ABSTRACT

Urban design and planning are increasingly geared toward increasing density, viewed by many as a way of achieving socio-economic and environmental sustainability. The quantitative measurement of density from the building-level to the area-level presents a challenge to practitioners. This paper demonstrates a new measure, Space Ratio, for the purposes of measuring and mapping the density potential of buildings and areas in London. Space Ratio describes the ratio of the existing density to the permissible density. It is a multi-variable tool that can potentially incorporate a range of measures of building, people or perceived density. Space Ratio can be utilised to test multiple density measures and scenarios. A tool for visualising density potentials, the 'Space Ratio Chart', has also been illustrated as part of this study. Drawing on three-dimensional data on building density and several upward density scenarios, Space Ratio has been measured and mapped in the London case study areas of Balham and Kensington. Although Space Ratio and the Space Ratio Chart are contingent on high-quality data, this study argues that they could aide the design and scenario planning of sustainable densification.

KEYWORDS

Space Ratio; Density; Architecture; Urban Design and Planning; Mapping; London

1. INTRODUCTION

As the amount of urban space decreases, the calculation of density potentials presents an important challenge to planners, designers and policy-makers (Amer et al., 2017). In order to facilitate sustainable densification, or densification that is resource-efficient and does not encroach on greenfield land (Urban Task Force, 1999; Heng and Malone-Lee, 2010), it is imperative that practitioners draw on accurate quantitative and qualitative representations of the potentiality of densification (Alexander, 1993). Building upwards in urban hubs through upward densification can sustainably increase residential and employment densities without demolishing existing buildings (Scanlon et al., 2018). Several studies of upward densification through airspace development contend that it is a sustainable alternative to sprawl that makes the most of existing space (Amer et al., 2017; Artés et al., 2017). Sprawl refers to the lateral expansion of cities onto greenfield land and has been criticised in the literature on a number of socio-economic and environmental levels (Newman and Kenworthy, 1989; Neuman, 2005; Gordon and Whitehead, 2016). For example, the proliferation of sprawl has been found to increase car dependency, air pollution and poor health outcomes (Newman and Kenworthy, 1989; Neuman, 2005). The research on the antithesis of sprawl, compact cities, is contested. Neuman (2005), Dempsey and Jenks (2010) and McConnell and Wiley (2010) note that the case for compact cities is empirically lacking. Upward densification differs from the concepts of sprawl and compact cities. Unlike sprawl and compact cities, upward densification can only take place vertically. Building upwards is characterised by the utilisation of existing urban space such as rooftops and reduces the reliance on sprawl and greenfield development (Allam and Jones, 2019). Drawing on qualitative data, Burdett et al. (2004), on the other hand, find that higher densities in London have been linked to overcrowding and socio-economic inequality. As Amer et al. (2017) argue, there are a lack of tools to aide practitioners in the planning and design of sustainable, high-quality upward densification.

The density of London has increased since the late 20th century but it remains a comparatively low-density city (Scanlon et al., 2018). Since the late 20th and early 21st century, planners in London have increasingly opted for densification over sprawl as a solution to the lack of space and the rising demand for new homes and sustainable development (Gordon and Whitehead, 2016). Building upwards, or upward densification, is a form of urban intensification being promoted as part of planning policy in London. The importance of urban intensification can be traced back to the launch of the Urban Task Force's (1999) report 'Towards an Urban Renaissance', which outlined how urban intensity and density can be increased in the UK while achieving sustainable development goals. Local councils in London such as Richmond Upon Thames Council (2009) and Southwark Council (2019a; 2019b) have outlined programmes that emphasise the importance of facilitating upward densification and intensification through airspace development. The Draft and New London Plans, the Greater London Authority's (2017; 2019) spatial development strategies for Greater London, state that building upwards is an important means by which to densify and intensify the city. The introduction of revised Permitted Development Rights at national-level regarding the construction of two-storey upward extensions could result in the construction of poor-quality homes that effectively bypass the planning system. The design and planning of upward densification should prioritise sustainability and the local context (Amer et al., 2017; Allam and Jones, 2019; Bellini and Mocchi, 2019). By context, this study refers to the parameters that underpin the urban fabric. Tools that aim to facilitate the increase density in London have been produced. The Density Matrix, a quantitative tool, was introduced in the late 20th century to increase density and the supply of new homes in London. It provided a framework for setting the density of new residential developments. According to the Greater London Authority et al. (2006), Allies and Morrison (2016) and Livingstone et al. (2021), the Density Matrix was too prescriptive and failed to adequately incorporate the local context. New tools such as Space Ratio are required to aide the measurement of density potentials in London and the design and planning of sustainable and contextual upward densification.

Noting the lack of consensus on density, Cheng (2010) argues that it can be calculated in terms of buildings, people or perceptions. Measures of building density include, but are not limited to: Floor Area Ratio, building height and Ground Space Index. Population density can be measured by counting the number of people per unit of area as in people per hectare. Meanwhile, perceived density is a qualitative measure that plays an important role in the design and planning of densification (Alexander, 1993; Churchman, 1999). Noble et al. (1993) state that while density tools such as people per hectare measure occupancy, others such as Floor Area Ratio, the latter of which denotes the ratio of the total floor area to the site area, account for volume and design. A limitation of many other density tools and studies is their two-dimensionality or the lack of a three-dimensional perspective (Pafka, 2013). Dwellings per hectare, for example, is a two-dimensional measure and does not illustrate the urban volume or the horizontal stratification of buildings and cities (Graham and Hewitt, 2012; McNeill, 2019). Dwellings per hectare is therefore less useful than Floor Area Ratio or building height as a measure of upward density, which is inherently three-dimensional. Noble et al. (1993) argue that the three-dimensionality of Floor Area Ratio can bring about innovation in the fields of design and planning. As Dovey and Pafka (2013) state, building height is another three-dimensional mediator of density but a poor predictor of total floorspace. The confusion surrounding the measurement of density has resulted in the creation of new quantitative methodologies.

Although new tools by which to measure and visualise density have been demonstrated in the critical literature (Berghauser Pont and Haupt, 2009; Hong, 2012; Perdue, 2013; Berghauser Pont and Marcus, 2015; Koziatek and Dragićević, 2017), there is a lack of research on the calculation of density potentials (Eggimann et al., 2021). Berghauser Pont and Haupt (2009) demonstrate Spacematrix, a visual tool that incorporates Floor Space Index (or Floor Area Ratio), Ground Space Index, Open Space Ratio and building height in the form of a chart. Spacematrix is a multi-dimensional and multi-scalar tool that enables the visual and statistical comparison of multiple buildings and scenarios (Berghauser Pont and Haupt, 2009; Berghauser Pont et al., 2017). Building on the work of Martin and March (1972), Berghauser Pont and Haupt (2009) make a significant contribution to the literature on the use of new quantitative tools to study densification. Perdue (2013) create the Personal Space Metric, a novel measure that provides a means by which to measure how much volumetric space people occupy as a percentage of residential buildings. The Personal Space Metric depicts the verticality of occupancy and is an alternative to two-dimensional cartographic representations of population density (Perdue, 2013). Similarly to Space Ratio and Berghauser Pont and Haupt's (2009) Spacematrix, Perdue's (2013) Personal Space Metric is a volumetric density tool. Unlike Space Ratio, however, neither Spacematrix nor the Personal Space Metric adequately incorporate the policy context. This study argues that there is a lack of research on the use of quantitative, multi-variable tools to aide the planning and design of sustainable and contextual upward densification (Amer et al., 2017).

The current state of the art on the measurement of density is limited on several levels. First, there is a distinct lack of multi-variable research on density (Dovey and Pafka, 2013). As Martin and March (1972) note, the various tools paint very different pictures of density. Multi-variable perspectives provide a better account of the dynamics of density (Fernández Per et al., 2007; Berghauser Pont and Haupt, 2009; Dovey and Pafka, 2013). Dovey and Pafka (2013) evaluate a variety of density tools including, but not limited to: Floor Area Ratio, dwellings per hectare and building coverage. According to Boyko and Cooper (2011), Pafka (2013) and Dovey and Pafka (2013), studies of density should incorporate a range of tools. Berghauser Pont and Haupt (2009) utilise Spacematrix to argue that studies of density should be multi-variable. Hanke (1965; 1966; 1972) also produce multi-variable tools, the Land Use Intensity Rating and Land Use Intensity Ratio, which incorporate several measures of permitted density. As Alexander (1993, p.185) states, these tools are not only "rigid" but also characterised by "complexity and lack of transparency". These tools also do not factor in several measures of perceived and population density. In order to reflect both quantity and quality (Dovey and Pafka, 2013), this study develops a multi-variable tool that can potentially incorporate quantitative and qualitative measures of density. Although the emphasis in this study is on building density – including building height in storeys and Floor Area Ratio – the tool can be adapted to measure the difference between existing and permissible people and perceived density. Another limitation of the literature on density is the lack of multi-scalar studies (Berghauser Pont and Haupt, 2009). Multi-scalar perspectives of density do not succumb to the Modifiable Areal Unit Problem, which occurs when density is aggregated to administrative areas that may differ significantly in terms of area (Berghauser Pont and Haupt, 2009; Dovey and Pafka, 2013; Berghauser Pont and Marcus, 2015). A number of studies are limited by their use of two-dimensional tools such as dwellings per hectare or people per hectare. For instance, Williams (2009) utilises dwelling density, a flat and two-dimensional measure, to study the spatial and temporal distribution of densification in the UK. Upward densification is highly volumetric, meaning two-dimensional tools are limited as quantitative representations. By comparison, drawing on three-dimensional spatial analysis, Guo et al. (2017) and Koziatek and Dragićević (2017) demonstrate that the impact of densification on the urban fabric can be analysed from a volumetric perspective. The critical literature on the use of three-dimensional tools such as building height to study upward densification is sparse and could be attributed to a lack of high-quality density data (Koomen et al., 2009; Ahmed and Sekar, 2015). Although Floor Area Ratio is three-dimensional and a more effective means by which to study upward densification, there is a lack of research on how it can be utilised as a zoning tool in London. This study is multi-variable, volumetric and multi-scalar, utilising storey counts in conjunction with Floor Area Ratio and new quantitative measures to study the upward density potential of buildings from the building-level to the area-level in Balham and Kensington in London.

A new tool, Space Ratio, has been demonstrated as part of this study. Space Ratio describes the ratio of the existing density to the permissible density. While the difference between the existing and permissible Floor Area Ratio has been the subject of significant study since the mid-20th century (Hanke, 1965; 1966; 1972; Kim and Choi, 2019), this is not the case for a range of other indicators. Meanwhile, Space Ratio can potentially incorporate the difference between the existing and permissible building, people or perceived density. It can additionally incorporate different density measures in the form of a chart, titled the ‘Space Ratio Chart’, aiding the comparison of density potentials. Moreover, the difference between the existing and permissible density has not been adequately mapped at building-level or area-level. Space Ratio is multi-scalar, providing a measure of the degree to which buildings or wider areas make use space. Building on the pioneering work of Berghauser Pont and Haupt (2009) and Dovey and Pafka (2013), Space Ratio is a multi-variable tool that measures density potentials. Space Ratio can measure the ratio of the existing to permissible building height, Floor Area Ratio or population density, for instance. Space Ratio can additionally measure the ratio of the existing to permissible flow of people, which is an indicator of urban intensity and rhythm (Jacobs, 1961; Clarke, 2006; Dovey and Pafka, 2013). A limitation of Space Ratio is that it relies on high-quality data on density, which may be absent for some density indicators. For example, the lack of granular, building-level data on population and perceived density means that the focus of this study is on building density. Nevertheless, Space Ratio is a tool that can potentially incorporate various qualitative and quantitative measures of density. This research contends that Space Ratio, if utilised cautiously and contextually, could be deployed by local authority planners or designers in an experimental capacity to test a range of density policy scenarios on a building-by-building basis or across a wider spatial scale in London.

The objective of this study is to provide a critical demonstration of Space Ratio in London. Space Ratio has been measured at the building and area scales and mapped in the London case study areas of Balham and Kensington. Drawing on multiple measures and scales, this study produces a case study analysis of several upward density scenarios. The Space Ratio Chart has additionally been demonstrated. This research provides a novel contribution to the literature on methods of statistically measuring and visualising densification. First, this study analyses the research context. It subsequently illustrates the research methodology. This study then presents the results from analysis of Space Ratio in the case study areas. Finally, it discusses the results and examines the strengths, limitations and implications of Space Ratio and the scenario modelling.

2. METHODOLOGY

2.1 Data

This study draws on a number of two-dimensional and three-dimensional datasets. Measuring existing and permissible building heights and Floor Area Ratios relies on two-dimensional data on building footprints as well as three-dimensional data. Space Ratio and permissible density can additionally draw on data on the policy and planning context.

Two-dimensional building footprints have been derived from Ordnance Survey MasterMap's Topography layer. This dataset includes granular two-dimensional data on building footprints. While the Ordnance Survey publishes open data on building footprints, this dataset does not include information on floorspace. In addition, this dataset includes micro built structures, which have been excluded from the analysis. Micro built structures are those with an area of less than 20 metres squared, which makes them unsuitable for upward extensions in terms of space constraints. Data on property extents and site areas have been derived from the Land Registry's INSPIRE Index Polygons.

In terms of three-dimensional datasets, this study utilises MasterMap's Building Height Attribute dataset, which is built on the Ordnance Survey's Topography layer. This dataset provides three-dimensional information that aides the calculation of building height in storeys, permissible building height and Space Ratio. Ordnance Survey deploy Light Detection and Ranging (LiDAR) to calculate the height of buildings. To obtain the measurements, a Digital Terrain Model was derived from a Digital Surface Model by way of interpolation (Wu et al., 2018) and a dataset detailing property extents. As Wu et al. (2018, p.1742) state, LiDAR surveys that utilise interpolation can contain errors derived from the inclusion of non-manmade objects. There is a severe lack of good-quality data on density in the UK (Orford, 2010), which somewhat hinders the spatial analysis of upward densification at area-level. For example, there is a notable lack of granular, high-quality data on floorspace and the number of storeys per building. Furthermore, there is a deficit of high-quality data on Floor Area Ratio in London. The case study analysis therefore estimates storey count, a mediator measure of building density that is deployed in parts of London as part of planning policy.

The calculation of Space Ratio additionally relies on policy data. Planning policy on upward density can place a limit on the number of storeys that can be constructed, for example. It can alternatively incorporate data on the height of the adjoining roofline. A number of local councils in London such as Kensington and Chelsea Council (2013) have implemented policies that require upward densification to adhere to the existing roofline and this is reflected in the scenarios. The coordinates of the case study areas of Balham and Kensington have been sourced from the Greater London Authority's (2016) London Plan. The spatial dataset has been downloaded from the London Datastore, an open data portal maintained by the Greater London Authority and the Mayor of London. These coordinates from the Greater London Authority's (2016) London Plan provide a basis from which to define the spatial extent of the case study areas.

Data on the location of listed buildings has been derived from Historic England. The National Heritage List is openly published by Historic England as a points-based shapefile. In some cases, this open dataset displays multiple addresses under one point, which is problematic from a spatial visualisation and analysis perspective. This study has extrapolated the entries in the National Heritage List and geocoded the data. Listed buildings in the case study areas were subsequently removed from the analysis and visualisation. Upward extensions are less appropriate atop listed buildings due to a variety of design, planning and structural constraints. As such, listed buildings have been removed from the maps of Space Ratio in the case study areas of Balham and Kensington.

2.2 Case Studies

The areas of Kensington and Balham in London have been chosen as part of the case study analysis (see Figure 1). Although both case study areas reside in inner rather than outer London boroughs, they present contrasting pictures in terms of fabric and density. Kensington is a high-density, predominantly residential area in the centre of London. The area displays a historic vernacular, a plethora of listed buildings and some of the most expensive property in the UK. Much of Kensington is designated as a Conservation Area, although this frequently does not hinder the construction of additional storeys on some rooftops so long as they are contextual with regards to the existing fabric. Meanwhile, Balham is a lower-density suburban area with a greater spread of retail, commercial and residential uses across the case study area. The rowhouse is the dominant form of housing in both areas. Building densities are generally lower in Balham and there are fewer adjoining structures than in Kensington. Since building height and the adjoining roofline are utilised as part of density regulations in these areas, this study opts to focus on storey count and adjoining densities to create the scenarios. The case study areas have also implemented policies and strategies around upward density. Wandsworth Council (2016), for instance, led an initiative that aimed to make the most of underutilised spaces such as rooftops for new homes. Kensington and Chelsea Council announced plans in 2019 to facilitate upward densification through airspace development as a way to address the lack of urban space and increase the supply of council homes (Aumord, 2019). These contrasting case studies provide a balanced foundation upon which to compare the distribution of Space Ratio in London.

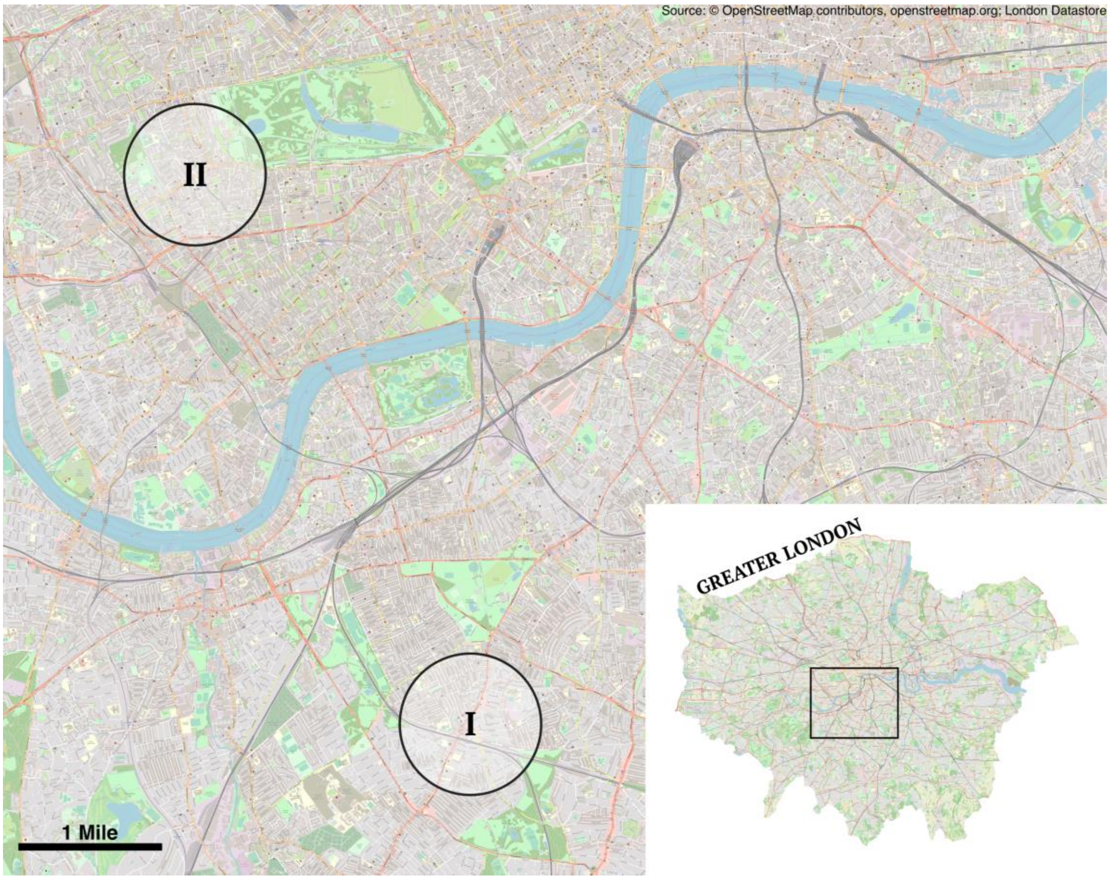

Figure 1. Map of Case Study Areas of Balham (I) and Kensington (II) in Greater London.

Using data from the 2016 London Plan via the London Datastore, circles with radii of 800 metres have been drawn around the town centres of Balham and

Kensington in order to define the spatial extent of the case study areas (see Figure 1) (Greater London Authority, 2016). Space Ratio has therefore been measured and mapped in the case study areas of Balham and Kensington at consistent spatial scales. Utilising circles with radii of 800 metres ensures that density is mapped at a human scale that reflects everyday experiences of the areas (Pafka, 2013). It additionally means that this study does not succumb to the Modifiable Areal Unit Problem, which can distort representations of density (Berghauser Pont and Haupt, 2009).

2.3 Measurement of Upward Density

Space Ratio describes the ratio of the existing density to the permissible density (see Equation 1). Permissible density is a widely-utilised measure that denotes the developable density according to a specified policy or scenario (Alexander, 1993). In order to calculate Space Ratio, the same indicator must be used for the measures of existing and permissible density. Space Ratio is measured at building-level and case study area-level as part of this study using data on existing and permissible building height in storeys and Floor Area Ratio. Since the permissible density is based on maximum storey count, the Space Ratio at building-level is identical across building height and Floor Area Ratio. The area-level calculations for Space Ratio in terms of building height and Floor Area Ratio are based on different statistical assumptions, however. At area-level, the Space Ratio for building height is based on aggregations of the total number of storeys while the Space Ratio for Floor Area Ratio is based on aggregations of total floorspace and site areas at building-level. The area-level measures utilise building-by-building data on density potentials and do not account for other land uses. This study utilises data from MasterMap to estimate the amount of developable airspace in metres squared as well as the total number of new homes that could be constructed in the case study areas according to the upward density scenarios.

$$\boldsymbol{Space\ Ratio}_x = \frac{E_x}{P_x}$$

$$\mathrm{E = Existing\ Density}$$

$$\mathrm{P = Permissible\ Density}$$

$$\mathrm{x = Scale\ of\ Analysis}$$

Equation 1. Space Ratio Formula

First, floorspace has been calculated by assigning storey counts to data from MasterMap. A standard estimate of 3 metres per storey has been utilised to determine storey counts at building-level. This study draws on data on contiguous densities, specifically the maximum height in storeys of contiguous buildings, to calculate Space Ratio. Using the programming language R, a comparative analysis of upward density in Balham and Kensington has been undertaken by calculating ancillary data from sets of contiguous buildings. The calculation of Space Ratio has been made according to several scenarios that incorporate building density, specifically the maximum height of contiguous buildings. Although building height is only a mediator of density (Dovey and Pafka, 2013), it is utilised more often than

Floor Area Ratio in London as part of density regulations. This study analyses Space Ratio in terms of storey count and Floor Area Ratio. A low Space Ratio indicates that a building has extra space for residential extensions and a high Space Ratio signals that a building makes better use of available space. If the existing density (E) exceeds the permissible density (P) then the Space Ratio defaults to one (see Equation 1). The construction of the scenarios determines if the density of pre-existing buildings exceeds the permissible density.

2.4 Visualisation and Analysis of Upward Density Scenarios

2.4.1 Space Ratio Chart

Space Ratio has been visualised using a proportional stacked bar chart, termed the 'Space Ratio Chart'. Figure 2 provides an illustrative example of the Space Ratio Chart. It demonstrates that Space Ratio can potentially incorporate a range of measures of building, people of perceived density. Using an illustrative dataset, Figure 2 depicts the ratio of the existing to the permissible density for seven indicators including: Floor Area Ratio (FAR), building height (H), Ground Space Index (GSI), Open Space Ratio (OSR), dwellings per hectare (DPH), people per hectare (PPH) and urban flow (FLO). The indicators are depicted along the x-axis and the Space Ratio from zero to one is shown along the y-axis. Space Ratio is depicted in black. The chart can be customised to reflect other density scenarios and measures along the x-axis. By aggregating data on existing and permissible density, the chart can be utilised to compare the Space Ratios of districts or cities. A lack of granular data on several indicators – including GSI, OSR, DPH, PPH and FLO – means that the Space Ratio Charts only depict FAR and H as part of the case study analysis.

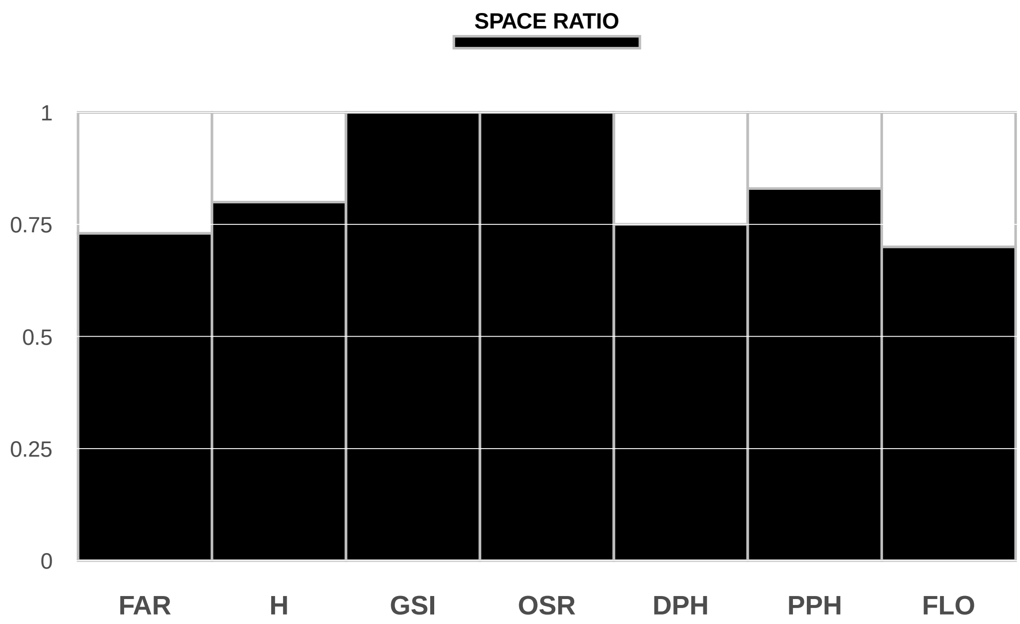

Figure 2. Space Ratio Chart

2.4.2 Dasymetric Technique

Space Ratio has been mapped in the case study areas using the dasymetric technique. The dasymetric technique involves thematically mapping ancillary data at a fine spatial scale rather than at the administrative scale (Petrov, 2012). Since density differs significantly based on the spatial scale of study and administrative areas can display vastly different areas (Pafka, 2013), borough-level or ward-level maps of upward density are somewhat limited. Administrative-level choropleth maps can display the Modifiable Areal Unit Problem and misrepresent spatial visualisations and analyses of densification

(Berghauser Pont and Haupt, 2009). The dasymetric technique has traditionally been used to visualise population density (Petrov, 2012) rather than building density. Perdue (2013) argues that the integration of the dasymetric technique with building footprints is an effective means by which to map the three-dimensionality of density. The dasymetric technique is well-suited to mapping building density at plot-level. A limitation of the technique is that dasymetric maps displayed at city-level can lack readability. This study utilises the dasymetric technique to visualise building density at fine spatial scales in the case study areas.

2.4.3 Comparative Analysis of Density

In order to facilitate the comparative analysis of upward density, Space Ratio has been measured and visualised in Balham and Kensington. As Berghauser Pont and Haupt (2009) and Dovey and Pafka (2013) argue, comparative density studies should incorporate multi-variable methodologies. Space Ratio enables the comparison of multiple density measures and scenarios. Space Ratio is dasymetrically mapped in Balham and Kensington using several upward density scenarios. The maps of Balham and Kensington have been stacked in order to aide the comparative case study analysis of Space Ratio. This study compares the spatial distribution of Space Ratio and the upward density scenarios across the entire case study areas.

2.4.4 Upward Density Scenarios

The analysis of upward density in London has been undertaken using two density scenarios: Scenario 1 and Scenario 2. The two scenarios differ in terms of permissible density, which aides the comparative analysis of the distribution of Space Ratio. By comparing two different scenarios, this study aims to demonstrate how Space Ratio can be utilised to facilitate scenario modelling at building-level and area-level. Scenario 1 incorporates data on contiguous densities, specifically building heights in storeys and Floor Area Ratios. In this upward density scenario, the storey counts of contiguous properties are raised to the level of the highest building. Scenario 1 is a high-density scenario. The second scenario, Scenario 2, is similar to Scenario 1 in that it incorporates data on the maximum height of contiguous buildings and rows in the case study areas. However, this scenario is more contextual with regards to the contiguous fabric as it places an upper limit of two storeys on upward development and does not surpass the level of the highest contiguous building. Scenario 2 is an adaptation of the revised Permitted Development Rights in England and Wales regarding the number of storeys that could be constructed on the rooftops of existing buildings. Both scenarios are applicable to London's prevailing rowhouse typology (Allies and Morrison, 2016). The use of a row-by-row analysis ensures that Scenarios 1 and 2 are more contextual with regards to prevailing densities in the case study areas. Space Ratio can also be applied to measure the upward density of a range of morphologies and typologies.

The stacked maps provide a means by which to compare multiple density scenarios across consistent spatial scales in the case study areas. Scenario 2, for example, provides a partial illustration of how the new Permitted Development Rights could potentially impact the fabric of Balham and Kensington over many years. Utilising the two density scenarios, Space Ratio has been calculated and mapped in order to study the extent to which the buildings in the case study areas make use of airspace. The roles of centrality and morphology in the spatial distribution of the density tools has been analysed. This study goes on to argue that Space Ratio could be used to map other density scenarios pertaining to a range of density measures. The measures and visualisations could ultimately aide the planning and design of upward densification in London (Amer et al., 2017).

3. FINDINGS AND ANALYSIS

Space Ratio has been calculated at building-level and area-level in Balham and Kensington. Tables 1 and 2 aggregate the building-level data on Space Ratio, producing area-level estimates for the entire case study areas. As Tables 1 and 2 show, with the exception of Scenario 2 and Floor Area Ratio, the Space Ratio for the entire case study area of Kensington is lower than that of Balham. Moreover, the Space Ratio for building height (H) is lower than that of Floor Area Ratio (FAR) (see Figures 3 and 4). This indicates that there is comparatively more airspace in Kensington for upward densification. Although densities are higher in Kensington, the density profile of the area is more varied, which creates pockets of airspace that raise the permissible density and lowers the Space Ratio, which means that more extensions could be constructed without significantly disrupting the prevailing urban fabric. These statistics provide a broad illustration of the extent to which the areas make use of airspace. According to Scenario 1, Balham contains 285,632 metres squared of airspace for upward extensions while Kensington contains 606,399 metres squared. These estimates decrease to 253,587 metres squared in Balham and 381,969 metres squared in Kensington for Scenario 2. If we draw on HTA Design LLP's (2016) methodology, which is based on real-world case studies and assumes an average of 60 metres squared per rooftop home, of which 75% is usable floorspace, then Kensington could build a maximum of 7,580 (Scenario 1) or 4,775 (Scenario 2) new homes. In contrast, Balham could build up to 3,570 (Scenario 1) or 3,170 (Scenario 2) new homes on existing rooftops.

	Balham	**Kensington**
Space Ratio – FAR	0.86	0.80
Space Ratio – H	0.85	0.71
Total Airspace (Metres Squared)	285,632	606,399
Total New Homes	3,570	7,580

Table 1. Summary Statistics for Scenario 1. In this scenario, the number of storeys is increased to the level of the highest contiguous building.

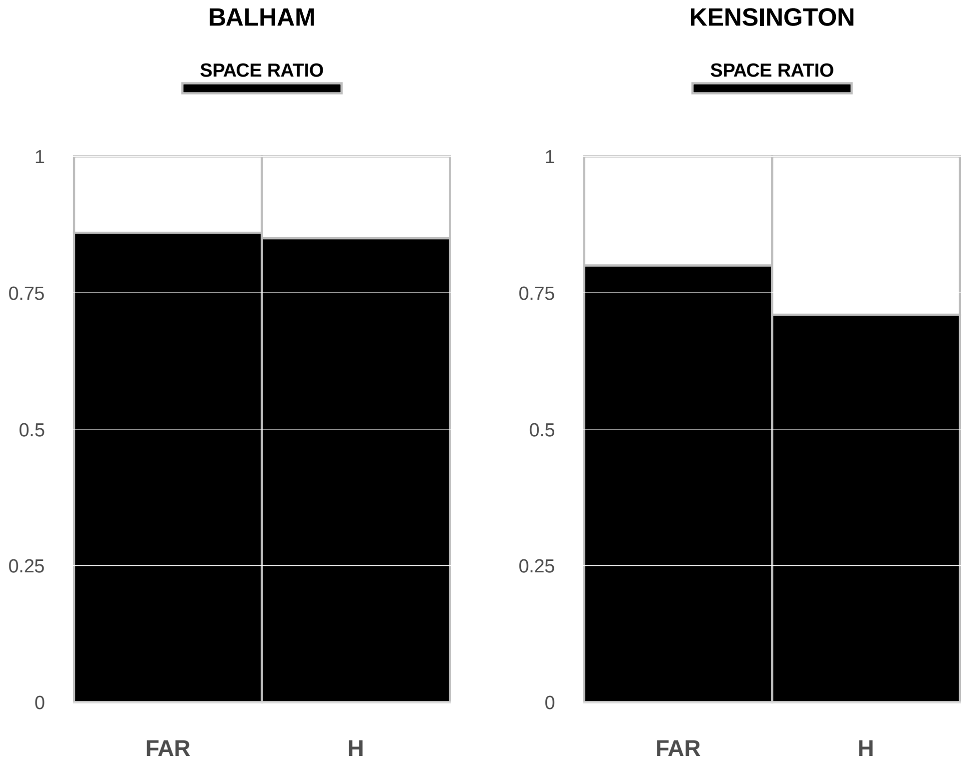

Figure 3. Space Ratio Charts for Scenario 1

	Balham	Kensington
Space Ratio – FAR	0.87	0.87
Space Ratio – H	0.86	0.80
Total Airspace (Metres Squared)	253,587	381,969
Total New Homes	3,170	4,775

Table 2. Summary Statistics for Scenario 2. Here, the number of storeys is increased to the level of the highest contiguous building but no more than two additional storeys can be constructed.

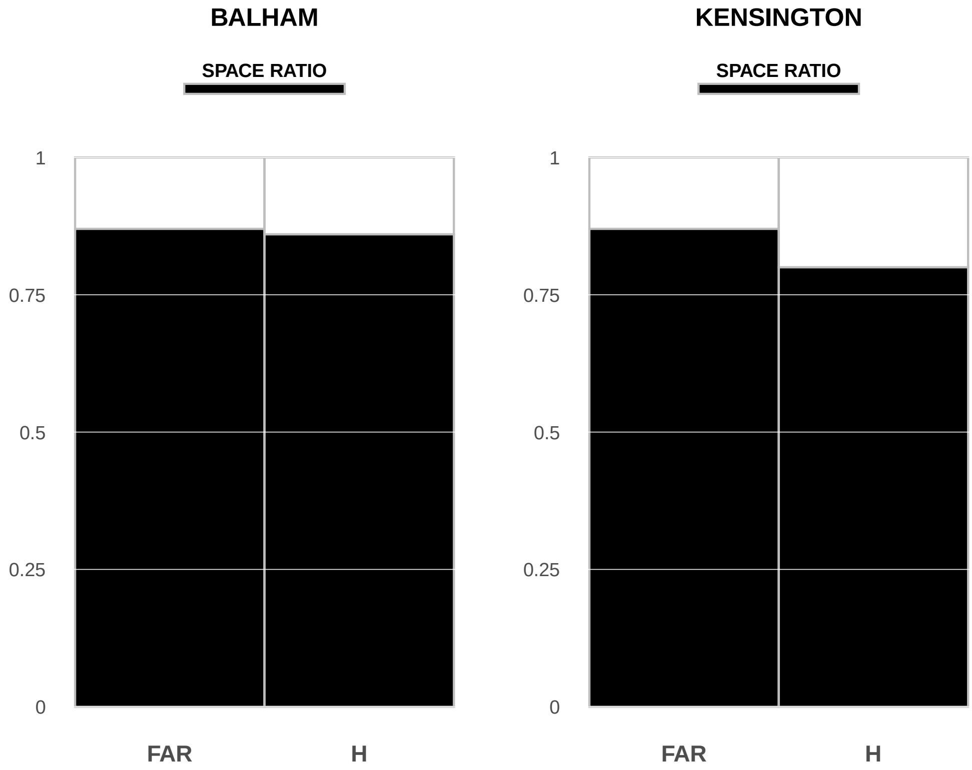

Figure 4. Space Ratio Charts for Scenario 2

The role of centrality is illustrated in the spatial distribution of Space Ratio at building-level. Upward density in Balham is indicative of a monocentric suburban area, where densities are higher in the centre and lower in the periphery. Here, permissible densities regarding upward extensions are broadly lower than in the urban area of Kensington for both scenarios. The difference between the measure of Space Ratio for Scenario 1 and Scenario 2 in peripheral areas of Balham is far lower than in Kensington (see Figures 5 and 6). The distribution of Space Ratio in central Balham shows that there are some pockets of airspace as outlined by the scenarios. Space Ratios are also lower along Balham High Road, which extends from the north to the south of the case study and through the centre. The spatial distribution of Space Ratio is far more varied in the more polycentric area of Kensington. Unlike Balham, peripheral areas of Kensington – including the north and south – demonstrate low Space Ratios (see Figures 5 and 6). Furthermore, the centre and south of Kensington show the greatest increase in Space Ratio between Scenario 1 and Scenario 2.

The findings show that the different typologies and morphologies in Balham and Kensington display different Space Ratios. Some morphologies with a higher number of storeys such as towers exhibit higher Space Ratios according to Scenario 1 and 2 due to the absence of contiguous buildings, which establish the permissible densities for our scenarios. There is moderately low statistical correlation between Space Ratio and storey count in Kensington (R-squared = 0.24 for Scenario 1 and R-squared = 0.27 for Scenario 2) and low correlation Balham (R-squared = 0.13 for Scenario 1 and Scenario 2). This partially indicates that as the number of storeys increases, particularly in Kensington, so does the Space Ratio. Kensington contains many mews houses with few storeys, high permissible densities and low Space Ratios. However, the presence of higher-storey contiguous buildings results in higher permissible densities and lower Space Ratios for mews houses and many may not be able to build additional storeys due to planning and design constraints. Towers tend to have much higher Space Ratios, again due to the specifications of our density scenarios. Towers in Balham in particular display high levels of Space Ratio, which could partly be attributed to the absence of contiguous structures. The measures of Space Ratio for rowhouses, prevalent in both Balham and Kensington, differ across the case studies. The story counts of rowhouses in Kensington tend to be higher and the rooftop profiles more variable. Meanwhile, Space Ratios are higher in the western and north-eastern sections of the Kensington case study area, for instance, due to the presence of houses with low dwelling densities and no contiguous buildings. The fluctuations in density with regards to rowhouses in Balham and Kensington results in more variable Space Ratios. This is broadly reflected in lower levels of Space Ratio and more pockets of airspace for new homes for high-density rowhouses in the centre of the case study areas (see Figures 5 and 6).

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Figure 5. Maps of Space Ratio for Scenario 1.

Figure 6. Maps of Space Ratio for Scenario 2.

4. DISCUSSION AND CONCLUSION

The results demonstrate that new density tools, Space Ratio and the Space Ratio Chart, can be utilised to measure, visualise and model upward density potentials. This study compares a range of upward density scenarios in Balham and Kensington. In Space Ratio and the Space Ratio Chart, density tools are illustrated that can provide an account of how much space there is for residential development. As this study illustrates, Space Ratio is a tool that can be adapted to measure and map the extent to which buildings and wider areas make use of airspace according to different scenarios. Scenario modelling Space Ratio at building-level and area-level provides a means by which to compare density potentials and aide the design and planning of sustainable densification.

The effective utilisation of Space Ratio is dependent on high-quality data on density. The calculation of Space Ratio potentially relies on data on a range of density indicators. Much of this density data is missing, not machine-readable or proprietary. This includes data on permissible density, which is notably lacking in cities like London. For instance, some local authorities in London do not publish data on permissible density or establish limits on Floor Area Ratio or building height. The lack of data on qualitative measures of urbanity is also limiting and poses a challenge for studies of Space Ratio with regards to perceived density. This study focuses on measures of building density, in particular Floor Area Ratio and building density, for which there is plentiful data. The lack of high-quality, granular data on easements and the implications of upward densification in London hinders the measurement and mapping of Space Ratio and the testing of the scenarios. The utilisation of high-quality data on easements such as rights to light, for example, would most likely yield higher Space Ratios and much lower estimates regarding developable airspace for new homes.

Space Ratio is a tool that can be customised and users should exercise caution. As Bertaud and Brueckner (2005) state, setting restrictions on storey count can have significant implications for the wider urban fabric. Context should play an important role in establishing permissible densities, which may necessitate a more granular, building-by-building perspective. The scenarios utilised as part of this study are, by design, variably contextual with regards to contiguous densities. Scenario 2 is also reflective of some of the policies and strategies currently in place in London. Users of the tool should acknowledge the role of scale in the calculation of Space Ratio and the setting of permissible densities. For instance, Floor Area Ratio is dependent on a range of density indicators and will vary significantly across different scales. The Space Ratio Chart can be utilised to compare density potentials across different scales. In setting permissible densities across multiple measures and scales, users should strive for transparency. The permissible densities and any underlying assumptions regarding the calculation of Space Ratio should be clearly stated. As Alexander (1993, p.185) argues, previous attempts to incorporate multiple measures of permitted density as part of quantitative tools have been too opaque and convoluted to effectively use in practice.

Space Ratio and the Space Ratio Chart have therefore been designed with simplicity, adaptability and diversity in mind.

Upward densification could have a significant effect on the urban environment. The extent to which upward densification through airspace development adheres to the design and planning context can vary. Zamperini and Lucenti (2014) argue that rooftop architecture is highly dichotomous and the degree to which design should be ‘symbiotic’ or ‘parasitic’ depends on the context. Parasitic rooftop design deviates from the design of the ‘host’, or pre-existing structure, while symbiotic airspace development is more contextual. Airspace development, parasitic or otherwise, may not be architecturally or structurally appropriate atop listed buildings of historic or architectural significance (Ireson, 2000; Zamperini and Lucenti, 2014; Bellini and Mocchi, 2019). Kensington contains a multitude of buildings of architectural significance: here, a poorly-designed rooftop extension could detract from its surroundings. In order to address this problem, listed buildings in the case study areas were removed pre-analysis. The planning and design of density should always consider the prevailing urban fabric and account for the local context (Dempsey and Jenks, 2010; Amer et al., 2017). The application of Permitted Development Rights at national-level should not replace the crucial role of the planning system in regulating density design. It is important to note that building contextual rooftop homes involves a number of factors (Hu et al., 2017). Although Space Ratio is an effective tool for comparing scenarios and aiding the design and planning of upward densification, it should be utilised in conjunction with other tools and frameworks. Space Ratio could alternatively be utilised to compare the application of new Permitted Development Rights with other scenarios.

The impact on service provision and local infrastructure should be an important consideration in the planning of upward densification (Burdett et al., 2004) and the utilisation of Space Ratio. Scaling densification in order to address the lack of urban space and the undersupply of new homes will significantly increase population densities and dwelling densities in some areas (Burdett et al., 2004; Amer et al., 2017). Increasing densities in suburban areas such as Balham could negatively affect the provision of services and local infrastructures. It is not advisable to build upwards in areas that are overcrowded or ill-equipped to deal with the increase in service use. In such cases, it may be necessary to incorporate new services alongside residential uses in the planning of upward densification through airspace development. Furthermore, it is important that planners and designers account not only for building densities but also the socio-economic context. By concentrating upward densification in urban hubs and around transport nodes rather than peripheries, the construction of additional storeys can be achieved sustainably and with consideration for existing local communities, services and economies (Amer et al., 2017). This study has elected to study the spatial distribution of Space Ratio at consistent scales around hubs rather than peripheries, thereby exploring best practice around the design and planning of upward densification. Beyond the exclusion of listed buildings, it does not incorporate the role of local infrastructure or the socio-economic landscape. Space Ratio is a multi-variable and multi-scalar tool that can be used to illustrate the degree to which urban hubs contain airspace for new rooftop homes and services. Space Ratio can be used to facilitate scenario planning and optimise the distribution of upward densification through airspace development.

Future studies could incorporate other scenarios pertaining to a range of density strategies. For instance, the comparative analysis of upward densification could involve differing scenarios for urban and suburban areas. Space Ratio is a flexible tool, meaning it can be tailored to different contexts and measures. This study has mapped Space Ratio across the entire case study areas of Balham and Kensington in London but other towns or cities could be utilised. Alternatively, real-world data on building, people and perceived density could be utilised in conjunction with Space Ratio and the Space Ratio Chart to visualise density potentials on a building-by-building or city-by-city basis. This study has focused on the role Space Ratio can play in increasing upward densification rather than outward densification. Space Ratio is well-suited to the three-dimensional measurement and mapping of the infill development potential, which encompasses lateral densification as well as upward densification. Using the dasymetric technique, the difference between existing and permissible densities could be mapped for different morphologies and typologies. This study has provided an exploratory illustration of upward densification using multiple scenarios. It has not provided an in-depth spatial modelling of upward density. Further studies could build models to examine the influence of socio-economic and environmental factors on the spatial distribution of Space Ratio. By modelling the socio-economic and environmental factors underpinning the spatial distribution of Space Ratio, planners and designers would be better-equipped to facilitate sustainable and contextual upward densification in London.

New tools for measuring and mapping density potentials, Space Ratio and the Space Ratio Chart, have been demonstrated as part of this study. Space Ratio is a measure of the degree to which buildings or wider areas make the most of space. An illustration of which buildings in Balham and Kensington could build upward extensions has been provided. In addition, area-level measures of Space Ratio have been calculated. Multiple upward density scenarios have been tested and the spatial dimensions of Space Ratio have been analysed. This study demonstrates that new quantitative tools can be applied to test density scenarios in London. The Space Ratio Chart, for instance, can be utilised to visualise density potentials. The results show that, by applying Space Ratio to buildings, upward density can increase in both case study areas. As urban populations increase and the amount of space for new homes decreases, it is imperative that practitioners are equipped with new tools such as Space Ratio and the Space Ratio Chart to facilitate sustainable and contextual densification.

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