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REGULAR PAPER

Stratifying and predicting patterns of neighbourhood change and gentrification: An urban analytics approach

Joshua Yee | **Adam Dennett**

University College London, London, UK

Correspondence
Joshua Yee, University College London, London, UK.
Emails: joshua.yee.18@ucl.ac.uk; jytg17@gmail.com

Abstract

While recent debates have widely acknowledged gentrification's varied manifestations, success in enumerating and disentangling the process and its defining features from other forms of neighbourhood change at-scale and across entire cities, has remained largely elusive. This paper addresses this gap and employs a novel, open and reproducible urban analytics approach to systematically examine the past and future trajectories of neighbourhood change using London, England, as a case-study example. Using suites of datasets relating to population, house prices, and built environment development, the nature of gentrification's mutations and its spatial patterns are extracted through a multi-stage data dimensionality reduction and classification methodology. Machine learning is subsequently adopted to model gentrification's observed trends and predict its future frontiers with interactive visualisation methods offering new insights into gentrification's projected dynamics and geographies.

KEYWORDS

gentrification, geospatial analysis, London, machine learning, neighbourhood change, predictive analytics

1 | INTRODUCTION

Gentrification, a term traced historically to sociologist Ruth Glass (1964), was initially coined to describe a complex, but distinctive, pattern of socio-spatial transformations observed around parts of inner London during the 1960s. In its purest form, gentrification referred to the process by which working-class neighbourhoods were increasingly being repopulated by the middle classes, precipitating upward shifts in property prices and the displacement of residents with lower socio-economic status from such areas (Hamnett, 2003; Lees et al., 2008). Smith attributed the basis of this phenomenon to the "rent gap" (1979, p. 545), wherein substantial differences between the cost of purchasing properties in disinvested neighbourhoods and the potential return on investment that gentrifiers could yield (through sale or rent) were the main mechanisms in attracting bouts of capital inflows and eventually middle-class residents. Now widely accepted as a phenomenon affecting cities across the globe (Lees et al., 2016) and in ways not necessarily aligned with its origins in Western

post-industrial cities, gentrification evokes strong debates in academia and policy circles as it is a process of neighbourhood change that is as disruptive and exclusionary as it is regenerative.

Gentrification is the archetypal "wicked problem" (Rittel & Webber, 1973) without simple definition or resolution. It is frequently the physical embodiment of wider issues associated with race, class, and exclusion in evolving urban landscapes (Perera, 2019; Snoussi & Mompelat, 2019), generally favouring those towards the top of the socio-economic hierarchy at the expense of those nearer the bottom (Slater, 2011). The first step in addressing any problem is careful delineation, which in an urban policy context usually boils down to "who" or "where." Fortunately, the resources at our disposal to do so have never been better.

The proliferation of new and varied urban datasets alongside computational methods to process, analyse, and interpret these data has led to what some are referring to as a new "urban analytics" (Batty, 2019; Singleton et al., 2018) paradigm emerging in human geography and planning. Setting urban analytics apart from the original quantitative turn in geography is the focus on disparate and "big" data sources coupled with open and reproducible methods and the importance of communicating meaningful patterns in an accessible manner, often through visualisation and particularly in the applied contexts that wicked problems tend to demand.

Gentrification is part of a complex mosaic of neighbourhood change that occurs in cities. Buzar et al. (2007) describe gentrification as the process of social uplift coupled with displacement and the renewal of the physical urban fabric. But within the literature other similar forms of neighbourhood evolution such as "incumbent upgrading" (Van Criekingen & Decroly, 2003, p. 2452) and "re-urbanisation" (Buzar et al., 2007, p. 64) have been identified. Some argue these processes of change have fuzzy boundaries (Hochstenbach & van Gent, 2015) and overlap to the point where drawing distinctions is unhelpful (Van Criekingen, 2010). However, in policy terms, being able to classify and differentiate is important where decision-making so often boils down to a binary choice – for example, granting permission for a new social housing estate redevelopment or 'iceberg' basement in a west London townhouse, or not. As Atkinson points out, a "vital part of any attempt to produce effective public interventions into [gentrification] lies in a need to profile empirically and actively enumerate" with policy-makers "unlikely to be moved by social problems that lack a sense of quantity and impact" (2008, p. 2634). Beyond local urban policy, gentrification's impact on other aspects of human existence such as population health has been highlighted, but as research by Firth et al. (2020) has shown inconsistency between gentrification measures [and] misclassification of gentrifying areas has been a real hindrance to developing effective interventions.

This point is crucial and situates our work here. Wyly's comment that "we must move beyond the obsessive geographical empiricism of looking for gentrification in the fine-grained details of the urban landscape" (2019, p. 20), while perhaps valid for those looking to develop broader theories, is of little practical use for those in charge of running our cities and who frequently lack an appreciation of the scale, extent, trajectory, and wider ramifications of the issue – indeed an issue also picked up on by Easton et al. (2020). In the UK, the forces driving gentrification have changed. The government improvement grants described by Lees and Ley (2008) that drove earlier waves of gentrification in cities like London have given way to globalised private finance, with developers keen to build properties that attract this money. In cities like London, financially constrained local councils are tasked with supporting businesses and providing additional and better dwellings for their constituents but increasingly rely on private developers to service this need. Pressures from austerity-riven budgets combined with a dearth of accessible city-level evidence on the extent of negative neighbourhood change means that planning authorities are on the back foot when published quotas and targets for social or affordable housing (Annunziata & Rivas-Alonso, 2018) are driven down by developers looking to maximise profits (Wainwright, 2020), accelerating gentrification and residential displacement (direct and indirect) where they do (for an excellent account of these issues, see Perera, 2019). The playing field is not level and the work of the planning authorities is made even harder by a lack of good evidence documenting the extent of the issue.

Some may question whether the political will to resist gentrification is there – indeed in some cities municipal authorities have positively encouraged the process (Alexandri, 2018) – but in London there are signs that there is a will, if not yet a means, to retain diverse residential ecosystems. The central borough of Westminster's "City for All" vision statement promotes that it will be a borough "which builds the homes it needs to remain a welcoming, vibrant place for people from every background, at every income level and at every age."[1] While we cannot claim definitively that a stronger evidence base would have made the difference to some high-profile examples of gentrification in other parts of the city such as the Heygate Estate redevelopment (Lees & Ferreri, 2016), a lack of evidence or a means to gather, process, analyse, and communicate the quantitative evidence that does exist (Almeida's (2021) report and analysis of London a notable exception here) is a huge hindrance.

In this paper we address this challenge through detailing an analytic process applied to data from a range of different sources and showcasing the outputs through interactive visualisations that allow for a novel and spatially explicit engagement with the various current dimensions and plausible futures of neighbourhood change across a whole city. This urban

analytic approach is scalable and the methods transferrable. And while we have used London as our example, the facets of neighbourhood change we are able to extract and illuminate correspond to and support some of the broader theories of differentiated neighbourhood reviewed earlier.

Each of the analysis, prediction, and visualisation workflows we use can be adapted and translated to different urban contexts, although differences in data availability mean that it is the general approach, methods, and outputs that will be transferrable, rather than specific workflows associated with individual datasets. Our main aim for this paper, therefore, is to highlight the benefits that our approach can bring to those looking to quantify, stratify, locate, and predict the different processes of neighbourhood change occurring at scale across cities. We expect our audience to be diverse, with these outputs relevant to academics, activists, practitioners, and policy-makers alike, but all of whom will have some interest in tempering the negative impacts of gentrification.

To achieve this aim our objectives are threefold. First, to devise a method to identify, characterise, and locate neighbourhoods which have undergone recent gentrification and other types of wider neighbourhood change in London, differentiating and enumerating these areas clearly and highlighting that while the theoretical boundaries between the concepts might be porous, logical partitioning is feasible. Second, to demonstrate that it is possible to move beyond observation to prediction in exploring which neighbourhoods are likely be next in line for gentrifying changes – we will illustrate this with two examples. Third, to present a reproducible workflow promoting open-science practices, making available data, code, and interactive visualisations as a comprehensive tool for supporting discussions, policy, and decision-making in the city. The accompanying interactive online visualisation tool and methodological code-base are shared through GitHub[2,3] and we would encourage readers to visit these.

2 | REVIEW

2.1 | Gentrification: Evolution, impacts, and the necessity of enumeration

While the term "gentrification" was first coined more than five decades ago, it retains relevance in identifying a distinct trajectory of neighbourhood transformation encompassing physical redevelopment, social reorganisation, displacement, and land-value uplift (Savage & Warde, 1993). Its roots are in observations within Western post-industrial cities, but evolving scholarship in the area (Lees et al., 2016; Shin, 2019) has globalised its geographical scope (Atkinson & Bridge, 2005, p. 1). Although theorists have situated the drivers of these processes of urban change in broader neoliberal and social Darwinism terms (Wyly, 2019), empirical work has been valuable in highlighting specific cases for comparison (see in particular the special issue of *Urban Studies* edited by Lees & Ley, 2008).

In parallel with its broadening reach, scholars have highlighted gentrification's increasingly diverse variants (Butler & Lees, 2006; Van Criekingen & Decroly, 2003). For example, "Super-gentrification" describes the further gentrifying of previously well-off neighbourhoods by the globally connected financial elites (Lees et al., 2008, p. 130). Under such circumstances, the displaced are middle-class residents rather than the working classes first identified by Glass (1964). Even where disinvested working-class neighbourhoods have been gentrified, research has shown that incoming gentrifiers do not necessarily conform to the wealthy, middle-class stereotype (Rose, 1984). Instead, some who may lack significant financial resources but nevertheless possess educational and cultural capital are attracted to the low rents, locational, cultural, and aesthetic appeals of working-class neighbourhoods and have sought to move into these places (Mendes, 2013) in a process that has been labelled " marginal gentrification" (Owens, 2012, p. 347).

The impacts of gentrification and neighbourhood change are multifaceted. Atkinson and Bridge (2005) contrast the positive – new investment and building, rising prosperity, and changing social mix – with the negative – such as rising rents, community displacement, homelessness, psychological damage, and rising living costs. Among these, displacement (both "direct displacement" through eviction or demolition and "exclusionary displacement" through rents or house prices making housing inaccessible (Marcuse, 1985)) arguably ranks most consequential of all, given the profound impact it has on individuals and communities who are forced to leave (Slater, 2011). Although there is debate about whether displacement is an integral part of the gentrification process or a consequence of it (Ghaffari et al., 2018), its negative impacts are particularly malign.

To combat these impacts, several studies have acknowledged the need for tools that effectively detect gentrification (Chapple & Zuk, 2016). Early warning systems such as those pioneered under the Urban Displacement Project (UDP)[4] are positive exemplars, whereby various US and other global cities are analysed for their vulnerability to gentrification and displacement (Zuk & Chapple, 2015). The outcomes of such empirical work include a series of policy briefs (Cash

et al., 2019), case studies, and workshops which have been important in shaping the policy agenda in cities like San Francisco.

As gentrification is a contextually specific phenomenon (Freeman et al., 2016), and data sources are not universal, insights drawn from these UDP studies are not transferable. In the UK's case, the nature of gentrification has proven quite dissimilar to that of the USA (Lees, 1994), while certain datasets adopted in UDP's methodology, such as those explicitly concerning low-income households, do not possess equivalents in the UK (White & McLaren, 2009). However, in an ever more digital world, new and increasingly diverse datasets about all aspects of urban fabric and population are becoming available. Even where direct data equivalents do not exist, analytic methods are able to be somewhat agnostic towards the data they process. The combination of these factors enables new pathways to enumerate the important dimensions of change, which with gentrification will eventually resolve to neighbourhood ascent.

2.2 | Typologies of neighbourhood ascent

Gentrification is only one form of neighbourhood ascent or change. Owens differentiates "incumbent upgrading" and "neighbourhood upgrading" from gentrification underneath the broader banner of neighbourhood change (2012, pp. 347–348). Although neighbourhood enhancements are inherent in all typologies of neighbourhood ascent, subtle differences distinguish these typologies. "Incumbent upgrading" refers to *in situ* improvements made by existing residents, potentially in terms of their socio-economic status or housing conditions, over time (2012, p. 347). Therefore, contrary to gentrification, "incumbent upgrading" does not entail displacement (Van Criekingen & Decroly, 2003, p. 2456) and we would argue that in policy and planning terms it would satisfy the desire of local governments to see an improvement for their residents, without the negative impacts that displacement would entail. In London – a city where average house prices virtually doubled between 2001 and 2011, a rise far in excess of that in other regions – it's likely that while the wealth of owner-occupier residents would be increasing, there may be few outward physical signs of change or improvement except for where, perhaps, equity release through re-mortgaging facilitates improvement to the dwelling stock through extensions and other home improvements.

Separately, "re-urbanisation" is another form of urban change that became prevalent in the UK following the 1990s when the "urban renaissance" movement was vigorously promoted (Boddy, 2007, p. 90). Characterised by the injection of new-built residences to regenerate city centres and brownfield sites, re-urbanised areas typically attract specific demographic groups such as "younger single people or childless couples" (2007, p. 95), but do not entail direct displacement since existing residences were unaffected. In policy terms, exclusionary displacement is nonetheless possible if the introduction of new developments and populations precipitate a local uplift making previously financially accessible houses in the vicinity unaffordable for low-income groups (2007, p. 99). However, again we would view this type of neighbourhood change as less disruptive than gentrification.

Owens argues for the merits of being able to discern these differences as it "sharpens the concept of gentrification and provides a fuller and more accurate depiction of neighbourhood ascent" (2012, p. 364). In practical terms, such insight allows neighbourhood issues to be properly framed – for example, a borough working towards a policy of reducing social cleansing (Snoussi & Mompelat, 2019) will need to carefully differentiate gentrification from other forms of neighbourhood ascent. It is therefore perhaps surprising that the typologies of neighbourhood ascent have not been duly considered or interrogated in the majority of gentrification studies. A case in point is Reades et al.'s (2019) recent study of gentrification trends in London. Notwithstanding the novel and insightful use of machine learning to model urban trends, because only census data are used, the study is forced to treat all "uplift" as a potential marker of gentrification (2019, p. 3). However, if these changes were due to "incumbent upgrading" or "re-urbanisation" instead, the reported incidence of gentrification may well have been overstated in their study.

2.3 | Empirical and methodological challenges

Delineating the boundaries of particular types of neighbourhood change is challenging and making reliable predictions even more so. Barton (2016) criticises that quantitative approaches have tended to depend overwhelmingly on census data that are heavily orientated towards socio-economic aspects of change and thus present only a partial picture of gentrification (2016, p. 93). Furthermore, since census data are typically produced only once per decade and the bulk of data outputs are cross-sectional rather than longitudinal, studies relying on these data struggle to

differentiate neighbourhoods undergoing "naturally occurring improvements (incumbent upgrading)" from those that were gentrifying (2016, p. 96).

In the introduction to this paper, we outlined the urban analytics paradigm that offers a new empirical toolkit that can be used to overcome some of these longstanding, methodological weaknesses (Brunsdon & Singleton, 2015, p. 322). The recent advent of "Big Data," specifically, administrative, retail, and even crowd-sourced social data (Hristova et al., 2018; Longley et al., 2018) now offer new opportunities for understanding human patterns and processes at more detailed spatial and temporal resolutions. In parallel, advances in analytical techniques that are able to process and detect signals in these ever more vast and messy sources of information have been rapid in recent years. Machine learning is a subdomain of artificial intelligence that has gained traction. Unlike classic statistical approaches, machine learning algorithms can handle extensive quantities of high-dimensional or collinear data effectively and are capable of modelling non-linear relationships between components of the dataset which standard linear regression analyses cannot achieve (Witten et al., 2011). Machine learning approaches are more useful for predicting rather than interpreting patterns, but where the desired outcome is forecasting, they are a useful tool to employ.

However, machine learning's adoption in gentrification studies is still in its infancy. Reades et al.'s (2019) study is a pioneering example that has exploited machine learning for the purpose of understanding gentrification. In their paper, a "random forest" (RF) algorithm was first applied to model patterns of neighbourhood "uplift" across London using past census data, and subsequently used to predict potential neighbourhood states by 2021. Other gentrification studies which have successfully incorporated machine learning into their workflows have focused on description and characterisation rather than prediction – these include Ilic et al.'s (2019) use of "machine mapping" on Google Street View images to identify visible improvements to housing facades as signs of gentrification, Chermesh et al.'s (2018) utilisation of cluster analysis to tease out gentrifying neighbourhoods across New York, and Johnson et al.'s, (2022) use of autoregressive models to identify gentrification in the same city. It is clear that as methods develop and data on all aspects of urban existence proliferate, opportunities exist to utilise machine learning alongside new forms of data and visualisation methodologies to further our understanding of the patterns and trajectories of gentrification and other forms of neighbourhood change in cities.

3 | DATA COLLECTION

The datasets utilised in this study were derived from three main sources: the Office for National Statistics (ONS), the Greater London Authority (GLA), and the Consumer Data Research Centre (CDRC). We acknowledge that these are data specific to the UK and London. However, there are cities in the world with just as comprehensive demographic data and even more extensive house price and built environment data, as we illustrate in the subsequent section. We are hence confident of the wider applicability of our approach.

Data "wrangling" and downstream analysis were carried out using Python and ArcMap – full details are available in the Supporting Information and on GitHub.[5]

3.1 | ONS Census and housing transactions data

ONS data outputs from the 2001 and 2011 censuses were used as the cornerstone for analysing the changing states of London's neighbourhoods. These data covered a range of themes from the socio-economic make-up of neighbourhoods to local housing characteristics. A major issue in working with data from the 2001 and 2011 censuses is that the underlying neighbourhood-level output geographies (Lower-Layer Super Output Areas – LSOAs), while consistent for most zones, are not for a small proportion. The dissimilarities stem from changing underlying populations between the censuses and the need to split and merge some 2001 LSOAs to meet the statistical population thresholds in 2011. To overcome this issue, a pre-processing step was undertaken to regularise all data produced for the 2001 LSOAs to match the updated 2011 boundaries using the UK Data Service's GeoConvert tool (2015).

Additionally, with the economic value of residential properties and housing turnovers being an integral factor and product of gentrification's cycles respectively, ONS datasets comprising median house prices and counts of residential sales transactions that transpired yearly at the LSOA level (between 2001 and 2016) were also re-estimated for 2011 boundaries. Apart from the UK, open-source data pointing to residential transaction values at the granular scale are not uncommon. Singapore, among others, captures and makes publicly available extensive records of private

property transactions that have taken place, including attributes like transactional values and characteristics of the transacted property.[6]

3.2 | The GLA's planning permissions data

The GLA's London Development Database (LDD)[7] is a data repository containing digital records of planning permissions granted to development projects. Although LDD data have not featured in academic research – and certainly gentrification research – to our knowledge, they are an excellent resource for urban research given their richness in documenting development projects, including residential (re)development works, around the city. The data do not contain information pertaining to small residential alterations (loft conversions, minor extensions) that would fall under "permitted development rights," only more substantial developments requiring planning permission. Since the redevelopment/conversion of existing houses and introduction of new-built residential properties in concentrated numbers were tendencies of different neighbourhood change typologies, the LDD dataset is ideal for distinguishing differing trajectories within the city. London is not unique in publishing building development data; project-level data on housing construction and demolition work, coupled with changes in the number of residential units over space and time, across the city have been availed as open data by the New York City Department of City Planning for some time.[8]

Data within the LDD had to be pre-processed in two ways. First, records which either did not pertain to residential properties or were missing key data attributes were removed. Second, as each entry in the LDD is a residential point, multiple points had to be summed by type of development within the 2011 LSOA boundaries for alignment with the other datasets.

3.3 | The CDRC's population churn data

The CDRC's population churn dataset[9] links data from electoral registers and consumer databases, validated by land registry property sales, to produce annual estimates between 1998 and 2016 of population churn at the LSOA scale. No other similar datasets exist for intercensal monitoring of population movements at this fine scale and importantly will pick up the kinds of short-term "decanting" (temporary – which may switch eventually to permanent) moves that would not be picked up readily by Census or NHS Patient Register statistics, but broadly correspond in aggregate to what would be expected from these gold-standard residential mobility data (Dennett & Stillwell, 2008). With population churn signalling changes to the residents within a neighbourhood, these data are valuable for analysing the population change dimension of gentrification and are key for differentiating incumbent upgrading from other forms of neighbourhood uplift in the study. The methodology adopted in producing this dataset are elaborated by Lansley et al. (2018), while the digitised population churn maps are displayed here.[10]

4 | METHODOLOGY

Our analysis requires a multi-stage workflow with every phase building on results of the former. Figure 1 illustrates the workflow diagrammatically, while explanations of individual methods are detailed in the Supporting Information document[11] with datasets and analysis code available on GitHub.[12]

To summarise Figure 1, the first stage involves identifying which neighbourhoods in the city are ascending or descending in terms of their socio-economic status. In stage two, neighbourhoods identified as ascending are further sub-classified into gentrifying and non-gentrifying types. A third classification stage then differentiates types of gentrification. Having identified areas undergoing different types of gentrification between 2001 and 2011, the final stage in the analysis is to try and predict, based on changes between 2001 and 2011, where the next likely candidate neighbourhoods for gentrification might be. Rather than throwing all variables into the mix at the beginning, as is sometimes done in geodemographic classification building, different variables are brought in to segment neighbourhoods in a hierarchy corresponding to socio-economic ascent (demographic variables) > gentrifying ascent (population churn and built environment change) > varieties of gentrification (social class differentiation). This

parsimonious approach means that variables such as "change in % households with dependent children," which are not very relevant to defining ascent but are very relevant for differentiating *in situ* change, do not cloud earlier parts of the analysis.

5 | ANALYSIS AND RESULTS

5.1 | Exploring the socio-economic profiles of London's LSOAs

The first stage in the analysis is to identify areas of recent neighbourhood change in the city. Borrowing at this stage from the methodology of Reades et al. (2019) and Owens (2012) (and as described in the Supporting Information), median house price, income, degree-level (level 4) qualifications, and those in the highest socio-economic class are selected as proxies for quantifying the underlying socio-economic statuses of neighbourhoods in 2001 and 2011. Principal components analysis was employed to combine and create a single composite socio-economic index (CI) variable for each year to determine if neighbourhoods had been ascending, declining, or stable over a period of time. In both years, high CI scores indicate areas with higher median house prices (the dominant component), higher proportions of residents with degree-level qualifications, and higher proportions of residents in the higher managerial, professional, and administrative occupations and with higher median incomes. Lower and indeed negative scores indicate areas where the reverse is true.

Lower-Layer Super Output Areas mapped according to their CI scores in 2001 and 2011 are provided in Figure 2a,b respectively and can be explored interactively.[13] Observing each year individually, the highest scoring LSOAs in 2001 were concentrated around Central London and along spines that extended out towards the city's north and south-western edges. Conversely, the lowest scoring LSOAs were typically located within outer boroughs towards the east, including Barking and Dagenham and Havering.

Quantifying change

By 2011, a general uplift in scores was noticeable across large swathes of the city, particularly in previously mid-scoring LSOAs situated around the north-west, east, and south of London. However, we caution against the assumption that all LSOAs exhibiting these broad, absolute score increments could definitively be branded as being in genuine ascent, since most LSOAs throughout London are likely to have undergone some degree of improvements and social upgrading with the upward-trending house prices and socio-economic conditions that have been generally evident across the city over the decades (Reades et al., 2019) and particularly between 2001 and 2011. It is nonetheless notable that the highest-scoring LSOAs in 2011 were established in the wealthiest areas of the city around Holland Park, Mayfair, Hampstead Heath, and Wimbledon.

A two-stage process encompassing both changes in rank position and absolute change in CI score was used (detailed in the Supporting Information) to classify LSOAs according to their changes between 2001 and 2011. LSOAs in ascent, decline, and steady states were identified and mapped in Figure 2c (and interactively[14]). Insofar as labels such as "ascent" and "decline" were used, it should be clarified that these labels should be interpreted in relative, and not absolute, terms since neighbourhood states were determined as function of *comparative* differences in LSOAs' CI scores and ranks. Particularly with knowledge that absolute uplifts have been the general tendency across most of London, descending LSOAs, for instance, need not necessarily be regressing in actual terms but were simply improving at a pace below the norm.

Between 2001 and 2011, 732 LSOAs were highlighted as ascending, 619 LSOAs as in decline, and the remaining 3,484 LSOAs were considered stable. While LSOAs in ascent and decline were dotted throughout the city, ascending LSOAs tended toward locations in Central and East London, while a denser congregation of declining LSOAs was situated toward the western peripheries. We note that at the extreme of the ascent category – i.e., those LSOAs with a rank change of >4 standard deviations from the mean (25 LSOAs) or an absolute composite index change in the top 5% (188 LSOAs) - tended to be places that were already very wealthy, becoming even wealthier in terms of both income and property wealth. At these extremes with already high proportions of people in the highest National Statistics Socio-economic classification (NS-SEC) and best educated groups, material wealth is the only dimension that has room for further increase.

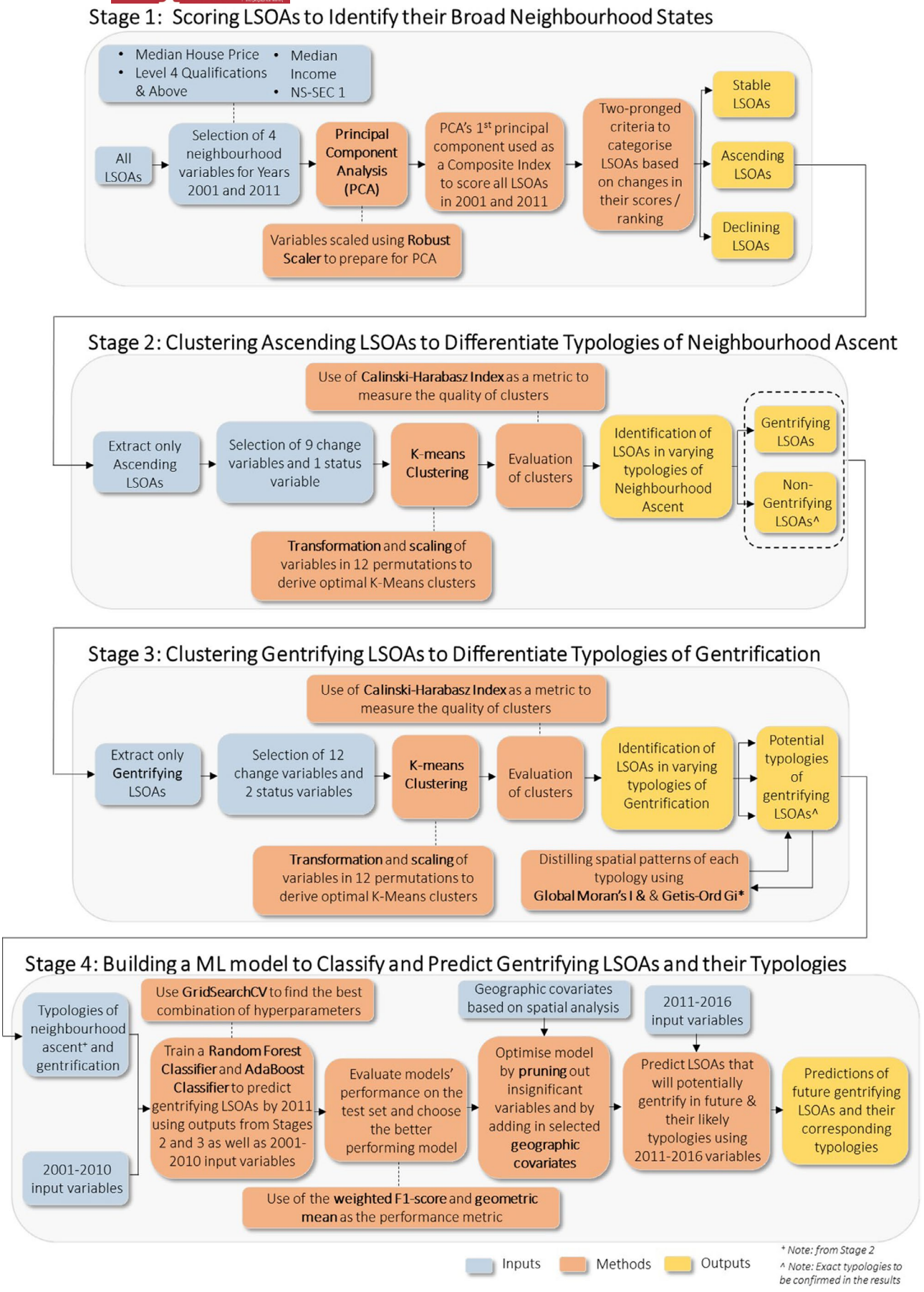


FIGURE 1 Overview of the entire workflow

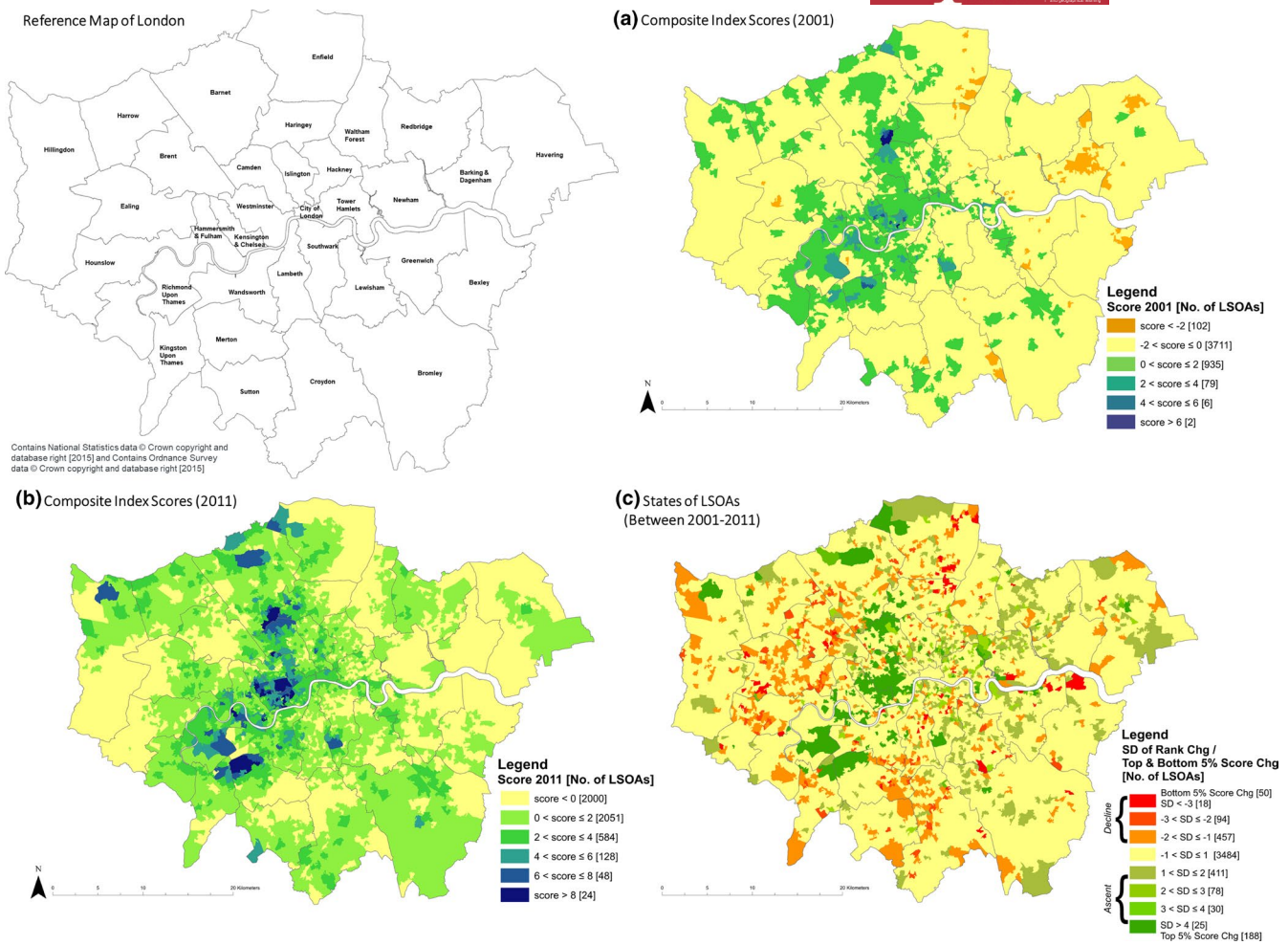


FIGURE 2 Reference map of London and LSOAs' composite index scores and neighbourhood states between 2001 and 2011

5.2 | Defining and contextualising typologies of neighbourhood ascent

A *k*-means algorithm[15] was used to isolate clusters of neighbourhoods within the ascending areas with similar ascent characteristics, according to a suite of variables selected to tease out the sorts of changes expected to correlate with the different typologies. Tying in with the quantitative work done by various scholars, contextual variables signalling changes in the physical environment (new building or conversion/renovation of existing properties) and the profile and demographic composition of the resident population will help differentiate gentrifying neighbourhood ascent from incumbent upgrading (ascending but not evolving physically or demographically beyond usual life-course progression in age family progression) and re-urbanisation (physical development but mainly in new-build, with little evidence of population displacement). Three clusters were identified: gentrification, incumbent upgrading, and re-urbanisation – their profiles are shown in Figure 3 (and interactively[16]).

Figure 3a plots the average (standardised) values of the gentrification cluster's centroid against the means of the entire dataset. LSOAs in this cluster had distinctively above-average population churn rates and planning permissions granted for redevelopment/conversion projects. These values also far exceeded the figures seen in the remaining clusters. The about-average growth of households at all stages of the lifecycle signalled that diverse types of households were coming into these LSOAs, though inclined towards older demographics given the higher-than-average increases of the ageing population.

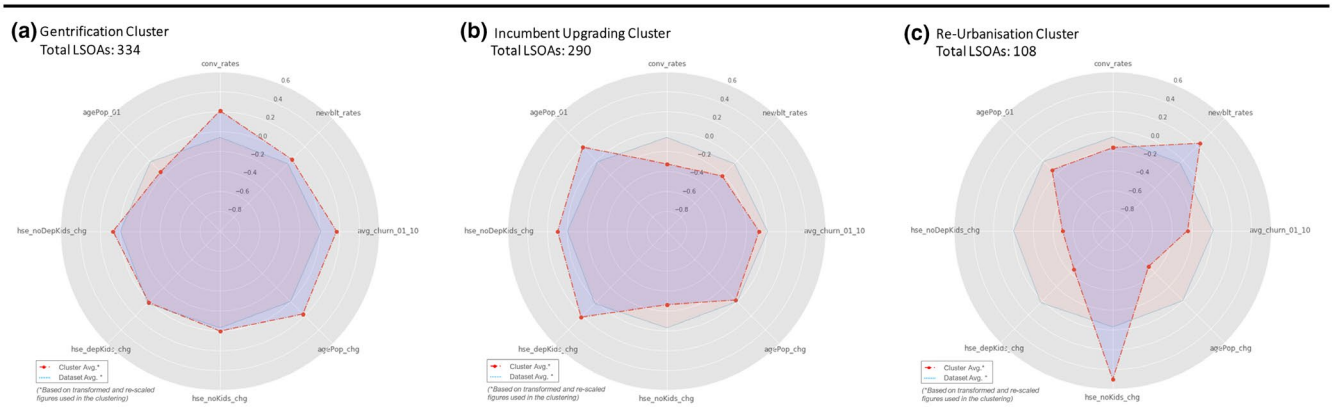
The high intensities of population turnover and works involving the re-adaptation of existing residences, potentially for new inhabitants, were hence indicative of gentrification where residents had been displaced and existing houses re-vamped to suit the needs of gentrifiers.

The incumbent upgrading cluster is presented in Figure 3b. It contains LSOAs which exhibit below-average population churn rates as well as planning permissions granted for redevelopment/conversion works[17] and new-build housing. Instead, conspicuous increases were seen in the percentage of households with children (both dependent, i.e., new young children and non-dependent, i.e., children who have grown out of dependency) which potentially imply an in situ and expected life-course evolution of families who remain in a given area for a decade. Uplift in socio-economic status would be entirely in line with the sorts of socio-economic escalator observations made by Fielding (1992) in his seminal work on London and the South-East of England, although perhaps given an additional boost through the increase in wealth enjoyed by home owners who saw their houses virtually double in value between 2001 and 2011. LSOAs in this cluster were relatively older in 2001 and experienced average changes to its ageing population by 2011. These characteristics resonate very much with the incumbent upgrading typology described earlier.

Juxtaposed against the earlier clusters, the re-urbanisation cluster's centroid averages, as displayed in Figure 3c, demonstrate that its LSOAs had distinctly higher rates of planning permissions granted for new-built residential developments and growths in the proportion of households with no children. Coupled with losses in the percentage of ageing residents (−5% in actual terms), these incoming households were likely of younger demographics and at relatively early stages of the family lifecycle. The lower-than-average population churn and planning permissions for redevelopment/conversion of existing houses signified that population turnover and the direct displacement of residents is not prevalent.

The influx of new-build developments and into them households with no children, combined with the attendant lack of population turnover, were consistent with the re-urbanisation typology where regeneration efforts were commonly made to introduce new developments and attract new populations. Despite not necessarily entailing direct displacement, LSOAs in this cluster are useful to identify from an urban policy perspective given their susceptibility to exclusionary displacement, as explained in the literature review.

The geographical distributions of the three neighbourhood ascent typologies are mapped in Figure 4 (and interactively – alongside radar diagrams for each LSOA depicting individual profiles[18]). There appears to be some degree of spatial association with each cluster, particularly among the re-urbanising LSOAs in East London (around the Olympic Park and the central-eastern boroughs of Tower Hamlets and Hackney where many new brownfield developments can be found) and with gentrifying LSOAs to the West of the city centre. Those LSOAs undergoing



Variables	Labels	Gentrification	Incumbent Upgrading	Re-Urbanisation
		Values in actual terms		
Rate of planning permissions granted for conversion of existing residential properties (per 1,000 dwellings)	conv_rates	+5.36	+0.77	+1.58
Rate of planning permissions granted for new-built residences (per 1,000 dwellings)	newblt_rates	+3.08	+1.39	+5.89
Average Population churn	avg_churn_01_10	+2.47%	+2.27%	+2.04%
Change in % of residents aged 65+	agePop_chg	+0.18%	-1.03%	-5.00%
Change in % of households with no children	hse_noKids_chg	+0.86%	+1.07%	+2.65%
Change in % of households with dependent children	hse_depKids_chg	+0.82%	+3.15%	-5.90%
Change in % of households with no dependent children	hse_noDepKids_chg	+0.74%	+0.87%	-2.52%
% of residents aged 65+ in 2001	agePop_01	10.49%	14.39%	10.57%

FIGURE 3 Clusters of ascending neighbourhoods

incumbent upgrading are more dispersed around the city, albeit with some evidence of clustering further East in Redbridge.

The apparent spatial clustering of gentrification in particular points towards the high possibility that "diffusion" effects were at play (Redfern, 1997, p. 1335), wherein the spread of gentrifying LSOAs was catalysed through local contagion effects in directly abutting neighbourhoods. Further unpacking of these gentrifying LSOAs, according to the characteristics of their socio-spatial implications, are discussed in the next section.

5.3 | Defining contextualised typologies of gentrification

In the final stage of the analysis, in order to ascertain the different types of gentrification occurring within the gentrification cluster, LSOAs were further re-classified using a similar methodology to the second stage. The new cluster analysis incorporated additional variables detailing change in the socio-economic profile of the neighbourhoods as well as changes in housing tenure and wealth between 2001 and 2011 (see the Supporting Information and GitHub[19] for details). Three sub-categories of gentrification are identified within this cluster and are described below.

The super-gentrification cluster (Figure 5a) reveals that LSOAs in this cluster were already wealthy neighbourhoods, given their higher-than-average income levels and house prices in 2001. By 2011, the proportion of residents ascribed with the NS-SEC 1 and 2 categories increased notably, though only moderate percentage changes in income and house prices were registered. It is nonetheless highlighted that these percentage changes in income and house prices were based on fairly large denominator values (i.e., 2001 figures), and if computed in absolute terms, their growth by 2011 would in fact be quite substantial. Above-average changes were also seen in the proportion of owned and socially rented houses, with declines both. While changes in the proportion of people in private rental tenure were below average, this nevertheless represented an overall increase.

These trends, particularly the influx of residents from the top NS-SEC tiers into already affluent LSOAs with expensive properties, were reminiscent of the super-gentrification typology wherein reasonably well-off, middle-class neighbourhoods were increasingly taken over by incomers possessing even higher social status and deeper capital resources.

Contrastingly, the marginal gentrification cluster's centroid averages (see Figure 5b) denote that the LSOAs here had below-average incomes and house prices in 2001. Moreover, by 2011, it was residents from the NS-SEC 4–7 tiers, instead of the top categories, that were expanding at above-average rates (either through positive net in-migration or residualised from the net out-migration of higher socio-economic groups). Nonetheless, house prices seemed to have also experienced above-average growth by 2011. In terms of tenures, as ownership and social rental rates receded between 2001 and 2011, the private rental sector has expanded significantly, potentially pointing to the sorts of exclusionary changes that resembled the marginal gentrification typology, whereby incomers who did not conform to the typical profile of an affluent, middle-class gentrifier increasingly took over previously affordably priced neighbourhoods.

Consisting of 45 LSOAs, the mainstream gentrification cluster, akin to marginal gentrification, starts off with relatively lower income levels and house prices in 2001 (see centroid averages in Figure 5c). However, unlike marginal gentrification, this cluster contains areas with well-above average gains in higher income/social status residents – from NS-SEC 1 and 2 – by 2011. In terms of housing tenure, this cluster experienced the largest shifts from those living in socially rented to privately rented accommodation. The steep inflows of residents from the top NS-SEC tiers into originally inexpensive and non-wealthy neighbourhoods, coupled with the rising income levels and diminishing stock of socially rented housing, were hallmarks of mainstream gentrification whereby traditionally working-class communities in affordable neighbourhoods were displaced by people of higher socio-economic status and which in turn propelled rising income levels in these areas.

5.4 | Uncovering spatial patterns

Figure 6 (and interactively[20]) maps the geographies of the three gentrification sub-typologies. Evidently, super-gentrifying LSOAs appear to manifest strongly in a collection of large LSOAs along the city's peripheries and Central London, including places where super-gentrification has been documented such as Richmond Avenue of Barnsbury (Butler & Lees, 2006) and Portland Road (Moore, 2012). Contrastingly, LSOAs in marginal gentrification are found towards boroughs in East London, such as a constellation of LSOAs bunched together east of Stratford. Spatial patterns for

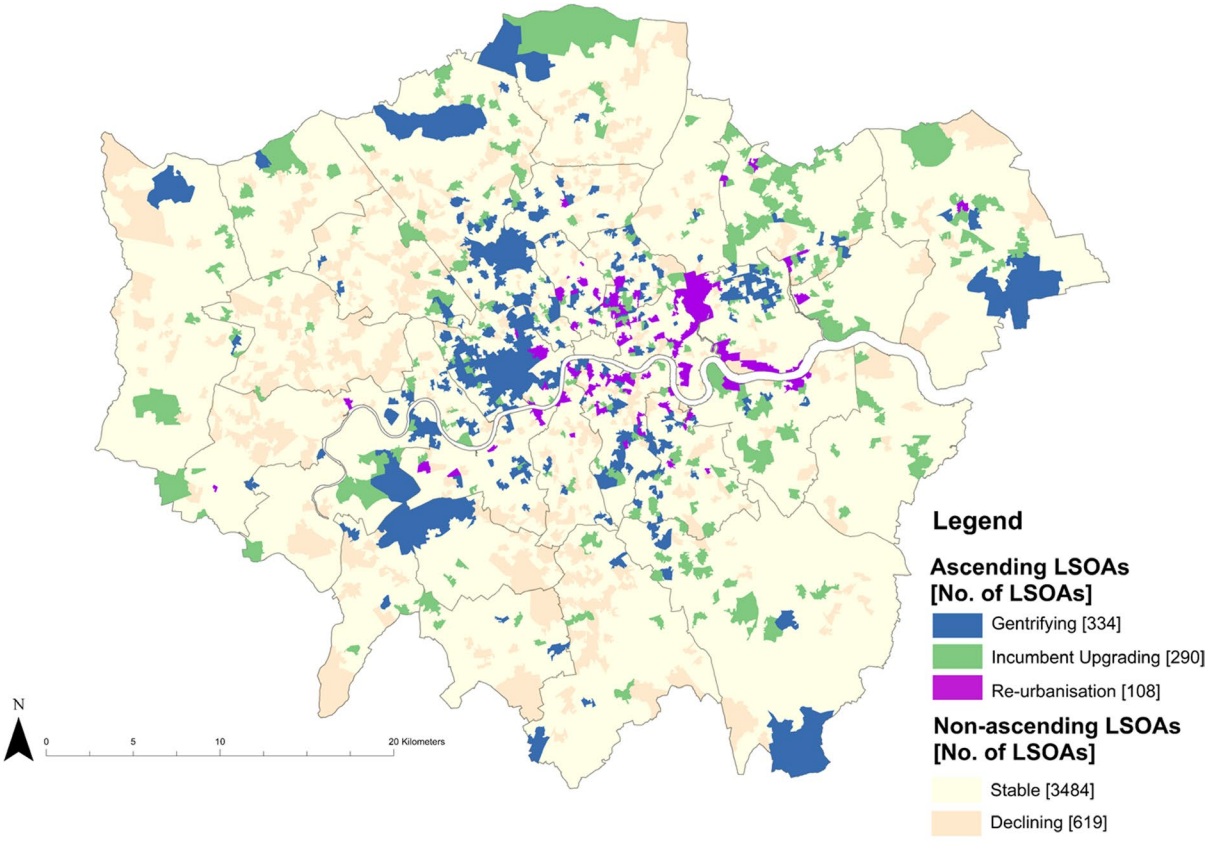
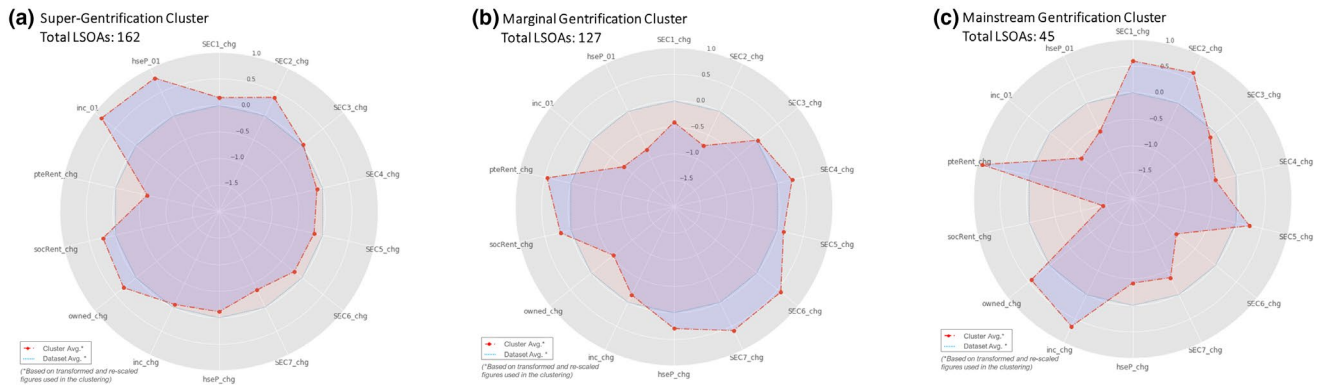


FIGURE 4 LSOAs in typologies of neighbourhood ascent



Variables	Labels	Super-Gentrification	Marginal Gentrification	Mainstream Gentrification
		Values in Actual Values		
Change in % of residents in the Higher Managerial, Administrative & Professional Occupation (NS-SEC Class 1)	SEC1_chg	+2.73%	+1.30%	+3.81%
Change in % of residents in the Lower Managerial, Administrative & Professional Occupation (NS-SEC Class 2)	SEC2_chg	+4.09%	+0.65%	+4.95%
Change in % of residents in the Intermediate Occupation (NS-SEC Class 3)	SEC3_chg	+1.48%	+1.33%	+1.26%
Change in % of residents in the Small Employers & Own Account Workers (NS-SEC Class 4)	SEC4_chg	+2.36%	+3.05%	+1.87%
Change in % of residents in the Lower Supervisory & Technical Occupation (NS-SEC Class 5)	SEC5_chg	-0.14%	+0.13%	+0.26%
Change in % of residents in the Semi-Routine Occupation (NS-SEC Class 6)	SEC6_chg	+0.27%	+1.47%	-0.85%
Change in % of residents in the Routine Occupation (NS-SEC Class 7)	SEC7_chg	+0.27%	+1.45%	+0.27%
% change in median house prices	hseP_chg	+163.9%	+181.5%	+143.6%
% change in median income	inc_chg	+46.65%	+45.23%	+54.27%
Change in % of residential properties owned by occupants	owned_chg	-2.78%	-7.34%	-2.00%
Change in % of residential properties socially rented by occupants	socRent_chg	-2.01%	-2.05%	-11.36%
Change in % of residential properties privately rented by occupants	pteRent_chg	+2.05%	+8.48%	+11.36%
Median income in 2001	inc_01	£37.24K	£27.14K	£25.13K
Median house price in 2001	hseP_01	£352.5K	£124.3K	£139.1K

FIGURE 5 Clusters of gentrifying neighbourhoods

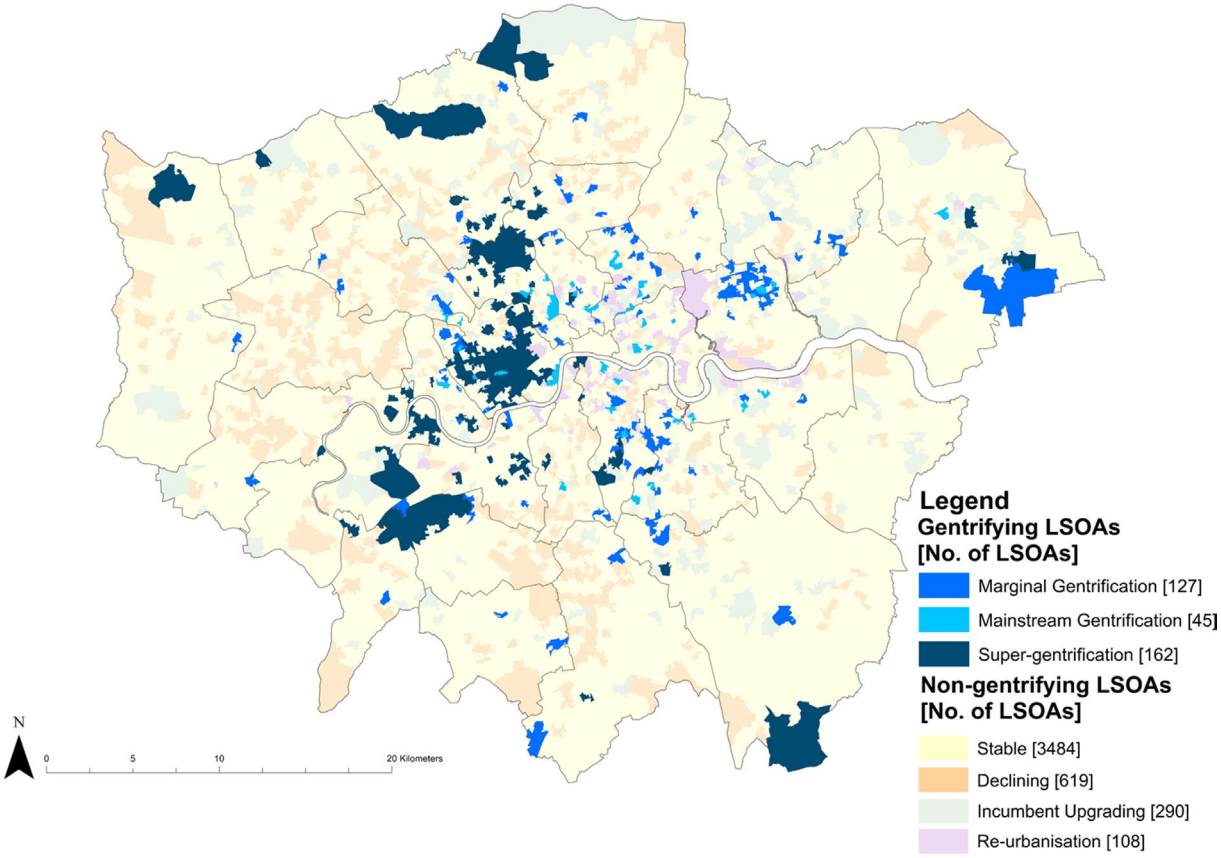
LSOAs experiencing mainstream gentrification were however less apparent, though they were mostly contained within London's inner boroughs.

5.5 | Predicting future gentrification

Having identified clear areas of recent gentrification, our attention is turned to exploring where the next phases of gentrification may occur in the city. The first stage of any prediction is to try and understand the factors influencing past trends. Machine learning algorithms can be particularly adept at this sort of challenge and so a suite of machine learning models were trained on the observed trends and spatial patterns of neighbourhood ascent and gentrification that unfolded between 2001 and 2011, with the aim of predicting which LSOAs will gentrify in the near future and their corresponding typologies. Results from the model-building process are outlined below; the full description is given in the Supporting Information and code for the analysis is also available on GitHub.[21,22]

Initial results were encouraging, with the multivariate random forest model able to predict 95% and 83% accuracy in predicting gentrifying and non-gentrifying LSOAs respectively. To further improve predictions, geographic covariates were incorporated in two ways. First through the addition of an inner London dummy and second through a gentrification neighbour dummy (see Supporting Information for details). The addition of geographic covariates improved the prediction of gentrifying and non-gentrifying areas to 100% and 85% respectively. Despite the high degree of accurate inferences made, the model has its limitations. In particular, the model was inherently prone to mis-classifying a proportion of non-gentrifying LSOAs as gentrifying (false positives), which potentially indicated a slight risk of over-fitting within the model.

A similar modelling methodology (see Supporting Information material and GitHub[23]) incorporating additional variables can be used to predict the specific typologies of future gentrifying LSOAs. According to the predictions mapped in Figure 7 (and for an interactive version, GitHub[24]), super-gentrifying trends will potentially retain a stranglehold over LSOAs in central-western London, around Hampstead Heath, Richmond Park, and the northern edges of Barnet and



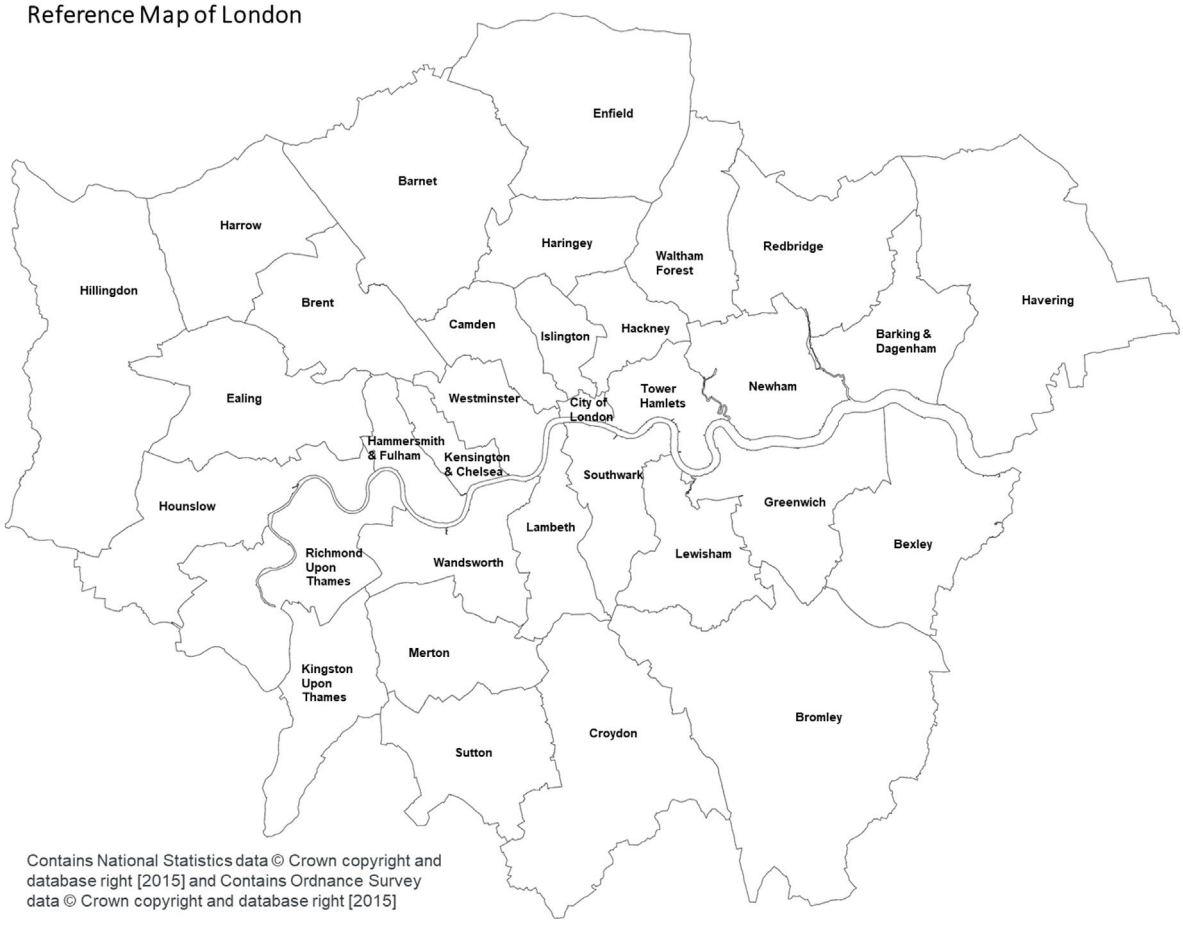


FIGURE 6 LSOAs in gentrifying typologies

Enfield. Previously isolated islands of super-gentrification near Chiswick, Clapham South, and Dulwich are nonetheless anticipated to expand. LSOAs experiencing marginal gentrification in future are likely to stay in East London, although potentially becoming more extensive around Brockley and Kensal Green. Separately, future mainstream forms of gentrification are predicted to be dominant within London's inner boroughs and north of the Thames, in boroughs such as Camden, Islington, and Hackney.

The question that quite rightly always follows such predictions is: are they reliable? Comparison between 2001 and 2011 suggests a small amount of type-1 (false positive) errors and so it is fair to say that the extent of gentrification is likely to be not as great as Figure 7 suggest. However, one of the advantages of much of our work exploring the period between 2001 and 2011 is that almost 10 years later we are able to explore what has happened since then, which we will now do using two case studies following the discussion below.

6 | DISCUSSION

Our main aim in this paper was to highlight the contributions to the study of neighbourhood change and gentrification that a city-scale urban analytics approach drawing in rich and disparate data sources and applying a clear and open methodology can make. Interactive graphical outputs reveal clearly that neighbourhood change continues to be a defining feature of London's urban landscape. As we have shown (corroborated by the findings of Reades et al., 2019), processes of neighbourhood ascent and decline collectively accounted for 1,351 or almost 30% of all LSOAs in the city. No borough, except for the City of London (where very few residents live), was spared from these processes.

One important finding from this work is that through interrogating a range of different datasets on both the built environment and population change, gentrification emerges from the data as just one sub-typology of change, corroborating already well-established theories on the subtle differences between gentrification, re-urbanising change, and in situ socio-economic uplift. We have shown, for example, that nearly all socio-economic uplift in London is driven by increases in house prices, but that it is possible to differentiate the areas of gentrification (with higher population turnover)

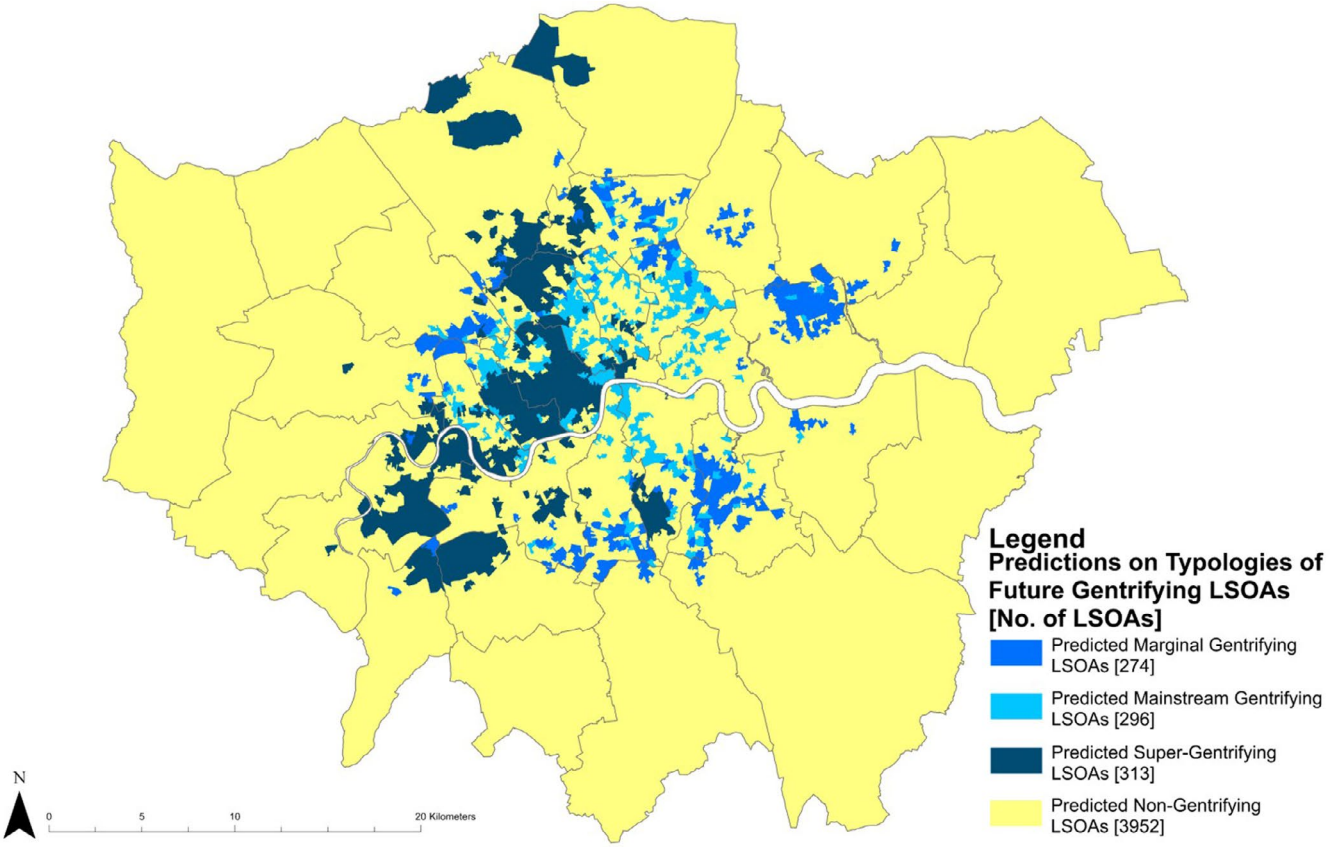


FIGURE 7 Model's predictions on the typologies of future gentrifying LSOAs

from those inhabited by incumbent upgraders (which show evidence of new children being born into *in situ* families and previously dependent children leaving) and re-urbanising areas (with high rates of new-build and households without children moving in). Previously unstudied (in the context of quantitative analyses of gentrification) population churn and planning permissions data have enabled us to successful stratify these changes, enriching our understanding.

Gentrifying LSOAs were found to comprise around 15% of all LSOAs in London, affecting over half-a-million residents, percolating through more affluent West London boroughs like Kensington and Chelsea and Westminster, as well as boroughs in East London historically associated with more working-class populations. Our quantitative observations are substantiated by previous qualitative work, ranging from Butler and Lees' (2006) study exposing gentrification's workings within affluent neighbourhoods in Barnsbury, to Butler et al.'s (2013) empirical examination of gentrification in the deprived parts of East London. These contrasting urban backdrops against which gentrification has materialised clearly hint at its existence in variegated forms. Our study has shown that super-gentrification, marginal gentrification, and mainstream gentrification were simultaneously occurring in London and are unlikely to diminish in the near future. To add colour to our city-wide analysis, two brief case studies will now be explored.

6.1 | "Icebergs" of Fulham's super-gentrifying neighbourhoods

Parsons Green in south Fulham has traditionally been an affluent neighbourhood that enjoys proximity to Central London, is home to fee-paying international schools like the Ecole Marie d'Orliac, and counts historic Victorian and Edwardian and the highly sought-after "lion houses" among its residential stock (Casey, 2015). Notwithstanding the high residential property values, super-gentrification has been creeping into Parsons Green, driven by international investors and capital in particular (The Resident, 2014). Capturing such trends in our analysis,[25] while super-gentrification appeared in only a sliver of LSOAs to the east of Parsons Green between 2001 and 2011, our model predicted the phenomenon would expand markedly in the future.

Since 2011 there has been a proliferation of hyper-luxurious basements in "iceberg houses" (Baldwin et al., 2018, p. 5) in the area. These are dug to accommodate the opulent amenities, from swimming pools to cinemas, of London's super-rich and turning what were relatively modest (but still expensive) houses into vast and prohibitively expensive mansions. Juxtaposing the geographies of "iceberg houses" in the borough[26] against our model's predictions of where super-gentrification will likely spread into, there is a clear mirroring between the two, which is hence symbolic of the "global excesses of wealth" and new "spatial expression" that have and will continue to define the trajectories of super-gentrification that are unique to London (Baldwin et al., 2018, p. 17).

6.2 | The gentrification frontier of Newham's north-east

Quintessentially East London, Newham's north-east has been home to some of London's working-class population for decades. Despite its proximity to Stratford, which was revitalised for the 2012 Olympics, and the planned Elizabeth Line stations at Manor Park and Forest Gate, house prices in this part of Newham have remained resolutely affordable through the years (EastBlam!, 2015), to the extent that estate agents have recently touted it as "a place where real Londoners can still afford to buy" (Bloomfield, 2018, n.p.).

However, as post-Olympic redevelopment in the area has continued, socio-economic transformations have started to occur. Based on our findings, marginal gentrifiers, who are attracted by the appeal of affordably priced neighbourhoods in accessible locations (Mendes, 2013), had started to enter the area between 2001 and 2011. Projecting forward, marginal gentrification, likely further catalysed by the opening of the Elizabeth Line, is predicted to inundate the area, while the minority of mainstream gentrifying LSOAs will gravitate closer towards the new stations.[27] Notwithstanding these forecasts, it is recognised that the future opening of the Elizabeth Line, and indeed other oncoming major infrastructural projects elsewhere (e.g., High-Speed 2 or Crossrail 2), could bring about rapid increases in house prices and advance gentrification in ways that our model can only partially speculate at present. Further in-depth modelling and scenario-casting will necessarily be required to better gauge such impacts and refine the predictions, which are beyond the scope of this paper but are certainly viable avenues for future research.

Though a boon for gentrifiers, such developments have spelled disaster for incumbent residents, especially low-income council tenants, as reportedly many have been evicted to make way for incomers (Hancox, 2014). Consequently, an ongoing struggle exists between segments of Newham's community and the local council, which most tangibly surfaced through the 2014 protests led by the "Focus E15" movement (Parkinson & Domokos, 2014).

7 | CONCLUSIONS

Returning to the three stated objectives of this paper, our approach has enabled us to comprehensively detail where in London between 2001 and 2011 different types of neighbourhood change occurred, presenting both a city-wide overview and a micro-level detailing of the types of change in different neighbourhoods. The use of novel data has enabled us to disentangle some of the types of neighbourhood change that have appeared in the literature, confirming at least in a London context that, rather than these changes all being part of a fuzzy conception of "gentrification," it is feasible to differentiate and classify more precisely. We have been able to demonstrate that incumbent upgrading is occurring everywhere, driven by house price rises fuelling wealth increases for property owners dispersed across the city. Re-urbanisation is occurring predominantly in the post-industrial docklands and East, while gentrification is occurring in boroughs across the city, but most frequently in central London and to the West.

We have been able to show that machine learning methods offer exciting opportunities to peer into plausible futures for neighbourhoods experiencing different types of change across the city. Our model suggests that post-2011, gentrification was set to become more prominent across most central London Boroughs. Only the publication of new 2021 Census data will allow for these predictions to be validated comprehensively, but as our brief case studies have shown, more recent qualitative evidence suggests our predictions of super-gentrification in Hammersmith and Fulham and marginal gentrification in Newham appear to have some validity. Of course, we should also acknowledge at this point the potential impacts on the geography of gentrification that the global COVID-19 pandemic may bring. There are signs in the UK and in London in particular that the demand for housing is shifting as enforced home working for many has opened up possibilities of longer-term remote-working trends. In London, this has seen demand for housing in the city reduce, evidenced by declining rents and stagnating house prices. Machine learning methods use past behaviours to predict future realities and where shocks to the established system are severe, as with COVID-19, future work will be needed to ascertain the exact impacts on predicted gentrification patterns.

Our third objective was to present an open and reproducible analytical workflow and a corresponding interactive tool for those with an interest in addressing the different challenges that different types of gentrification and neighbourhood change bring. Illustrating the potential impact that this could have in our case-study city, we can turn to Newham, where the issues associated with more mainstream and marginal gentrification are already well documented (see, for example, Watt, 2013). One of the most ethnically diverse and more deprived boroughs in London, changes precipitated by the developments associated with the 2012 Olympic Games have highlighted the challenges faced by councils where money and investment were channelled into regeneration (re-urbanisation) projects that at best bore few tangible benefits to existing residents and at worst were to the active detriment of working-class and frequently black, Asian, and minority ethnic communities living in the area. What our work has shown, however, is that given the particular socio-economic environment of the borough, it is likely that the new challenge will be to ensure that a new wave of marginal-gentrifiers – predicted to have a sizeable presence in the Borough – while perhaps not changing the area immediately through their wealth, do not lead to the indirect exclusion of those residents least likely to resist change.

In boroughs like Hammersmith and Fulham and Kensington and Chelsea, where super-gentrification is taking hold, it is tempting to view the travails of the rich as in some ways less important than those at the bottom of the socio-economic hierarchy in Newham. However, there are several reasons why the areas of super-gentrification should not be neglected – in London and in other cities. First, as Atkinson et al. (2017) show in their interviews with wealthy residents of Kensington priced out by newer wealthier arrivals, there are real social and community impacts that affect even those nearer the top of the socio-economic hierarchy. The problems are somewhat different – new owners frequently not living there for much of the year and carrying out disruptive building works – but the outcomes, which include slow degrading of the social cohesion of the area, are universal, and indeed form a potential point of empathy around which broader progressive policies (that these groups are more likely to have influence over) may be formed.

Second, where these wealthier residents are forced out, it only serves to move the problem elsewhere in the city as they then move to the next most desirable place, precipitating gentrification in that area. Third, London is a patchwork of communities and it is in places like Kensington and Chelsea where pockets of social housing are most under threat. As interviews conducted with residents in the borough by Snoussi and Mompelat (2019) attest, while super-gentrification is dominating, new developments, dwindling social housing, and private rental uplift in the borough is causing real hardship for many working-class, frequently black, Asian, and minority ethnic, residents.

In achieving the objectives set, we have realised our main aim of highlighting the benefits that an urban analytics approach can bring to bear on a fundamental urban issue such as gentrification. We highlighted in the introduction to this paper Atkinson's (2008) and Firth et al.'s (2020) observations that inaccurate and inconsistent measurement of gentrification has

hindered both policy and associated research on the topic. In presenting this approach, we have progressed towards dealing with these specific examples and others that may arise from historically poor enumeration of the issue. Future waves of new data in London and experiments in different urban contexts will offer opportunities for validation and the refinement of methods, with the real challenge ahead being to demonstrate the utility of evidence like this in applied urban policy contexts.

ACKNOWLEDGEMENTS

We would like to thank the anonymous reviewers of earlier versions of this manuscript for their detailed critiques and helpful suggestions, and for pushing us to improve this piece. We would also like to thank Professor Karen Chapple and colleagues at the Urban Displacement Project for motivating this analysis in the first place.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in GitHub at https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes, under the folder named 'data'. It is also acknowledged that part of the data for this research have been provided by the Consumer Data Research Centre, an ESRC Data Investment, under project ID CDRC 334, ES/L011840/1; ES/L011891/1.

ORCID

Joshua Yee https://orcid.org/0000-0003-4650-0855
Adam Dennett https://orcid.org/0000-0001-8036-0185

ENDNOTES

[1] See https://www.westminster.gov.uk/city-for-all [Accessed 1st November 2021].

[2] See https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes [Accessed 1st November 2021].

[3] See https://jytg17.github.io/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories/ [Accessed 1st November 2021].

[4] See https://www.urbandisplacement.org [Accessed 1st November 2021].

[5] See https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes [Accessed 1st November 2021].

[6] See https://www.ura.gov.sg/realEstateIIWeb/transaction/search.action [Accessed 1st November 2021].

[7] See https://www.london.gov.uk/what-we-do/planning/london-plan/london-development-database [Accessed 1st August 2019].

[8] See https://www1.nyc.gov/site/planning/data-maps/open-data.page [Accessed 1st November 2021].

[9] The data for this research have been provided by the Consumer Data Research Centre, an ESRC Data Investment, under project ID CDRC 334, ES/L011840/1; ES/L011891/1 (https://archive.data.cdrc.ac.uk/dataset/cdrc-population-churn-index) [Accessed 1st August 2019].

[10] See https://maps.cdrc.ac.uk/#/indicators/churn/default/BTTTFFT/10/-0.1500/51.5200/ [Accessed 1st November 2021].

[11] Refer to Supporting Information document, section SI1.

[12] The full datasets and analysis code are available online for those wishing to reproduce the analysis (https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes) [Accessed 1st November 2021].

[13] See https://jytg17.github.io/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories/#page4 [Accessed 1st November 2021].

[14] See https://jytg17.github.io/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories/#page4 [Accessed 1st November 2021].

[15] We are aware that we could well debate the merits of k-means versus any other clustering algorithm. See Supporting Information for a more detailed discussion of this methodology and the accompanying GitHub site for details of its implementation.

[16] See https://jytg17.github.io/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories/#page3 [Accessed 1st November 2021].

[17] Lower rates of conversion might seem counter-intuitive in the incumbent upgrading cluster until it is realised that only conversions requiring planning permission are included in the LDD. These then are more major works such as the conversion of single dwellings into multiple flats, rather than the sorts of home improvements made under permitted development rules by those not planning to move.

[18] See https://jytg17.github.io/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories/#page3 [Accessed 1st November 2021].

[19] See https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes/blob/master/5b%20Clustering%20Gentrifying%20LSOAs.ipynb [Accessed 1st November 2021].

[20] https://jytg17.github.io/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories/#page6 [Accessed 1st November 2021].

[21] See https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes/blob/master/6%20Data%20Prep%20for%20Modelling.ipynb [Accessed 1st November 2021].

[22] See https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes/blob/master/7a%20Model%20%26%20Predict%20Ascending%20LSOAs.ipynb [Accessed 1st November 2021].

[23] See https://github.com/jytg17/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories-codes/blob/master/7b%20Model%20%26%20Predict%20Gentrifying%20LSOAs.ipynb [Accessed 1st November 2021].

[24] See https://jytg17.github.io/Unpacking-the-Nuances-of-Londons-Neighbourhood-Change-Gentrification-Trajectories/#page6 [Accessed 1st November 2021].

[25] Refer to Supporting Information document, section SI2 (Figure 15a–b).

[26] Refer to Supporting Information document, section SI2 (Figure 15c).

[27] Refer to Supporting Information document, section SI2 (Figure 16).

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

Appendix S1. Technical Details on Methodology and Case Study Visuals

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