conduct a more in-depth analysis, which has also been reflected in the recent spatial approaches such as place syntax (Ståhle et al., 2005) and Urban Network Analysis (Sevtsuk et al., 2016).

1.2 Social impact of spatial configuration

Spatial configuration is commonly measured through spatial network analysis, which is widely used in morphological studies (Rashid, 2019, Gu et al., 2017, Tsou and Cheng, 2013, Shen and Karimi, 2016). In recent years, there has been an increasing interest among researchers in the capability of the physical and spatial configuration on shaping and affecting some aspects of social life (Sun et al., 2020). People's activity in a space is an important component of urban vitality (Zerouati and Bellal, 2019). The role of streets in attracting people and supporting activities has been highlighted in the works of Jacobs (1961) and Gehl et al. (2006 and 2011), which recognize streets are essential spatial elements for movement and are pivotal to vitalize the urban life. The fundamental role of streets in shaping the spaces and ways people move through them was echoed in Hillier's (1984) theory of space, 'spatial configuration'. The theory considers 'relations which take account of other relations', focusing on the whole system rather than its parts. Zerouati et al. (2019) summarize the concept of spatial configuration, based on two claims: i) the tight link between space and people, and ii) space as a configurational entity. This configuration creates opportunities for social actions through the provision of encounters and presence for people. Considering the city as embodying the duality of form and space, the configuration can be arranged through both of them. Space should not be understated as the vacancy left over between buildings; rather, only through this arrangement are various socio-physical interactions, such as people's patterns of movement, feasible. These assumptions have been further developed as a powerful theory that builds upon mathematical measurements of the variables associated with movement and navigation, namely space syntax (Hillier & Hanson 1984). Essential to this theory is 'spatial network analysis', which enables the mathematical understanding of the built form. Spatial network analysis facilitates the 'morphological description' of a physical entity like a building or an urban setting to be directed in a systematic and scientific way (Ståhle et al., 2005, Önder and Gigi, 2010). In a study of social segregation through spatial analysis, Rokem et al. (2019) showed that the spatial configuration of the city of Stockholm blocked the potential for co-presence, which resulted in segregation between new migrants and local people. In this study, segregation was defined as scarce opportunities for people to interact in public areas, or lack of co-presence (Rokem

and Vaughan, 2019). In a similar approach, Rejeb et al. (2019) aimed to study human interaction with urban morphology and the way the two are connected in a city's organization. They showed that the accessibility and centralities explored through configuration by spatial analysis had a major influence on the land use distribution of their case study (Rejeb Bouzgarrou et al., 2019). Other studies of this nature in recent literature include mapping spatial configuration to social phenomena, such as social interaction (Askarizad and Safari, 2020), sexual harassment (Mohamed and Stanek, 2020), street livability (Li et al., 2017), crime studies (Matijosaitiene, 2016), and walkability behavior (Koohsari et al., 2016, Oakes et al., 2007).

Even though such studies investigate the individual aspects of social outcomes, the literature still lacks a comprehensive study that looks at spatial configuration in close relation to density while accounting for their combined impact on multiple social aspects of a neighborhood. This could be due to the complexity of quantifying social outcomes to integrate them in a computational or spatial analysis approach. This study attempts to bridge the gap by conducting a multi-staged case study to identify the social patterns that are concurrent with particular spatial patterns within specific density ranges. To do this, the study employs a complementary set of spatial analysis tools to address both spatial configuration and density integrated with the social sustainability outcomes, which will be introduced in Section 2.2. This is a novel approach that leads to a detailed description of the correlational associations of these elements to achieve a more comprehensive insight as well as better explain the existing patterns.

2. Methods and materials

To address the study's aim, two interrelated case studies have been designed to identify and validate the correlational associations between social sustainability, spatial configuration and density. A multiple-case study approach has been chosen for this research due to the advantages in offering additional insights via comparison. The two case studies in this research are also considered as literal replications as the second one precisely aims to test if the outcomes of the first case study can be replicated in a new context.

Case Study I consists of fifteen neighborhoods in the UK from varying density ranges with social sustainability outcomes available from a secondary source (Bramley et al., 2009b). This case study has been selected from the literature as the base for our analysis because it is one of the most comprehensive studies of the kind, offering a well-established description of the association of density and social sustainability. Although this case study produced significant outcomes, the design factors only remained at an abstract level with little connection to the spatial configuration attributes of the neighborhoods. Provided that a study is well designed based on such secondary sources, the contribution would be a greater understanding of a phenomenon, supporting knowledge transfer, and linking the outcomes from different studies to each other. Therefore, we obtained the street and building maps of the same neighborhoods to study the spatial configuration through spatial analysis. Statistical analyses have been performed to explore the patterns of associations between density, social sustainability, and spatial configuration, which were also triangulated with the knowledge gained from the literature, leading to the development of several hypotheses to be tested in Case Study II. The underpinning logic of hypothesis-driven approaches is that if the study applies the same methodology on a new case using the same variables and measurements, and if the hypotheses are constructed credibly, they will be met to some extent. A hypothesis cannot be proved, but only supported by the results and retained for further investigations, but it can be disproved or not supported by the results (Mathison, 2013). The identified associations in Case Study I are statistically significant, but in order for them to be externally validated

further empirical evidence using a second case study from a different context is needed. While most hypothesis-driven studies in the built environment research only utilize the knowledge gained from the literature to construct the hypotheses (Sevtsuk, 2014b, Amini Behbahani et al., 2016), this study takes a step further and reinforces the literature with additional spatial and statistical analysis results for constructing the hypotheses. Case Study II is then conducted for external validation of the identified associations between density, social sustainability, and spatial configuration from Case Study I through examining the hypotheses.

Case Study II consists of local cases in Australia, using two suburbs in *** as a primary source of data to test the hypotheses developed from the results of Case Study I. The study selects two neighborhoods in the same density category. The spatial configuration has been studied through a complementary set of spatial analysis methods to target both street and building networks, incorporated with social sustainability outcomes using statistical analysis. Case Study I (hypothesis-construction) and Case Study II (hypothesis-examination) together establish and externally validate the correlational associations, addressing the following research objectives:

- To understand the role of spatial configuration on social sustainability and density (Case Study I)
- To examine the external validity of the developed relationships between spatial design, density, and social sustainability (Case Study II)

Table 1. Research design in relation to the research objectives

	Research Objectives	Profile		Data sources	Analysis
Hypotheses development	To understand the role of spatial configuration on social sustainability and density	**Case Study I**	Fifteen neighborhoods in the UK Varying density Varying spatial configuration	Literature knowledge Secondary social and density data Online maps: Open Street Map (building + streets)	Spatial analysis: space syntax and UNA Statistical analysis: descriptive analysis, correlational analysis
Hypotheses validation	To examine the external validity of the developed relationships between spatial design, density, and social sustainability	**Case Study II**	Two suburbs in Australia Similar density Varying spatial configuration	Survey questionnaire GIS maps (building + streets) ABS Population dataset- MB Mesh Block 2011 Census for Australia	Spatial analysis: space syntax and UNA Statistical analysis: inferential tests, correlation and regression analyses

2.1 Data collection

2.1.1 Data for Case study I

Case Study I is a secondary data source conducted in the UK, from CityForm UK (Bramley et al., 2009b). They offer a category for social sustainability consisted of five indicators, 1) sense of place, 2) safety, 3) social interaction, 4) community stability, and 5) community participation, which has been investigated through fifteen neighborhoods with various density ranges (Dempsey et al., 2011). This category has been selected as the basis for our research in both case studies because it is amongst the most cited and widely used categories in the field of built environment research as employed in other studies and outlined in Table 2. The method that these studies utilize to measure social sustainability is through survey questionnaire. This is a subjective mean commonly used in the social studies of built environment research. Our study superimposes the subjective outcomes with objective results yielded from the spatial analysis to enhance the validity of the identified patterns in Case Study I and Case Study II.

Table 2. Indicators of social sustainability

Indicator	Definition	Authors, other examples
Sense of place	The feeling of 'belonging' to the neighborhood and the quality of the physical attributes of the neighborhood	El-Husseiny and Kesseiba (2012), Comstock et al. (2010), Wood et al. (2010)
Social interaction	An exchange between two or more individuals	Abass and Tucker (2018), Thomas et al. (2011), Talen and Koschinsky (2014)
Safety	The condition of being protected from harm or other non-desirable outcomes	Karuppannan and Sivam (2011), Burton (2003), Raman (2010), Talen and Koschinsky (2014)
Community stability	The tendency to stay and live in the neighborhood	Abass and Tucker (2018), Lee et al. (2017), Comstock et al. (2010)
Community participation	Participating in group activities in the neighborhood and having shared interests with the other residents	Karuppannan and Sivam (2011), Abass and Tucker (2018)

Three sets of data were utilized: 1) social sustainability outcomes, 2) density data, and 3) spatial data. The social sustainability was measured by the CityForm project, using household surveys and interviews. The average scores for each of the social sustainability indicators were obtained from Bramley et al. (2006), density data from Bramley et al. (2009a), and the location of the cases from Dempsey et al. (2010). Building and street layout of the cases were needed for spatial analysis, acquired from Open Street Map (OSM), an online maps website. Because the CityForm study was conducted years ago, the neighborhoods' maps were compared with the historical database available from Google Earth Pro enabling the adjustments to the network maps. The maps then were simplified and modified following the principles explained in Kolovou et al. (2017) and Sevtsuk (2018) to be suitable for the analysis. Figure 1 shows the cases' maps and their density ranges.

Figure 1. Neighborhoods in Case Study I (Google Maps 2020), (optional color use)

2.1.2 Data for Case study II

In Case Study II, two suburbs in ***, Australia, have been identified from the low-density category (ABS, 2018), representing different spatial configurations while controlling for socio-demographic characteristics, economic profile, and accessibility and distance to the main infrastructures in the CBD area. The criteria have been selected based on a study on the factors affecting accessibility in metropolitan *** (Somenahalli et al., 2016). The two suburbs, Suburb 1 and Suburb 2, have been shown in Figure 2.

Figure 2. Satellite views of Suburb 1 (right), and Suburb 2 (left) (Google Maps 2020), (optional color use)

A survey questionnaire has been carried out to provide data on social sustainability, while the spatial data and land-use data have been acquired from the GIS file of ***. The survey questionnaire has been developed based on previous work by Raman (2010), exploring the relationship between social interaction and urban density, and Dempsey (2007) structuring the concept of social sustainability in the built environment focusing particularly on urban density. The survey contains multi-choice answers for the general questions, and rating questions for the five categories of social sustainability in form of close-ended questions to get the most relevant answers to the questions. The closed-ended questions were all followed by open-ended questions for participants to provide reasons for their responses and share their views on the aspects, which might not have been covered in the questionnaire.

The respondents were randomly selected from the general public residing in the suburbs. They were asked to express their attitude towards the five indicators of social sustainability (Table 1). The survey was conducted from August to December 2019 through online questionnaires published on the community's social media as well as paper-based questionnaires distributed in public places across the two suburbs.

Sample size n has been calculated based on the following formula (ABS 2020):

$$n = N \times X/(X + N - 1)$$

Where:

$$X = \frac{Z^2 \times (P) \times (P-1)}{C^2}$$

N= population size

Z = Z value at α /2 (e.g., for a confidence level of 95%, α is 0.05 and the critical value is 1.96)

p = sample proportion, expressed as decimal

c = confidence interval, expressed as decimal

The population size for Suburb 1 is 14108 and Suburb 2 is 11783 (ABS 2020). The minimum sample size, which is common in built environment research is based on an 80% proportion estimation, 95% confidence level, 0.1 confidence interval and 5% standard error (Soebarto et al., 2019). Accordingly, it is calculated to be n=130 (65 in each suburb). Exceeding the minimum sample size, 161 survey questionnaires were collected from the two suburbs, 88 from Suburb 1, 73 from Suburb 2.

2.2 Data analysis

2.2.1 Spatial analysis

The study has followed the same process for data analysis in both case studies. To study the social impact of urban density through spatial configuration, we propose a computational approach that combines two spatial analysis methods; the social patterns are studied through space syntax (Hillier and Hanson, 1984), while density is addressed by Urban Network Analysis (UNA) toolbox (Sevtsuk and Mekonnen, 2012). The spatial data have been acquired through spatial analysis on the building and street layouts of the cases. The street layouts have been analyzed by space syntax been conducted from depthMapX software

(Turner, 1998) through Angular Segment Analysis (ASA) technique (Hillier and Iida, 2005). The building layouts have been analyzed through UNA, performed in Rhinoceros 3D.

Space syntax is a theory and method that mathematically represents the spatial configuration of an urban area and relates it to the embedded social behaviors. In this sense, space syntax is not only an abstract representation of the built environment, but it has inherently established its fundamental theories based on the people's observation, perception and behavior in response to their surrounding built form (Hillier and Hanson, 1984). However, despite its powerful methodology in capturing several social aspects, space syntax does not address density (Sevtsuk and Mekonnen, 2012, Pont and Marcus, 2015). To complement the space syntax analysis and address density, we employ a novel method in spatial analysis, named Urban Network Analysis (UNA) (Sevtsuk and Mekonnen, 2012). UNA method can be utilized for a wide range of analyses from spatial accessibility to trip estimation, capturing the influence of urban form and land-uses on active mobility (Sevtsuk, 2018). In addition, UNA has been identified as a complementary method to space syntax due to its unique representation of a network ***[1]. While space syntax considers the street layout as the fundamental element of the spatial configuration, UNA adds buildings to the networks as well. Adding building networks, UNA offers wide flexibility in targeting the analysis on various functions of the buildings by weighing them according to their particular features.

Since the study intends to explore the potential patterns, all the relevant measurements that proven in the literature to have an influence on the relevant social aspects of the built form have been taken into account. These measurements are introduced in Table 3.

Table 3. Spatial configuration measurements

Spatial Design Factors	Definition	Application
Integration (NAIN_rn)	Closeness of a space in relation to the other surrounding spaces (Al-Sayed, 2018)	Number of people presenting in a given area (Penn et al., 1998) Social encounter and retail activities (Al-sayed, 2018)
Choice (NACH_rn)	Probability of falling on any shortest path that links any pair of segments of a street segment (Al-Sayed, 2018)	Pedestrian and vehicle movement (Al-Sayed, 2018) Commercial land uses (Kolovou et al., 2017) Movement pattern and activity density by the previous studies (Hillier et al., 2012)
Depth (NAtd_rn)	Shortest distance between the spatial elements (Al-Sayed, 2018)	Crime and safety (De Filippi et al., 2020, Hillier and Sahbaz, 2008).
Connectivity	Number of the immediate neighbors of each space (Al-Sayed, 2018)	
Reach	Number of destinations and opportunities around each building (Sevtsuk, 2012)	Areal density measures (Sevtsuk, 2014a, Sevtsuk and Mekonnen, 2012)
Gravity	Attractiveness of the destinations and associated travel costs based on distance between two or more buildings (Sevtsuk, 2012)	Pedestrian accessibility (Sevtsuk et al., 2016)

[1] Reference has been hidden to comply with the blind review process

			Probabilities of finding retailers (Sevtsuk, 2014b)
Combination or associates			
Spatial Design Characteristic	**Definition**	**Measurement**	**Application**
Intelligibility	Located on a well-connected part of the network, which is also well-integrated (Hillier et al., 1986)	Pearson correlation coefficient: global integration connectivity	Perception of place (Agirbas, 2019) Movement pattern and activity density (Hillier et al., 2012) Wayfinding (Al-Sayed, 2018) Legibility (Long and Baran, 2011)
Permeability	Well-connected and integrated streets that allow pedestrians to permeate an urban fabric (Hillier and Sahbaz, 2008)	Integration Depth	Social interaction (Can and Heath, 2016, Jacobs, 1969, Gehl, 2010) Safety (Hillier and Sahbaz, 2008)
Layout accessibility and movement	Probability of attracting movement flow	Local choice Connectivity Local integration Local depth	Walkability (Koohsari et al., 2019, Hajrasouliha and Yin, 2014) People movement (Read, 1999) Pedestrian and vehicle movement (Al-Sayed, 2018)
Spatial density	Opportunities that density creates within a network to reach the attraction points	Gravity Reach	Areal density measures (Sevtsuk, 2014a, Sevtsuk and Mekonnen, 2012)
Spatial accessibility	Ease of access to destinations across a network (Sevtsuk and Mekonnen, 2012)	Gravity	Pedestrian accessibility (Sevtsuk et al., 2016) Land uses and active mobility (Sevtsuk, 2018) Housing price (Kang, 2018) Land use intensity (Liu et al., 2016)

As evidenced in past studies, these individual measurements (spatial design factors) can be associated with particular spatial characteristics of the layout (spatial design characteristics) when considered in combination. The combination of the measurements will also be explored in the interpretation of the results to dig deeper into the socio-spatial relationships in the cases. To enable comparison across various scales, such as cities with different sizes or multiple places within a city, all these measurements have been normalized in ASA (Al-Sayed, 2018). Strong theoretical and cognitive evidence suggest that the ASA analyses, driven from RCL, are more representative of the actual patterns of people's movement and the geometry of the streets (Turner, 2007). Radius n, or global scale, refers to the overall characteristics of the layout. And radius 600 meters, or local scale, to refer to the smaller scales. While the walkable distance can vary in different contexts based on different travel purposes, to keep the analysis consistent, this radius has been chosen as an average walkable distance mentioned in several studies including in transportation studies (Sevtsuk and Mekonnen, 2012, Vecchio et al., 2020, Daniels and Mulley, 2011, Mavoa et al., 2018).

2.2.2 Statistical analysis

The results of spatial analysis have been combined with the social sustainability results in one single database to conduct statistical analysis. Statistical analysis deals with quantitative data to identify trends and patterns in the underlying population or sample data (Bandyopadhyay and Forster, 2011), which has been carried out in IBM SPSS.

3. Results and discussion

3.1 Case Study I

3.1.1 Spatial analysis and statistical analysis results

Space syntax and UNA analysis have been conducted on the street and building layouts of the fifteen neighborhoods, categorized according to their relative density range into high, middle, and low-density areas. The extensive results of the space syntax and UNA analyses have been provided in the Supplementary Materials. Correlation analysis was employed to explore whether any statistically significant correlation exists among social sustainability indicators from the CityForm, and the spatial configuration of the cases, using the numerical data provided from the spatial analysis. Correlation Coefficient has been selected for the correlational analysis as a common method that is widely used for linking spatial data to social data especially in space syntax studies (Hillier et al., 2012, Hillier and Sahbaz, 2008, Askarizad and Safari, 2020). Table 4 shows the results of the correlation analysis.

Table 4. Correlation matrix between social sustainability indicators and spatial design factors

		NACH_r600	NAtd_r600	NAIN_r600	NAtd	Connectivity	NACH	NAIN	Gravity	Reach
Overall social sustainability	Correlation Coefficient	.755**	-0.336	0.287	0.229	-0.574	0.461	-0.263	-0.451	-.808**
	Sig. (2-tailed)	0.005	0.286	0.366	0.473	0.051	0.132	0.409	0.164	0.003
	N	12	12	12	12	12	12	12	11	11
Sense of place	Correlation Coefficient	.741**	-0.252	0.147	0.367	-.627*	0.422	-0.442	-0.556	-.868**
	Sig. (2-tailed)	0.006	0.430	0.649	0.241	0.029	0.172	0.150	0.075	0.001
	N	12	12	12	12	12	12	12	11	11
Social interaction	Correlation Coefficient	.608*	-0.175	0.168	0.282	-.599*	0.432	-0.256	-0.395	-.740**
	Sig. (2-tailed)	0.036	0.587	0.602	0.374	0.040	0.161	0.422	0.229	0.009
	N	12	12	12	12	12	12	12	11	11
unsafety	Correlation Coefficient	-.881**	.781**	-.656*	0.372	0.555	-.745**	-0.184	0.215	0.480
	Sig. (2-tailed)	0.000	0.003	0.021	0.233	0.061	0.005	0.566	0.526	0.135
	N	12	12	12	12	12	12	12	11	11
Community participation	Correlation Coefficient	0.351	-0.049	0.098	0.158	-.619*	0.471	0.148	0.007	-0.202
	Sig. (2-tailed)	0.263	0.879	0.761	0.625	0.032	0.122	0.646	0.984	0.552
	N	12	12	12	12	12	12	12	11	11
Community stability	Correlation Coefficient	-0.528	0.124	-0.091	-0.445	0.611*	-0.283	0.427	0.498	0.695*
	Sig. (2-tailed)	0.078	0.701	0.779	0.147	0.035	0.372	0.167	0.119	0.018
	N	12	12	12	12	12	12	12	11	11

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.005 level (2-tailed).

The correlations presented in Table 4 will be discussed in the following subsections. This involves each social sustainability indicator that has shown at last two significant correlations ($p < .005$) with design factors together with the knowledge obtained from the literature and the interpretations provided in the CityForm study. Therefore, community participation and community stability were excluded from the rest of the investigation (Table 3).

3.1.2 Hypotheses development

Safety was measured by a reversed score in the CityForm, referred as unsafety, which will be noted in the interpretations provided here. In correlation analysis, unsafety is correlated to some or all associates of the layout accessibility; NACH_600 ($R = -.881$, $p < .005$), NAtd_600 ($R = .781$, $p < .005$), connectivity ($R = .555$, $p = 0.061$), and NAIN_600 ($R = -.656$, $p < .05$), intelligibility; NAIN (-0.184, $p = 0.566$) and connectivity ($R = .555$, $p = 0.061$), permeability; NAIN (-0.184, $p = 0.566$) and NAtd ($R = 0.372$, $p = 0.233$) and spatial accessibility; NACH_r600 ($R = -.881$, $p < .005$) and gravity ($R = 0.215$, $p = 0.526$).

In the CityForm project, the level of safety and crime rate have been studied as one of the pivotal aspects of social sustainability. It was also reported that the suburbs were or felt safer, especially where the layout is a less elemental network (cul-de-sac or grid). Conventional studies of space syntax on social impacts of the built form report a nuanced link between *depth* value and the crime rate in an area. Some studies show that more burglaries occur in the less connected and deeper areas in a network, suggesting too many isolated areas are vulnerable to crime (Hillier and Sahbaz, 2008). Other studies provide a different pattern wherein the crime rate is higher in areas that are more accessible, and consequently, there are more people present who could be the victim of crimes like burglary (Summers and Johnson, 2017).

Figure 3 shows a scatterplot of unsafety as the spatial metrics arise, which suggests unsafety is increasing in the layouts where higher *depth* is accompanied by lower values of *choice* and *integration*. These patterns also suggest a combined impact of these variables on *safety*. For instance, *depth* value, along with *integration* value, represents the level of *permeability* of a layout (Hillier, 1999). It can be interpreted that the less permeable layouts are more likely to have a higher *safety* rate.

Figure 3. Scatterplot of feeling unsafe and space syntax measurements (optional color use)

Out of all the social sustainability indicators, safety has strong associations with a number of design factors. Feeling of unsafety is more likely in the high-density areas and is correlated with local *NAtd* and *NACH*. Moreover, safety has a significant correlation with the associates of *intelligibility* and *spatial accessibility*. This leads us to the first set of hypotheses to be tested in the new case study:

I. Feeling of safety is more likely in the layout that is more a) intelligible; b) likely to produce pedestrian movement; and c) spatially accessible.

Social activity is assumed to be higher in mixed-used high-density areas (ref). In contrast, in the CityForm study, *social interaction* and *sense of place* had their highest values in outer low-density areas and exponentially decreased as density became higher. This was in line with our analysis where *sense of place* and *social interaction* were negatively correlated to *gravity* and *reach* values. *Reach* values had a strong positive correlation with net density, suggesting a good indicator of density while only considering the number of accessible buildings within a defined radius.

Through our spatial analysis and correlations, these indicators also followed similar patterns with spatial design factors. They show strong positive correlations with the local value of *NACH*, as seen in Figure 4, which can be explained by the layout characteristics. The higher total value of *choice* means the layout is becoming more segregated. The mean *NACH* can also measure the level of deviation from a straight line or a regular grid. Thus, these values of *NACH* with a desirable level of connectivity in these cases, representing segregated and non-grid layout, might have supported social encounters, social activity and social interaction in the context of this case study. This pattern was reported in the more recent literature, where well-connected streets had an influential role in triggering social interaction and activities (Can and Heath, 2016).

Figure 4. Scatterplot of *NACH_r600* with *social interaction* (upper line), and *sense of place* (lower line), (optional color use)

The strong correlation among most of the social sustainability indicators with local and global values of *NACH* highlights the importance of layout characteristics in influencing opportunities for interaction and activities, as well as sense of place. As shown in Table 4, *sense of place* is correlated with *NACH_r600* ($R = .741$, $p < 0.005$), *NAIN* ($R = -0.442$, $p = 0.150$), and *connectivity* ($R = -.627$, $p < 0.05$), which are associates of layout accessibility and intelligibility (see Table 3). That is, accessibility, when accompanied by *intelligibility*, is expected to be accompanied by a stronger *sense of place*. These insights formulate the second set of hypotheses:

II. *Sense of place* is supported by a more a) accessible layout and b) intelligibility

Similar to *sense of place*, *social interaction* has also shown strong correlations with *NACH_r600* ($R = .608$, $p < 0.05$) and *connectivity* ($R = -.599$, $p < 0.05$). The correlation of this indicator with *gravity* ($R = -0.395$, $p < 0.229$) and *reach* ($R = -.740$, $p < 0.005$) was negative, as associates of *spatial accessibility*. These findings construct the third set hypotheses:

III. Social interaction is higher in the layout that a) attracts more movement flow; and b) has a lower spatial accessibility

Overall social sustainability among the CityForm cases gained a low score in the high-density areas and received its highest score in the low-density cases. This score was calculated as a composite score adding up all the five indicators of social sustainability to yield a composite index. In our analysis, the overall social sustainability index had a negative correlation with *reach* value. *Gravity* value, representing *spatial accessibility*, also was negatively related to this index. The overall index of *social sustainability*, however, was positively correlated to *NACH_r600.*

The scatterplots shown in Figure 5 indicate a very strong interaction between these variables. Similar to the previous indicators, because *gravity* and *reach* can implicate density, these results match the CityForm results. The positive interaction between *NACH*_r600 and *social sustainability* indicates the important role of *layout accessibility* in the overall improvement of *social sustainability*.

Figure 5. Scatterplot of *social sustainability* with *NACH_r600* (left), and with *reach* (right), (optional color use)

In the CityForm study, better accessibility was reported to be complemented by better *social sustainability*, negatively associated with density. Overall social sustainability in our analysis showed a

positive correlation with local *NACH* (R = .755, p < 0.005), representative of people's movement, and a negative correlation with *reach* (R = -.808, p < 0.005). So, in the next case study, accessibility will be studied in relation to overall social sustainability. Moreover, the study did not have full access to the spatial data of all the neighborhoods; as such, the *gravity* value was not weighted. In order to make use of the *spatial accessibility* indices, Case Study II will weigh the network-based land use for *gravity* analysis. In doing that the analyses can focus on *spatial accessibility* and *spatial density* instead of the conventional measurements of density. The fourth hypothesis claims:

IV. Better *social sustainability* is accompanied by a) better layout accessibility; b) lower spatial density; and c) lower spatial accessibility

Although the social results from the CityForm study had an obvious interaction with the change of density and received better scores in less denser areas, the correlation matrix from this study does not present an orderly pattern (ascending/descending) of correlation between social results and spatial design factors. In the literature, similar social sustainability indicators used by other empirical studies did not show a similar pattern with density and various studies have had different and sometimes contrasting results. Therefore, it is proposed that the social results would have a more consistent pattern with the spatial configuration of a neighborhood rather than density. And thus, in Case Study II, the neighborhoods from a similar density will be compared against their design and social indicators. This leads to the final hypothesis:

V. Same density areas with different spatial configuration do not necessarily have similar social sustainability outcomes

3.2 Case Study II

Previous analysis identified associations that are statistically significant yet need to be validated with further empirical studies in Case Study II. The spatial design factors have shown the capability of explaining some of the social sustainability outcomes by the correlation analysis. In Case Study II, the research examines whether social sustainability indicators can be associated with spatial design in a similar way if applying the same methodology, through testing the hypotheses. Seeing the same correlations with the same magnitude on Case Study II as for the contextual differences would not be anticipated, but the occurring patterns in some categories with stronger relationships will be expected.

3.2.1 Survey results

Social sustainability data has been obtained from a survey questionnaire from the general public living in the two suburbs. The survey data aggregated from both suburbs has provided valuable information about the nature of the interrelationships between various indicators of social sustainability in the new context of Australian suburbs. Table 5 demonstrates the results of the Pearson correlation coefficient to understand the pattern of interrelationship within the social sustainability indicators. Prior to the correlational analysis, the primary analysis was performed to test if the assumptions of the normality were not violated (Field, 2009, Allen, 1997).

Table 5. Pearson correlation coefficients in both suburbs

		Overall social sustainability	Composite social sustainability	Sense of place	Social interaction	Community participation	Community stability
Overall social sustainability	Pearson correlation	1	.705**	.662**	.445**	0.138	.366**

	Sig. (2-tailed)		0.000	0.000	0.000	0.108	0.000
Composite social sustainability	Pearson correlation	.705**	1	.862**	.671**	.453**	.565**
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.000
Sense of place	Pearson correlation	.662**	.862**	1	.372**	.270**	.276**
	Sig. (2-tailed)	0.000	0.000		0.000	0.002	0.002
Social interaction	Pearson correlation	.445**	.671**	.372**	1	.291**	.564**
	Sig. (2-tailed)	0.000	0.000	0.000		0.001	0.000
Community participation	Pearson correlation	0.138	.453**	.270**	.291**	1	.170*
	Sig. (2-tailed)	0.108	0.000	0.002	0.001		0.047
Community stability	Pearson correlation	.366**	.565**	.276**	.564**	.170*	1
	Sig. (2-tailed)	0.000	0.000	0.002	0.000	0.047	
Safety	Pearson Correlation	.457**	.570**	.377**	.215*	0.097	0.054
	Sig. (2-tailed)	0.000	0.000	0.000	0.014	0.264	0.531

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

To compare the results of the survey across the two suburbs, all the categories have been tested through inferential statistics using an independent sample t-test. The results of the test will allow the study to determine whether the mean values of the social sustainability indicators across the two groups are meaningfully different. The results of the t-test (Table 6) showed there are statistically meaningful and significant differences in all the variables ($p < .05$), which means the comparison of the mean values is possible (Field, 2009).

Table 6. Independent t-test results

Case name		**Test Value = 0**					
		t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Suburb 1	Overall social sustainability	44.711	73	0.00	4.12162	3.9379	4.3053
	Composite social sustainability	54.354	65	0.00	3.61818	3.4852	3.7511
	Sense of place	59.982	73	0.00	4.17868	4.0398	4.3175
	Social interaction	41.504	70	0.00	3.59624	3.4234	3.7691
	Community participation	33.93	74	0.00	3.3	3.1062	3.4938
	Community stability	27.125	74	0.00	3.34667	3.1008	3.5925
	Safety	32.576	72	0.00	3.68493	3.4594	3.9104
Suburb 2	Overall social sustainability	41.034	64	0.00	4.30769	4.098	4.5174
	Composite social sustainability	59.17	56	0.00	3.86101	3.7303	3.9917
	Sense of place	58.683	61	0.00	4.09319	3.9537	4.2327
	Social interaction	53.438	66	0.00	3.9005	3.7548	4.0462
	Community participation	38.177	65	0.00	3.59091	3.4031	3.7788
	Community stability	36.472	65	0.00	4.14394	3.917	4.3709

Safety	23.149	62	0.00	3.66667	3.35	3.9833

Figure 6 presents a bar diagram for comparison between the mean values of the social sustainability results in the two suburbs.

Figure 6. Comparison of the social sustainability indicators in the two suburbs, (optional color use)

3.2.2 Spatial analysis results

Following the same method as Case Study I, the spatial configurations of the two suburbs have been analyzed. Similar to the previous stage, the method chosen for space syntax is ASA using two radii of n for global scale, and 600 meters for local scale. The descriptive statistics of the space syntax measures are shown in Table 7.

Table 7. Descriptive statistics of space syntax measures

Case name		N	Mean	Std. Deviation
Suburb 1	Connectivity	6380	2.35	0.63
	NACH_r600	6380	1.09	0.23
	NAtd_r600	6380	1.55	0.39
	NAIN_r600	6380	0.72	1.63
	NACH_r	6380	0.94	0.23
	NAtd_r	6380	2.52	0.59
	NAIN_r	6380	0.42	0.09
	Valid N (listwise)	6380		
Suburb 2	Connectivity	2802	2.5	0.76
	NACH_r600	2802	1.04	0.35
	NAtd_r600	2802	1.33	0.34
	NAIN_r600	2802	0.82	0.47
	NACH_r	2802	0.92	0.33
	NAtd_r	2802	2.39	0.64
	NAIN_r	2802	0.44	0.13
	Valid N (listwise)	2802		

The building networks of the cases have been analyzed with the UNA toolbox on Rhinoceros 3D. The radius has been assigned to 600 meters as an average walking distance, making it consistent with the previous stage. The network has been selected as origins and destinations, meaning accessibility from all buildings in the network to all other buildings within a radius of 600 meters. Since the density and land use data were provided through the GIS file of the suburbs in this stage, the density analysis can be fully performed through the UNA analysis. The UNA results are demonstrated in Table 8.

Table 8. Mean *reach* and *gravity* values from UNA analysis in the two suburbs

Case name		Mean
Suburb 1	Reach_ r600	962.14

	Gravity_ r600	528.27
Suburb 2	Reach_ r600	264.18
	Gravity_ r600	69.35

3.2.3 Hypothesis testing

The results of the computational analysis will be combined with the results of the survey in Case Study II to test the five hypotheses that have been set out from the results of Case Study I.

3.2.3.1 Hypothesis I

Three claims have been posed for *safety*. Firstly, in Case Study I, it has been discovered that those layouts with a high degree of correlation between *NAIN_r*, and *connectivity* has been strongly associated with the *safety* outcomes. In Case Study II, it is expected that the layout that is more intelligible is likely to be accompanied by higher *safety*. From the survey results, *safety* along with all the corresponding sub-questions have been ranked higher by the residences in Suburb 1, as shown in Figure 7.

Figure 7. Comparison of the safety results in the two suburbs, (optional color use)

For measuring *intelligibility*, *NAIN_r* and *connectivity* have been correlated using Pearson Correlation Coefficient, shown in Table 9.

Table 9. The Correlation Coefficient between NAIN_r and connectivity in the two suburbs

Case name			**Connectivity**
Suburb 1	NAIN_r	Correlation	.173**
		Sig. (2-tailed)	0
		N	6380
Suburb 2	NAIN_r	Correlation	.155**
		Sig. (2-tailed)	0
		N	2802
****. Correlation is significant at the 0.01 level (2-tailed).**			

According to the results in Table 9, *intelligibility* in Suburb 1 is higher than Suburb 2, which supports the first part of the hypothesis.

The second part of the hypothesis states that the layout in the suburb with more pedestrian movement opportunity is more likely to have a higher *safety* rank. This claim has been tested by measuring *NACH* in radius n and 600m for both suburbs. As shown in Figure 8, *NACH* value for both radii are higher in Suburb 1, with a higher safety level, than in Suburb 2. Hence, this hypothesis is supported by the results.

Figure 8. NACH results on radius n and 600 m, (colors necessary)

All of these claims have been fully supported by the results suggesting *intelligibility*, *spatial accessibility* and *layout accessibility* as important characteristics associated with a feeling of *safety*. These findings support past studies reporting antisocial behavior is more likely to happen in deeper layouts with low natural surveillance (De Filippi et al., 2020, Hillier and Sahbaz, 2008). Studies suggest even in one layout

form, a cul de sac, for example, the higher degree of visibility of dwellings provided by simple linear pathways compared to hierarchical and interlinked pathways are less vulnerable (Hillier 2004). This hierarchical and less visible network pattern is evident in the Suburb 2 case study, which perhaps led to a lower feeling of safety for the residents. However, this association is very nuanced, and care needs to be taken in interpreting the results. The complication of making cities and urban areas sustainable through a compact city strategy concurrent with making them safe is challenging. Hillier et al. (2008) explain, on one hand, intensifying urban areas means making them more compact and permeable, where facilities are easily accessible with fewer detours required. On the other hand, open areas with high permeability might be more susceptible to crime. In the spatial analysis, the Suburb 1 case study turned out to have a less permeable layout (Figure 8), which might also have an impact on the higher *safety* rate, along with the studied spatial configuration properties. While more permeable spaces facilitate co-presence and movement through being more visible and connected, they also lead to the presence of strangers, which might increase the chance of crime or reduce the feeling of safety for locals. Recent studies also show that more highly used areas are not necessarily safer (Mohamed and Stanek, 2020). Even though balancing layout density, *permeability* and *safety* seems challenging, *intelligibility* can mediate this relationship by adding a social surveillance element to increase *safety*. This association is also dependent on the form that buildings take to create the required density range and the way the buildings are located and connected to the public area in a residential suburb. This was raised in the comment section under the *safety* question category in Suburb 2; residents pointed out '*houses are too close to each other*' or '*fences are too short*', resulting in a lower rating for privacy and security of the neighborhood as well.

3.2.3.2 Hypothesis II

Two propositions for *sense of place* have been set out. Firstly, *sense of place* in Case Study I resulted higher in the layouts with higher values of local *NACH*. Accordingly, the layout with a higher flow of pedestrian movement is accompanied by a higher *sense of place*. Since *NACH* is higher in Suburb 1 (Figure 8), *sense of place* is expected to be higher as well. The results shown in Figure 7 report a higher rate of sense of place in Suburb 1. Hence, these results are in accordance with the first part of Hypothesis II.

The second part of the hypothesis states that higher *intelligibility* is accompanied by a stronger *sense of place*. According to Table 9, *intelligibility* is stronger in Suburb 1. This hypothesis has been fully supported by the results, suggesting *layout accessibility* and *intelligibility* as important spatial configuration characteristics associated with a *sense of place*. Moreover, the new set of analyses in Case Study II suggested an association between this indicator and *permeability*. The findings suggest a similar pattern of association between *permeability* and *sense of place* with *safety*. The layout with lower *permeability* but higher *intelligibility* seems to better support this indicator. These findings provide new insights into socio-physical relationships embedded in spatial configuration research since s*ense of place* is rather less studied (Seamon, 2015). This pattern has occurred in this study in Suburb 1, where *sense of place* showed a strong positive correlation with *community participation* ($R = .33$, $p < .005$), whereas, in Suburb 2, the association was not significant ($R = .023$, $p = .08$). The link between this indicator and *community stability* was also stronger in Suburb 1 ($R = .38$), supporting the findings of past studies (Abass and Tucker, 2018, Lee et al., 2017, Comstock et al., 2010). In contrast, in a study of three social factors, being social interaction, community participation, and place attachment, greater *sense of place* was associated with less community participation (Zhang et al., 2018).

In the correlation results presented in Table 5, *sense of place* was the only indicator with significant correlation with all other indicators of social sustainability having the strongest correlation with *safety* (R

= .38) and the lowest correlation with *community participation* (R = .27). These results are interesting because *sense of place*, along with *safety*, turned out to have strong associations with spatial design factors in both case studies.

3.2.3.3 Hypothesis III

According to the results of Case Study I, the third hypothesis postulates the layout that attracts more movement flow supports higher *social interaction*. This indicator has been measured through four items in the survey, which mainly focused on the interaction between residents in their community. The overall value, as well as the score in individual items, have been reported higher in Suburb 2, as seen in Figure 9. Hence, a higher value of *NACH* is expected in Suburb 2.

Figure 9. *Social interaction* results of the two suburbs, (optional color use)

Spatial analysis on the two suburbs has indicated a higher value of *NACH_r600* in Suburb 1, as shown in Figure 8. These results do not support the hypothesis.

In addition to Case Study I, previous studies also found a positive association between *social interaction* and greater opportunities for movement and walkability (Zuniga-Teran et al., 2019, Brookfield, 2017, Talen and Koschinsky, 2014, Wood et al., 2010, Yin, 2013). However, there are studies, like that of Ferguson (2007), that found the increased potential of encounters provided by a higher pedestrian flow does not always facilitate *social interaction*.

The fact that this hypothesis has not been met in Case Study II can be explained by further exploring the survey results in regard to the layout characteristics. Looking closer to the profile of the two suburbs, the higher *social interaction* in Suburb 2 seems to be more affected by the social profile of the suburb than the layout and design characteristics. Suburb 2 contains a more unified population, mainly local Australians with a median age of 41, whereas in Suburb 1, the population involves more diversity, including international students and various cultural groups. This assumption has been tested by comparing the *social interaction* rate in the two suburbs with their corresponding *community stability* indicators. Results of the *community stability* indicator have revealed that residents in Suburb 2 have a longer median stay length, are mainly house owners, and plan to stay longer in the neighborhood compared to those living in Suburb 1, whose profile is younger, with lower house ownership, and inhabitants less likely to maintain long-term residency in the neighborhood. Moreover, in the results of the survey, *social interaction* has the strongest correlation with community stability, R = .564, p = .000, as shown in Figure 10. This has also been reflected in the comment section under the *social interaction* category. Several residents in Suburb 1 stated that they did not know their neighbors, while in Suburb 2, many reported the neighborhood was friendly with residents knowing a lot of neighbors and community groups for a long time.

Figure 10. Scatterplot of *social interaction* and *community stability,* (optional color use)

In addition to the social context, layout characteristics may also play a role in supporting *social interaction* in Suburb 2. This suburb has higher local and global *integration* values along with receiving lower *safety* and *security* scores. When the layout provides less opportunity for a passer-by to find their way across the neighborhood, it might affect the sense of safety in a negative way. Nevertheless, this seclusion may be desirable for the residents living in a small block of buildings, contributing to the enhancement of their *sense of community,* and thus, endorsing interactions. This assumption is supported by the findings where

social interaction has the strongest correlation with *sense of community*, and the lowest correlation with *safety*, r = .215, p = .014, as shown in Figure 11.

Figure 11. Scatterplot of *social interaction* and *safety,* (optional color use)

In order to further explore the layout characteristics that might have influenced the higher *social interaction* in Suburb 2, the correlation between the local measure of *integration* and *connectivity*, as other associates of *layout accessibility,* is carried out. The results in Table 10 show a strong correlation between *NAIN_r600* and *connectivity* in Suburb 2, while this correlation is not strong nor significant in Suburb 1 (p > .583). The well-connected and locally integrated layout seems to accord with the higher *social interaction*.

Table 10. The correlation between local *NAIN* and *connectivity* in the two suburbs

Case name			**NAIN_r600**
Suburb 1	Connectivity	Correlation	0.007
		Sig. (2-tailed)	0.583
		N	6380
Suburb 2	Connectivity	Correlation	.042*
		Sig. (2-tailed)	0.026
		N	2802

*. Correlation is significant at the 0.05 level (2-tailed), highlighted.

Even though this hypothesis has not been supported by the initial results, further explorations indicated the context-based nature of the *social interaction* indicator, reliant on the social status and the smaller scale characteristics of the layout configuration.

The second part of the hypothesis claims that the layout with the lower overall number of accessible buildings, approximating building density, supports higher *social interaction*. As shown in Table7, the mean values of *reach* and *gravity* are lower in Suburb 2, with a higher *social interaction* rate. This part of the hypothesis is supported by the results. The negative impact of *spatial density* on *social interaction* can be explained by the values that measure this characteristic of the layout, *reach* and *gravity*. In Case Study I, these two values showed strong correlations with net and gross density, which both had a negative impact on *social interaction*. This pattern has occurred again in Case Study II, where the layout with more accessible buildings showed a lower *social interaction*. This supports the results of recent studies (Dempsey et al., 2012, Raman, 2005), while refuting the earlier studies suggesting high density areas support social activities and interactions (Jacobs, 1969). Especially in the context of Case Study II, it seems the strong association of *social interaction* with *community stability* has indicated the level of context-dependency of this variable.

Comparing this pattern with other spatial configuration characteristics, *permeability* shows the more permeable layout in Suburb 2 is accompanied by higher *social interaction*. This supports recent studies providing evidence for the interrelation between higher *social interaction* and activities in the permeable layouts (Zerouati and Bellal, 2019). While the higher accessibility of a layout in a residential area provides potentials for social encounters, the occurrence of the interaction seems to be more reliant on the cultural and contextual features. In this sense, our analysis showed the local characteristics of a layout are as

important as the global features in providing a well-connected and well-integrated network at a smaller scale.

3.2.3.4 Hypothesis IV

The fourth hypothesis states that the layout with higher values of *NACH_r600* is accompanied by a better range of *social sustainability*. Since *NACH_r600* is higher in Suburb 1 (Figure 8), *social sustainability* in Suburb 1 is expected to be higher. The survey results showed that *social sustainability* is lower in Suburb 1, which does not support the hypothesis. This refers back to the previously discussed point regarding the refinement of the *layout accessibility* measurements. The higher value of *NACH_r600* in Suburb 2, representing higher opportunities for people movement, along with higher *connectivity*, has occurred with the lower value of *NAIN_r600*. Additionally, in Suburb 2, the highly integrated layout at a local scale showed a correlation with *connectivity*, whereas in Suburb 1, these two factors were not correlated. These findings indicate the importance of studying the spatial design factors in an integrated manner to achieve a more comprehensive insight as well as better explain the existing patterns. Along with the contextual factors involving in the deviation from the expected pattern, the individual associates of *layout accessibility* may also have played a part. The higher value of the main associate of layout accessibility, *NACH_r600*, was not concurrent with higher social sustainability, while the other factors, *NAIN_r600* and *connectivity*, are both higher in Suburb 2. This further emphasizes the importance of the local characteristics of the layout, and refinement of the *layout accessibility* measurements.

The second part hypotheses that higher *spatial accessibility* is expected to be accompanied by lower *social sustainability*. As discussed in the previous section, the average scores for *NACH_r* and *gravity* are lower in Suburb 2, which supports the second part of the hypothesis.

The third part claims that the layout with lower values of the associates of spatial density, *reach* and *gravity,* are more likely to have a higher *social sustainability* range. *Spatial density* has been measured by *reach* and *gravity* values in UNA analyses. This shifts the focus of the analysis from considering average scores for density to the pattern of density distribution. Table 8 shows the mean *reach* and *gravity* values, both are higher in Suburb 1, supporting the hypothesis. The mean *gravity* and *reach* values are lower in Suburb 2 (Table 7); however, as explained in the introductory sections, we are interested in examining the distributed density pattern instead of the average density. The visualized maps of the UNA results of the same measurements in Figure 12 show a more evenly distributed density pattern in Suburb 2, which refers to a more equal accessibility across the suburb. In other words, various opportunities and facilities have been more evenly spread in Suburb 2, potentially providing a more desirable level of *spatial density*, whereas in Suburb 1, only one concentrated density area is seen on the map. This concentrated density refers to the accumulation of the main facilities in one location, and thus, lower accessibility for the residents in more distant areas.

Figure 12. *Gravity* and *reach* results of the two suburbs, (colors necessary)

As a result, the layout with a more even distribution of density was accompanied by a better range of social sustainability. This suggests a more refined measurement for accessibility closely integrated with density enhances our understanding when considering the social impact. This is in accordance with recent

studies criticizing the traditional density measurements in discarding the design characteristics, land uses, and attraction points, etc. (Pafka, 2020, Zainol and Elsawa, 2018, Berghauser Pont, 2018).

3.2.3.5 Hypothesis V

The fifth hypothesis claims that the same density areas with different spatial configurations do not necessarily yield similar *social sustainability* outcomes. Overall, this hypothesis has been so far examined through exploring in-depth relationships within *social sustainability* indicators and spatial design factors in two suburbs with similar ranges of density. The t-test results on *social sustainability* outcomes (Table 5) have also disclosed that there are statistically meaningful and significant differences in all these categories between the two suburbs. Thus, this hypothesis is supported by the results. This further confirms that generalizing the social outcomes based on density categories, when the spatial configuration has not been included, would not yield accurate results. Therefore, a fine-grained categorization of the cases in such urban studies would be incorporating both density and spatial configuration characteristics. This notion is in accordance with recent studies on novel accessibility tools, like the Spacemate Matrix and Urban Calculator (Berghauser Pont et al., 2020), which attempt to engage various scales and morphological plot measures to the measurements of density, addressing a wider scope of the spatial and built density.

The aggregated results yielded from both case studies during hypotheses construction, examination, and validation will be summarized in the next section to highlight the key findings from these analyses.

4. Aggregated results

Case Study I informed about the role of the spatial configuration on social sustainability and density, which was then used to develop the series of hypotheses. Case Study II externally validated the majority of the identified correlational associations through examining the hypotheses. The aggregated results from both case studies together address the aim of the research in providing a fine-grained description of the relationship between these three elements. In doing so, this research showed how spatial configuration significantly influences social sustainability indicators. Social sustainability indicators have been framed by some current studies as being generally affected by the built environment. However, the close investigation as to how these indicators are affected by the spatial configuration has not been clearly identified in those studies. The findings of the relationships between spatial configuration, density, and social sustainability will be discussed in the following subsections.

4.1 Relationships between spatial configuration and social sustainability

In summary, out of the five indicators of social sustainability studied in this paper, *safety*, *sense of place* and *social interaction* have shown to be significantly affected by spatial configuration. In case of *safety*, the spatial configuration has a stronger impact than density. Even though *community stability* and *community participation* have not shown strong association with spatial configuration, they are necessary to be studied in order to understand the contextual features. In Case Study II, the degree of the correlation between these two indicators with other indicators of social sustainability helped explain the context-dependency of the associations. More specifically:

- safety is affected by some or all associates of the intelligibility, layout accessibility, permeability, and spatial accessibility (Hypothesis I)
- sense of place is affected by some or all associates of permeability, layout accessibility, and intelligibility (Hypothesis II)

- *social interaction* is affected by some or all associates of *spatial density* (Hypothesis III)
- social sustainability is affected by some or all associates of spatial density, and spatial accessibility (Hypothesis IV)

4.2 Relationships between spatial configuration and density

It has been shown that density is also affected by spatial configuration, while it cannot represent the design of a neighborhood. In the same way, similar density ranges do not necessarily yield similar social sustainability outcomes (Hypothesis V). This is a significant point for future studies into the social impact of urban density, as most of such studies only focus on density ranges for categorization. Overlooking spatial configuration, only referring to the median density, would not effectively capture the differences. This study showed that the proposed approach in addressing density in relation to spatial configuration would mitigate two fundamental challenges in the conventional density measurements in 1) discarding design attributes, and 2) assuming equal distribution of attraction points and accessibility.

The results of this study in utilizing *spatial density* and relating it to various accessibility measures showed the analysis should be more targeted to the way in which density makes some opportunities more accessible to residents, such as access to integral facilities, services etc. This approach has led to taking the benefits that density can offer regarding the arrangement of streets and building form into account along with other factors.

4.3 An integrated and context-based approach to studying the impacts of urban density on social sustainability

With the complexity of sustainability problems, adding to rapid urbanization, there is an urgency for multidisciplinary and innovative approaches, effectively taking advantage of advancements across various fields using technology. The research conducted a novel integrated computational approach using complementary sets of spatial analysis methods to target both street network and building networks, incorporated with social sustainability outcomes, which successfully addressed the aim. This approach proposed evidence-based urban analytic methods in addressing social impacts of urban density from a design research standpoint, through studying spatial configuration. More importantly, the proposed approach makes the framework of social sustainability more concrete for urban designers and planners. Even though the social aspects of urban life might be challenging to quantify, this study showed the potential in the current approaches exist. Acknowledging how urban life is a complex system, the contextual aspects can still be captured to some extent. This seems a critical component in determining the interrelationships between social sustainability indicators studied in this research. The results also emphasize that the context impacts the dynamic of the studied relationships, meaning the indicators are not of the same importance and priority in different contexts. For instance, as demonstrated in Case Study II, the pattern of relationships within social sustainability indicators provided valuable information in interpreting the results in a context-based manner, which otherwise would have remained unraveled.

5. Conclusion

The aim of this research was to examine the interrelationship between social sustainability and density relating to neighborhood spatial design, using a complementary set of spatial analysis tools. In achieving the research aim, the study has had several contributions. Firstly, the findings enhance the understanding of the social impact of design by correlating design to the relationship between social sustainability and density. Secondly, the associations identified in this study provide new insights into socio-physical

relationships embedded in spatial configuration research, while widely overlooked in the literature of social sustainability and density. These insights are based not just on descriptive but also evidence-based findings relying on rigorous statistical and spatial analysis triangulated to empirical evidence. Thirdly, this research introduced an approach that would enable more meaningful analysis of the topic, not only referring to a number defining density but also putting it in the social sustainability and design context considering various effects, risks and opportunities that could be created through different physical arrangements. Finally, the analysis presented in this study contributes to the spatial configuration research by identifying the individual, as well as the combined effect of spatial design factors and characteristics on various social sustainability indicators. Even though some of the associations have been presented in past studies, the combination of all these indicators in one study has not yet been explored. The findings indicate the importance of studying the spatial design factors in an integrated manner to achieve a more comprehensive understanding and better explain the existing patterns. Overall, the findings from this study will offer urban designers and planners a broader view of the possible effects of their decision-making on social sustainability regarding densifying urban areas.

The scope of this study has been limited to the spatial configuration of a neighborhood that affects social sustainability. However, it is important to acknowledge that social sustainability is a very complex and multifaceted concept, being affected by multiple socio-demographic, economic, and environmental factors, amongst others. Thus, the results of this study need to be interpreted appropriately within the defined scope and the inherited limitations of the employed methodologies. The primary hypotheses have been developed in Case Study I based on a significant existing study (in a UK context) and validated through Case Study II with new cases (in a different Australian context). All the selected neighborhoods are residential areas with varying spatial design attributes. For the Australian cases, the suburbs have been selected from a similar density range while controlling for socio-demographic and economic profiles, and accessibility and distance to the main infrastructures (in the CBD area). Even though some scholars equal 'external validity' with 'generalizability' in case study research (Tsang, 2013), the scope of the generalizability of the inferences can be enhanced by careful profiling, employing mixed methodology and integration of evidence (Polit and Beck 2010). The final results are expected to be applicable to both UK and Australian cases within the profile that the cases have been selected from, which belong to developed countries. Given that the dynamics of the relationships would be different compared to those of developing countries, the results cannot be generalized to such contexts. However, the approach developed in this study can be effectively adapted to other contexts. Future research may also expand the scale and context by incorporating other design considerations, as well as broadening the scope to other land uses i.e., commercial, or recreational.

References

ABASS, Z. I. & TUCKER, R. 2018. Residential satisfaction in low-density Australian suburbs: The impact of social and physical context on neighbourhood contentment. *Journal of Environmental Psychology,* 56**,** 36-45.

AGIRBAS, A. 2019. Characteristics of social formations and space syntax application to quantify spatial configurations of urban regeneration in Levent, Istanbul. *Journal of Housing and the Built Environment,* 35**,** 171–189.

AL-SAYED, K. 2018. *Space syntax methodology* UK, Bartlett School of Architecture, UCL: London.

ALLEN, M. P. 1997. The problem of multicollinearity. *In:* ALLEN, M. P. (ed.) *Understanding Regression Analysis.* Boston, MA: Springer US.

AMINI BEHBAHANI, P., OSTWALD, M. J. & GU, N. 2016. A syntactical comparative analysis of the spatial properties of Prairie style and Victorian domestic architecture. *The Journal of Architecture,* 21**,** 348-374.

ASKARIZAD, R. & SAFARI, H. 2020. The influence of social interactions on the behavioral patterns of the people in urban spaces (case study: The pedestrian zone of Rasht Municipality Square, Iran). *Cities,* 101**,** 102687.

BANDYOPADHYAY, P. S. & FORSTER, M. R. 2011. *Philosophy of statistics,* Oxford, North-Holland.

BERGHAUSER PONT, M. 2018. An analytical approach to urban form. *In:* OLIVEIRA, V. (ed.) *Teaching Urban Morphology.* Springer International Publishing: Cham.

BERGHAUSER PONT, M., MARCUS, L. & BOBKOVA, E. 2017. *Cities as accessible densities and diversities*.

BERGHAUSER PONT, M., STAVROULAKI, G., MARCUS, L. & FITGER, M. 2020. Urban calculator. Chalmers University.

BRAMLEY, G., DEMPSEY, N., POWER, S. & BROWN, C. 2006. What is 'social sustainable', and how do our existing urban forms perform in nurturing it? *Proceedings of Planning Research Conference.* Bartlett School of Planning, University College London, London.

BRAMLEY, G., DEMPSEY, N., POWER, S., BROWN, C. & WATKINS, D. 2009a. Social Sustainability and Urban Form: Evidence from Five British Cities. *Environment and Planning A,* 41**,** 2125-2142.

BRAMLEY, G., DEMPSEY, N., POWER, S., BROWN, C. & WATKINS, D. 2009b. Social sustainability and urban form: Evidence from five British cities. *Environment and Planning A: Economy and Space,* 41**,** 2125-2142.

BRAMLEY, G. & POWER, S. 2009. Urban form and social sustainability: The role of density and housing type. *Environment and Planning B: Planning and Design,* 36**,** 30-48.

BROOKFIELD, K. 2017. Residents' preferences for walkable neighbourhoods. *Journal of Urban Design,* 22**,** 44-58.

BURTON, E. 2003. Housing for an urban renaissance: Implications for social equity. *Housing Studies,* 18**,** 537-562.

CAN, I. & HEATH, T. 2016. In-between spaces and social interaction: A morphological analysis of Izmir using space syntax. *Journal of Housing and the Built Environment,* 31**,** 31-49.

COMSTOCK, N., MIRIAM DICKINSON, L., MARSHALL, J. A., SOOBADER, M.-J., TURBIN, M. S., BUCHENAU, M. & LITT, J. S. 2010. Neighborhood attachment and its correlates: Exploring neighborhood conditions, collective efficacy, and gardening. *Journal of Environmental Psychology,* 30**,** 435-442.

DANIELS, R. & MULLEY, C. 2011. Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use,* 6**,** 5-20.

DAVE, S. 2011. Neighbourhood density and social sustainability in cities of developing countries. *Sustainable Development,* 19**,** 189-205.

DE FILIPPI, F., COCINA, G. & MARTINUZZI, C. 2020. Integrating different data sources to address urban security in informal areas. The case study of Kibera, Nairobi. *Sustainability,* 12**,** 2437.

DEMPSEY, N., BRAMLEY, G., POWER, S. & BROWN, C. 2011. The social dimension of sustainable development: Defining urban social sustainability. *Sustainable Development,* 19**,** 289-300.

DEMPSEY, N., BROWN, C. & BRAMLEY, G. 2012. The key to sustainable urban development in UK cities? The influence of density on social sustainability. *Progress in Planning,* 77**,** 89-141.

DEMPSEY, N., BROWN, C., RAMAN, S., PORTA, S., JENKS, M., JONES, C. & BRAMLEY, G. 2010. Elements of urban form. *In:* JENKS, M. & JONES, C. (eds.) *Dimensions of the Sustainable City.* Dordrecht: Springer Netherlands.

EL-HUSSEINY, M.-A. & KESSEIBA, K. 2012. Challenges of social sustainability in Neo-liberal Cairo: Re-questioning the role of public space. *Procedia - Social and Behavioral Sciences,* 68**,** 790-803.

FERGUSON, P. 2007. The streets of innovation: An exploratory analysis of knowledge transfer in the public realm. *Proceedings of the 6th International Space Syntax Symposium.* İstanbul.

FIELD, A. 2009. *Discovering statistics using SPSS,* London, UK, SAGE
GEHL, J. 2010. *Cities for people* Washington, DC, Island Press.
GROSVENOR, M. & O'NEILL, P. 2014. The density debate in urban research: An alternative approach to representing urban structure and form. *Geographical Research,* 52**,** 442-458.
GU, N., YU, R. & OSTWALD, M. 2017. Unpacking the cultural DNA of traditional Chinese private gardens through mathematical measurement and parametric design. *In:* LEE, J.-H. (ed.) *Morphological Analysis of Cultural DNA.* Singapore: Singapore Springer.
HAJRASOULIHA, A. & YIN, L. 2014. The impact of street network connectivity on pedestrian volume. *Urban Studies,* 52**,** 2483-2497.
HANSEN, W. G. 1959. How accessibility shapes land use. *Journal of the American Institute of Planners,* 25**,** 73-76.
HERNÁNDEZ-PALACIO, F. 2017. A transition to a denser and more sustainable city: Factors and actors in Trondheim, Norway. *Environmental Innovation and Societal Transitions,* 22**,** 50-62.
HILLIER, B. 1999. The hidden geometry of deformed grids: Or, why space syntax works, when it looks as though it shouldn't. *Environment and Planning B: Planning and Design,* 26**,** 169-191.
HILLIER, B., BURDETT, R., PEPONIS, J. & PENN, A. 1986. Creating life: or, does architecture determine anything? *Architecture & Comportement/Architecture & Behaviour,* 3**,** 233-250.
HILLIER, B. & HANSON, J. 1984. *The social logic of space,* Cambridge, Cambridge University Press.
HILLIER, B. & IIDA, S. 2005. Network and psychological effects in urban movement. *In:* COHN, A. G. & MARK, D. M. (eds.) *Spatial Information Theory.* Berlin, Heidelberg: Springer Berlin Heidelberg.
HILLIER, B. & SAHBAZ, O. 2008. *An evidence based approach to crime and urban design or, can we have vitality, sustainability and security all at once?* [Online]. Available: https://spacesyntax.com/wp-content/uploads/2011/11/Hillier-Sahbaz_An-evidence-based-approach_010408.pdf [Accessed December 2020.
HILLIER, B., YANG, T. & TURNER, A. 2012. Normalising least angle choice in Depthmap and how it opens new perspectives on the global and local analysis of city space. *Journal of Space Syntax* 3**,** 155-193.
JACOBS, J. 1969. *The death and life of great American cities,* New York, The Modern Library.
KANG, C.-D. 2018. Valuing spatial access to types of retail and effects on the housing price in Seoul, Korea. *Journal of Urban Planning and Development,* 144**,** 5018007.
KARUPPANNAN, S. & SIVAM, A. 2011. Social sustainability and neighbourhood design: An investigation of residents' satisfaction in Delhi. *Local Environment,* 16**,** 849-870.
KOLOVOU, I., GIL, J., KARIMI, K., LAW, S. & VERSLUIS, L. 2017. Road centre line simplification principles for angular segment analysis. *Proceedings of the 11th Space Syntax Symposium.* Instituto Superior Técnico, Portugal: Lisbon, Portugal.
KOOHSARI, M. J., OKA, K., OWEN, N. & SUGIYAMA, T. 2019. Natural movement: A space syntax theory linking urban form and function with walking for transport. *Health & Place,* 58**,** 102072.
KOOHSARI, M. J., OWEN, N., CERIN, E., GILES-CORTI, B. & SUGIYAMA, T. 2016. Walkability and walking for transport: Characterizing the built environment using space syntax. *International Journal of Behavioral Nutrition and Physical Activity,* 13**,** 121.
KYTTÄ, M. & BROBERG, A. 2014. The multiple pathways between environment and health. *Wellbeing: A Complete Reference Guide* Hoboken: John Wiley & Sons, Ltd.
KYTTÄ, M., BROBERG, A., HAYBATOLLAHI, M. & SCHMIDT-THOMÉ, K. 2016. Urban happiness: Context-sensitive study of the social sustainability of urban settings. *Environment and Planning B: Planning and Design,* 43**,** 34-57.
KYTTÄ, M., KAHILA, M. & BROBERG, A. 2011. Perceived environmental quality as an input to urban infill policy-making. *Urban Design International,* 16**,** 19-35.

LAATIKAINEN, T., TENKANEN, H., KYTTÄ, M. & TOIVONEN, T. 2015. Comparing conventional and PPGIS approaches in measuring equality of access to urban aquatic environments. *Landscape and Urban Planning,* 144**,** 22-33.

LEE, K. O. & KAUFMAN, P. 2020. The effect of urban density on mental health: A systematic review. *University of Toronto Medical Journal,* 97**,** 21-29.

LEE, S. M., CONWAY, T. L., FRANK, L. D., SAELENS, B. E., CAIN, K. L. & SALLIS, J. F. 2017. The relation of perceived and objective environment attributes to neighborhood satisfaction. *Environment and Behavior,* 49**,** 136-160.

LI, X., LV, Z., ZHENG, Z., ZHONG, C., HIJAZI, I. H. & CHENG, S. 2017. Assessment of lively street network based on geographic information system and space syntax. *Multimedia Tools and Applications,* 76**,** 17801-17819.

LIU, Y., WEI, X., JIAO, L. & WANG, H. 2016. Relationships between street centrality and land use intensity in Wuhan, China. *Journal of Urban Planning and Development,* 142**,** 5015001.

LONG, Y. & BARAN, P. K. 2011. Does intelligibility affect place legibility? Understanding the relationship between objective and subjective evaluations of the urban environment. *Environment and Behavior,* 44**,** 616-640.

LYNCH, K. 1960. *The image of the city,* Cambridge Mass., Technology Press.

MATHISON, S. 2013. *Encyclopedia of evaluation,* Thousand Oaks, Sage Publications.

MATIJOSAITIENE, I. 2016. Combination of CPTED and space syntax for the analysis of crime. *Safer Communities,* 15**,** 49-62.

MAVOA, S., EAGLESON, S., BADLAND, H., GUNN, L., BOULANGE, C., STEWART, J. & GILES-CORTI, B. 2018. Identifying appropriate land-use mix measures for use in a national walkability index. *Journal of Transport and Land Use,* 11**,** 681-700.

MCCREA, R. & WALTERS, P. 2012. Impacts of urban consolidation on urban liveability: Comparing an inner and outer suburb in Brisbane, Australia. *Housing, Theory and Society,* 29**,** 190-206.

MOHAMED, A. A. & STANEK, D. 2020. The influence of street network configuration on sexual harassment patterns in Cairo. *Cities,* 98**,** 102583.

NEUMAN, M. 2005. The compact city fallacy. *Journal of Planning Education and Research,* 25**,** 11-26.

OAKES, J. M., FORSYTH, A. & SCHMITZ, K. H. 2007. The effects of neighborhood density and street connectivity on walking behavior: The Twin Cities walking study. *Epidemiologic Perspectives & Innovations,* 4**,** 16.

ÖNDER, D. E. & GIGI, Y. 2010. Reading urban spaces by the space-syntax method: A proposal for the South Haliç Region. *Cities,* 27**,** 260-271.

PAFKA, E. 2020. Multi-scalar urban densities: From the metropolitan to the street level. *Urban Design International***,** 11.

PENN, A., HILLIER, B., BANISTER, D. & XU, J. 1998. Configurational modelling of urban movement networks. *Environment and Planning B: Planning and Design,* 25**,** 59-84.

PEPONIS, J., ALLEN, D., FRENCH, S., SCOPPA, M. & BROWN, J. 2007. Street connectivity and urban density: Spatial measures and their correlation. *Proceedings of the 6th International Space Syntax Symposium.* İstanbul.

POLIT, D.F. & BECK, C.T. 2010. Generalization in quantitative and qualitative research: Myths and strategies, *International Journal of Nursing Studies*, vol. 47, no. 11, pp. 1451-1458.

PONT, M. B. & MARCUS, L. 2015. What can typology explain that configuration can not. *Proceedings of the 10th International Space Syntax Symposium.* Lisbon

QUASTEL, N., MOOS, M. & LYNCH, N. 2012. Sustainability-as-density and the return of the social: The case of Vancouver, British Columbia. *Urban Geography,* 33**,** 1055-1084.

RAMAINA, R., LEDUC, T. & MOREAU, G. 2014. A new method to characterize density adapted to a coarse city model. *In:* POPOVICH, V., CLARAMUNT, C., SCHRENK, M. & KOROLENKO, K. (eds.)

Information Fusion and Geographic Information Systems (IF AND GIS 2013): Environmental and Urban Challenges. Berlin, Heidelberg: Springer Berlin Heidelberg.
RAMAN, S. 2005. *Social sustainability in the city: The relationship between density and social interaction.* U204957 Ph.D., Oxford Brookes University
RAMAN, S. 2010. Designing a liveable compact city: Physical forms of city and social life in urban neighbourhoods. *Built Environment,* 36**,** 63-80.
RASHID, M. 2019. Space syntax: A network-based configurational approach to studying urban morphology. *In:* D'ACCI, L. (ed.) *The Mathematics of Urban Morphology* Switzerland Cham: Springer International Publishing.
REJEB BOUZGARROU, A., CLARAMUNT, C. & REJEB, H. 2019. Visualizing urban sprawl effects of a Tunisian city: A new urban spatial configuration of Monastir. *Annals of GIS,* 25**,** 71-82.
ROKEM, J. & VAUGHAN, L. 2019. Geographies of ethnic segregation in Stockholm: The role of mobility and co-presence in shaping the 'diverse' city. *Urban Studies,* 56**,** 2426-2446.
SEAMON, D. 2015. Understanding place holistically: Cities, synergistic relationality, and space syntax. *Journal of Space Syntax,* 6**,** 19-33.
SEVTSUK, A. 2014a. Analysis and planning of urban networks. *In:* ALHAJJ, R. & ROKNE, J. (eds.) *Encyclopedia of Social Network Analysis and Mining.* New York: Springer New York.
SEVTSUK, A. 2014b. Location and agglomeration: The distribution of retail and food businesses in dense urban environments. *Journal of Planning Education and Research,* 34**,** 374-393.
SEVTSUK, A. 2018. *Urban Network Analysis for Rhinoceros 3D,* Cambridge, City Form Lab.
SEVTSUK, A., KALVO, R. & EKMEKCI, O. 2016. Pedestrian accessibility in grid layouts: The role of block, plot and street dimensions. *Urban Morphology,* 20**,** 89- 106.
SEVTSUK, A. & MEKONNEN, M. 2012. Urban Network Analysis toolbox. *International Journal of Geomatics and Spatial Analysis,* 22**,** 287- 305.
SHEN, Y. & KARIMI, K. 2016. Urban function connectivity: Characterisation of functional urban streets with social media check-in data. *Cities,* 55**,** 9-21.
SOEBARTO, V., BENNETTS, H., HANSEN, A., ZUO, J., WILLIAMSON, T., PISANIELLO, D., VAN HOOF, J. & VISVANATHAN, R. 2019. Living environment, heating-cooling behaviours and well-being: Survey of older South Australians. *Building and Environment,* 157**,** 215-226.
SOMENAHALLI, S., TAYLOR, M. & SUSILAWATI, S. 2016. Road network accessibility and socio-economic disadvantage across Adelaide metropolitan area. *Transportation in Developing Economies,* 2**,** 1-8.
STÅHLE, A., MARCUS, L. & KARLSTRÖM, A. 2005. Place syntax—geographic accessibility with axial lines in GIS. *Proceedings in 5th Space Syntax Symposium.* Delft, Netherlands.
STEEMERS, K. 2003. Energy and the city: Density, buildings and transport. *Energy and Buildings,* 35**,** 3-14.
SUMMERS, L. & JOHNSON, S. D. 2017. Does the configuration of the street network influence where outdoor serious violence takes place? Using space syntax to test crime pattern theory. *Journal of Quantitative Criminology,* 33**,** 397-420.
SUN, X., WANG, L., WANG, F. & SOLTANI, S. 2020. Behaviors of seniors and impact of spatial form in small-scale public spaces in Chinese old city zones. *Cities,* 107**,** 102894.
TALEN, E. & KOSCHINSKY, J. 2014. Compact, walkable, diverse neighborhoods: Assessing effects on residents. *Housing Policy Debate,* 24**,** 717-750.
THOMAS, J. A., WALTON, D. & LAMB, S. 2011. The influence of simulated home and neighbourhood densification on perceived liveability. *Social Indicators Research,* 104**,** 253-269.
TSANG, E. 2013. Generalizing from research findings: The merits of case studies. *International Journal of Management Reviews*, vol. 16, no. 4, pp. 369-383.
TSOU, K.-W. & CHENG, H.-T. 2013. The effect of multiple urban network structures on retail patterns – A case study in Taipei, Taiwan. *Cities,* 32**,** 13-23.

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**,** 539-555.
VALLANCE, S., PERKINS, H. C. & DIXON, J. E. 2011. What is social sustainability? A clarification of concepts. *Geoforum,* 42**,** 342-348.
VAUGHAN, L. 2007. The spatial syntax of urban segregation. *Progress in Planning,* 67**,** 205-294.
VECCHIO, G., PORRECA, R. & RIVERA, D. 2020. Socio-spatial concerns in urban mobility planning: Insights from competing policies in Quito. *Sustainability,* 12**,** 2923.
WALTON, D., MURRAY, S. J. & THOMAS, J. A. 2008. Relationships between population density and the perceived quality of neighbourhood. *Social Indicators Research,* 89**,** 405-420.
WANG, Y. & SHAW, D. 2018. The complexity of high-density neighbourhood development in China: Intensification, deregulation and social sustainability challenges. *Sustainable Cities and Society,* 43**,** 578-586.
WOOD, L., FRANK, L. D. & GILES-CORTI, B. 2010. Sense of community and its relationship with walking and neighborhood design. *Social Science & Medicine,* 70**,** 1381-1390.
YIN, L. 2013. Assessing walkability in the City of Buffalo: Application of agent-based simulation. *Journal of Urban Planning and Development,* 139**,** 166-175.
ZAINOL, R. & ELSAWA, H. 2018. Relationship between adequate healthcare facilities and population distribution in Melaka using spatial statistics. *Journal of design and the built environment***,** 131-137.
ZEROUATI, W. & BELLAL, T. 2019. Evaluating the impact of mass housings' in-between spaces' spatial configuration on users' social interaction. *Frontiers of Architectural Research,* 9**,** 34-53.
ZHANG, H., MATSUOKA, R. & HUANG, Y.-J. 2018. How do community planning features affect the place relationship of residents? An investigation of place attachment, social interaction, and community participation. *Sustainability,* 10**,** 2726.
ZUNIGA-TERAN, A. A., STOKER, P., GIMBLETT, R. H., ORR, B. J., MARSH, S. E., GUERTIN, D. P. & CHALFOUN, N. V. 2019. Exploring the influence of neighborhood walkability on the frequency of use of greenspace. *Landscape and Urban Planning,* 190**,** 103609.