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REFLECTIONS ON THE USE OF K-NEAREST-NEIGHBOURS BESPOKE NEIGHBOURHOODS IN URBAN STUDIES

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ABSTRACT

During the first decades of the 21st century, bespoke neighbourhoods have often replaced predefined areas in urban studies. This development has been enabled by the improved availability of detailed data, as well as methodological innovations (e.g. the construction of bespoke neighbourhoods based on *k*-nearest neighbours, or *k*nn). This paper argues that, while *k*nn-based bespoke neighbourhoods facilitate more nuanced results in several respects, they do not provide all the advantages claimed by their advocates; as have been pointed out, they also present new problems. A literature review of the arguments for *k*nn, illustrated by concrete examples of how *k*=400 neighbourhoods fit the varying physical urban environments, leads to the conclusion that, despite explicit claims to the contrary, the modifiable areal unit problem (MAUP) still remains, and certainly various physical aspects of urban space, are largely ignored. Finally, this article discusses various possible ways to include aspects currently missing.

Key words: *k*-nearest neighbours (*k*nn); bespoke neighbourhoods; geographical units; MAUP; Sweden; physical reality; physical urban environments

INTRODUCTION

The spatial aggregation of data to some kind of geographical units is a common necessity in various kinds of quantitative urban studies. In this way, spatial positions are provided with geographical contexts, which they are expected to influence and be influenced by due to their proximity. For many years, the freedom to shape these units was limited, as data availability was restricted to a few predefined sets of geographical areas. As the specific form of data aggregation employed will affect the results of studies to an unknown extent, this situation is often described as problematic. Since Openshaw's (1984) detailed presentation of the problem he had been involved in naming the modifiable areal unit problem (MAUP) in the late 1970s, the effects of modifications in the geography used for data aggregation have been thoroughly discussed within the academic discipline of geography. This has even more so been the case since Kwan (2012) pointed out the uncertain geographic context problem (UGCoP) as a separate problem. Nowadays, these problems are often considered by researchers in other disciplines as well (e.g. Pinchak *et al.* 2021; Souza-Maia *et al.* 2024).

Certain specific drawbacks of predefined areas have also been pointed out as problems on their own. Examples (elaborated on below) include borders that divide cities into subareas in un-called-for ways, difficulties in comparing results due to geographically varying practices of spatial subdivision, and geographical units that host very small populations.

To avoid the distortive effects caused by these problems, Petrović *et al.* (2020: 1118)

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encourage researchers to 'break away from the tyranny of neighbourhood' in order to better represent the fuzzy space in which the real people being studied live. The introduction of the concept of *bespoke neighbourhoods* into urban studies is a step in that direction. This paper focuses on the type of bespoke neighbourhood that is delimited based on each studied individual's *k*-nearest neighbours (*k*nn), which has become common in studies during the 2000s. While acknowledging this valuable development within urban geography, the main purpose of this paper is to provide a critical review of the *k*nn-based approach's ability to meet the claims made by its advocates. This work has, of course, benefited from previous critiques developed within the field. To identify the appropriate literature, Google Scholar has been used, along with reference lists in relevant papers. Rather than the entire body of literature, the explicit arguments for using *k*nn presented there, are taken as the starting point for the selection and the outline of the present paper.

The first section briefly accounts for the evolution of bespoke neighbourhoods as an alternative to employing predefined geographical units in urban studies. The next section compiles the arguments presented for *k*nn by its advocates, and the subsequent section examines these arguments based on two empirical examples. Finally, the last section discusses possible ways forward in the light of the findings.

FROM PREDEFINED GEOGRAPHICAL UNITS TO *K*NN

With the improved availability of geographically detailed data in many countries during the first decades of the 21st century, new ways of tailoring the geographical units to be analysed have opened up. The most common manifestation of this development is the replacement of predefined spatial areas of data aggregation with bespoke neighbourhoods. This means that every point object (e.g. residential coordinate) in such a study is supplied with an individual buffer – or a set of nested buffers of various sizes – that is intended to comprise individual contexts. Thus, with this development the spatial resolution of a study is multiplied as the number of geographical units to analyse increases, all units are constructed in a similar way, and the possibility of varying the size allows the study of phenomena at various scales. The size of these (overlapping) buffers is usually determined by specified radii as a metric distance, or by a specified number (*k*) of nearest neighbours, and the ideal form of such neighbourhoods usually (roughly) corresponds to a circle. However, other variants of individual neighbourhoods occasionally appear, such as Thiessen polygons (e.g. Kryvobokov 2013) or network buffers (e.g. Roberto 2018).

In some fields of study (e.g. epidemiology and criminology), the radius-determined buffer is the most common variant of bespoke neighbourhood. It is a simpler idea and easier to perform than *k*nn. The radius-determined buffer also occurs in studies of segregation and various kinds of neighbourhood effects (e.g. Petrović *et al.* 2018, 2022; Lan *et al.* 2020), although the *k*nn variant of bespoke neighbourhoods is now the dominant type within these fields of research.

A British research team studying neighbourhood effects in voting has been credited with being forerunners in their use of *k*nn bespoke neighbourhoods by merging adjacent enumeration districts (EDs) – that is, predefined spatial units of about 500 inhabitants previously used in UK censuses (e.g. Johnston *et al.* 2000; Tunstall *et al.* 2000). However, the idea has a longer lineage in the literature, albeit under different guises. For example, as early as in the 1960s, Nordbeck and Rystedt (1970) developed a similar 'computer cartographic function' (let be with an unclear purpose) and interestingly remarked that its computation was very time-consuming.

Thus, aside from improved data availability, an obvious enabler of *k*nn in urban studies is the development of the necessary computational capabilities and, more specifically, the advent of the EquiPop software in the early 2010s. EquiPop was developed to analyse Swedish grid data at a resolution of 100 × 100 m. As the data already contained some geographical imprecision when it was delivered, *k*nn-based bespoke

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neighbourhoods could be computed from the gridded (instead of precise) coordinates without more spatial precision being lost. Consequently, it became possible to speed up the computational process enough to make *k*nn a useful method for analysing country-wide data in practice (Östh 2014).

A first use of *k*nn is in segregation studies. Since the scale of a segregation process cannot be determined in advance, *k*nn's ability to reveal numerous results, based on varying *k*-levels (i.e. scales), is useful. Employing predefined spatial units means that only a single result appears (at an arbitrary scale and based on an arbitrary delimitation). Segregation studies using gridded data have been conducted in Sweden (e.g. Östh *et al.* 2014), Belgium (e.g. Imeraj *et al.* 2018), the Netherlands (e.g. Sleutjes *et al.* 2018), Germany (Wildfang 2020), Norway (Rogne *et al.* 2020), Denmark (Stonawski *et al.* 2022b), Poland (Stonawski *et al.* 2022a), and the Czech Republic (Křížková & Šimon 2022); it has also been used to compare several countries (Andersson *et al.* 2018b; Haandrikman *et al.* 2023). British (e.g. Buck 2001) and American (e.g. Clark *et al.* 2015) *k*nn-based studies often use census geography, although this is still sometimes based on gridded data (e.g. Östh *et al.* 2015).

A second use for *k*nn is to provide studies of neighbourhood effects with theoretically motivated geographical contexts, at either a single scale or multiple scales. Such studies address various empirical themes, including residential mobility (e.g. Kadarik 2020; Fjellborg 2021), demographic patterns (e.g. Bergsvik 2020; Souza-Maia *et al.* 2024), educational issues (e.g. Hedefalk & Dribe 2020; Troost *et al.* 2023), life-course or intergenerational transmission of neighbourhood context (e.g. Hedman *et al.* 2015; Andersson *et al.* 2023), voting patterns (e.g. MacAllister *et al.* 2001; van Wijk *et al.* 2020), health issues (e.g. Propper *et al.* 2005; Kawalerowicz *et al.* 2023), and well-being (Westra 2024), to mention just a few.

A third use for *k*nn is to provide a location with a geographical context for some other purpose. Again, the ability to select one or multiple appropriate scales is a significant advantage. Sometimes, wider geographical surroundings need to be considered in analyses. EquiPop supports a decay function that may be beneficial here, although it appears to be seldom used (however, see Fjellborg 2021; Türk & Östh 2023). Bolster *et al.* (2007) considered the importance of various kinds of 'neighbouring neighbourhoods', while Fowler (2016) focused on the relationships between scale and segregation, as such. Amcoff (2017) identified rural concentrations of disadvantaged groups of people far away from food shops. More recently, Swedish researchers have constructed 'tenure-type landscapes' by applying a cluster analysis on tenure forms at various *k*-levels and classifying the homogeneity of the clusters (Wimark *et al.* 2020; Andersson *et al.* 2022). Olteanu *et al.* (2020) suggested a method to measure the extent to which the continuous *k*-levels of every grid square diverge from a city-wide average. Finally, *k*nn has also been used in primarily method-oriented studies (e.g. Hennerdal & Nielsen 2017; Fowler *et al.* 2020).

ARGUMENTS FOR THE USE OF *K*NN

In this section, five types of arguments for using *k*nn in urban studies have been compiled based on the literature. The references have been selected to provide examples from all the fields of *k*nn research identified in the previous section. However, as most studies of segregation and neighbourhood effects employing *k*nn primarily have an empirical focus, the rationale behind their choice of geographical data aggregation method is not necessarily very detailed and explicit. Nonetheless, most arguments supporting the use of *k*nn are based on the shortcomings of predefined geographical units. In the third field of *k*nn-based studies identified above, predefined geographical units cannot serve as feasible alternatives to *k*nn, which might explain the even less explicit motivations in these studies.

Arguments related to MAUP and UGCoP – Several arguments put forward for *k*nn are related to the general issues of MAUP and UGCoP. Openshaw (1984) pointed out two sides of the MAUP. The *zoning problem* (originally named 'aggregation problem') refers to the fact that the way the geographical units (to which the data to be analysed is aggregated)

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are delimited, affects the results of the studies making use of them, and the units can be delimited in an indefinite number of alternative ways. The *scale problem* refers to the fact that the changeable number/size of these geographical units also affects the results. Whereas one specific geographical aggregation (e.g. census tracts or a specific *k*-level) may pick up some of the processes generating segregation, for example, other processes may be hidden at more or less detailed levels of spatial scale. The UGCoP specifically refers to the fact that a set of spatial units of data aggregation may 'deviate from the "true causally relevant" geographic context' (Kwan 2012: 959).

In their pioneering studies on a possible neighbourhood effect in voting patterns, MacAllister *et al.* (2001) motivated their creation of multiscale bespoke neighbourhoods out of EDs as being due to their lack of knowledge of the spatial scale of the phenomenon under study. The relevant level(s) of scale may also vary depending on attributes that change over time, such as individual age (e.g. Andersson *et al.* 2018a; Türk & Östh 2019) or the size of a particular group of people (i.e. that shares some attribute, such as ethnicity; e.g. Östh *et al.* 2015; Sleutjes *et al.* 2018). In fact, the most common explicit argument for *k*nn is that it offers the capability to search for phenomena at several spatial levels of scale at the same time (e.g. Wildfang 2020; Knies *et al.* 2021; Andersson *et al.* 2022). In this way, MAUP can also be seen as a resource, since the fact that various processes come about at specific scales enables for researchers to identify them (e.g. Manley *et al.* 2006; Fowler 2016). Hennerdal and Nielsen (2017) argue that also the area of reference ought to be multi-scalar based on nearest neighbours, rather than a city, region, or country.

With reference to the zoning effect of the MAUP and the UGCoP, two lines of reasoning can be identified, each leading to a key argument in favour of using *k*nn. Many studies point out that predefined geographical areas are typically constructed for purposes other than the study of urban phenomena (e.g. for carrying out a census, mail delivery, or urban administration) and, therefore, do not necessarily *correspond* to the geographical contexts of their inhabitants. According to this first line of reasoning, *k*nn may produce better alternatives in this respect (e.g. Hedman *et al.* 2015; Kadarik 2020; Souza-Maia *et al.* 2024).

In other studies, correspondence to these contexts is not mentioned at all as an advantage of *k*nn. This likely suggests that *k*nn is seen – in the words of Petrović *et al.* (2020) – as a measure applied at an abstract *analysis scale*, rather than at the *phenomenon scale* (where social structures and processes may occur). According to this second line of reasoning, the key advantage of *k*nn over predefined areas, in relation to the zoning effect, is that *k*nn can be applied uniformly across different settings. As a result, *k*nn-induced multiscale 'neighbourhoods' will appear the same everywhere, facilitating comparability between studies of different cities and countries (e.g. Östh *et al.* 2015; Sleutjes *et al.* 2018; Haandrikman *et al.* 2023) and over time (e.g. Kadarik 2020; Hedman & van Ham 2021).

With reference to any of these three arguments, it is occasionally asserted that replacing predefined areas with bespoke neighbourhoods can circumvent (Östh *et al.* 2014; Clark *et al.* 2015), avoid (e.g. Vogiazides & Chihaya 2020), overcome (Wimark & Fortes De Lena 2022), or offer a solution to (Haandrikman *et al.* 2023) the MAUP. The UGCoP is mentioned less often, but for example, Hedefalk and Dribe (2020) assert that they can overcome it simply by using *k*nn, and Malmberg *et al.* (2014) claim to address it by combining *k*nn with factor analysis to produce indications of an area's most relevant contextual dimensions.

Other arguments – A fourth common concern regarding predefined geographical units is that they may cause problematic border effects. A border between – for example – two census tracts is not necessarily separating groups based on some attribute (such as ethnicity or socio-economic status) and may also be unperceived and meaningless to the people residing on its two sides. Similarly, the extent to which a phenomenon affects aggregated data may depend on whether it happens to be localized in the middle of a geographical unit or at the borders (and will thus be spread out over several units). With a *k*nn-based approach, on the contrary, no

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individuals will be living just at a border, and any localized social phenomenon will take place in the middle of someone's individual neighbourhood, according to the argument. (e.g. van Ham & Manley 2012; Kadarik 2020; Stonawski *et al.* 2022a).

Finally, a fifth argument of a practical and ethical – as much as theoretical – nature is that, unlike predefined areas, *k*nn-based bespoke neighbourhoods allow researchers to ensure that the numbers of inhabitants in the analysed areas are large enough for drawing conclusions and maintaining confidentiality regarding the studied individuals (Östh *et al.* 2015; Fjellborg 2021).

A CLOSER LOOK AT THE ARGUMENTS FOR THE USE OF *K*NN

This section examines the arguments for the use of *k*nn. As will become clear, most of the specific problems with *k*nn have already been addressed in individual papers. Here they are presented within a cohesive context, which also allows for the uncovering of possible incoherencies in certain viewpoints. To provide clarity and concretion, the discussion is based on two aerial views, each overlaid with 100 m grids – a common resolution in empirical studies. Five examples of $k=400$ individual 'neighbourhoods' (obtained from gridded data) are marked as A–E and illustrated in the figures with thicker lines and red shading.

Some (often semi-central) parts of cities consist of what may be called a 'continuous urban fabric'. This can be exemplified by a part of the district of Södermalm in Stockholm, Sweden (Figure 1), where dwellings are mixed with office space and amenities (e.g. shops, cafés, and restaurants) almost everywhere, and where traffic thoroughfares and railways have been buried in tunnels. With the exception of parkland, churches, open squares, and so forth, there are generally a few hundred inhabitants per grid square (100 × 100 m). Typically, two grid squares are required to reach (well above) $k=400$. In Figure 1, setting out from grid square B and adding any of the four nearest grid squares would fulfil this criterion (cf. Sleutjes *et al.* 2019). Grid square A holds 455 inhabitants and thus reaches $k=400$ on its own.

In many cities, the urban fabric looks different farther away from the centre. Figure 2

Figure 1. *Part of the semi-central district of Södermalm in Stockholm, Sweden, 100 × 100 m grid, and two k = 400 areas (in case B four alternative delineations). Source: Google Maps (photo).*

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Figure 2. *Parts of the outskirt districts of Skår, Kallebäck, and Almedal, in Gothenburg, Sweden 100 × 100 m grid, and three k = 400 areas. Source: Google Maps (photo).*

illustrates three named subareas in the southern parts of Gothenburg, Sweden. Several gatherings of buildings, each of a certain type, can be identified in the picture, separated by natural or constructed barriers. A villa above the scarp in the upper left part of the picture (which, due to its location, has a good view) is valued at about 20 million SEK (according to the Swedish real estate site Booli.se), and the detached and row houses in the area below (including grid cell C) are valued at about 10 million SEK each. In Kallebäck, on the other side of the motorway to the right of grid square C, there is first a group of blocks of rented flats with 3–4 floors, and then a gathering of tower blocks and large housing estates (including grid cell D). In the upper right of the picture, Almedal can be glimpsed, with plenty of retail and office space, as well as a few residential buildings. Reaching $k = 400$ would require 21 squares setting out from grid square C and 45 squares setting out from grid square E (just partly illustrated), whereas just over 400 persons reside in grid square D on its own.

Knn, the MAUP, and the UGCoP – First, the shapes of *k*nn-based areas will be addressed, and the ability of *k*nn to solve the zoning effects of MAUP will be questioned. In one of the pioneering studies within the field, Buck (2001) pointed to the existence of physical or social fault lines as a reason to doubt that individual neighbourhoods could be satisfactory represented by circular areas centred on individuals. Lund (2018) makes a similar argument and concludes that the advantages of *k*nn come at the cost of considerations of the sense of place. Studies of perceived neighbourhoods confirm these concerns (e.g. Siordia & Coulton 2015; Charreire *et al.* 2016; von Stülpnagel *et al.* 2019) and draw attention to the fact that the ways in which people delimit their perceived neighbourhoods vary with individual and contextual attributes (e.g. Coulton *et al.* 2013; Charreire *et al.* 2016; Finlay *et al.* 2023). Moreover, in a qualitatively oriented study, Campbell *et al.* (2009) noticed that one third of their informants actually changed the delimitation of their stated perceived neighbourhood *during* their interview. Of course, such a result should be expected if it is true that real neighbourhoods are fuzzy and multi-scalar (cf. Petrović *et al.* 2020). To make the state of knowledge about perceived neighbourhoods even more difficult to interpret, recent research has reported that neither egocentric nor perceived neighbourhoods align with activity areas (Christensen *et al.* 2021; Pinchak *et*

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al. 2021) – that is, the areas within which people spend their time and can interact with others on an everyday basis and within which any neighbourhood effects would logically appear. Thus, aside from the more theoretical considerations regarding the true nature of a neighbourhood, it appears challenging, if not impossible, to identify them empirically in a clear, unambiguous, and convincing manner.

Nonetheless, in line with Buck's (2001) concern (referred to above), there is now empirical evidence that various kinds of natural or built urban barriers (e.g. rivers, railways) have a structuring influence on people's lives and thereby on issues such as segregation (e.g. Roberto 2018; Huszti *et al.* 2021; Mahajan 2024). Figure 2 illustrates this influence in relation to *k*nn. The semicircle-shaped $k=400$ neighbourhood represented by grid square C in Skår includes a few blocks of flats in Kallebäck on the other side of the motorway and a group of luxury villas above the scarp, but does not include the houses 300–400 m away along the local street (in the bottom left of the picture), which seem to be a continuation of the houses in grid square C. The $k=400$ neighbourhood of grid square E is also criss-crossed by both a river, railway, and motorway. Thus, Figure 2 hints that an alternative zoning approach, for example, one considering urban barriers, may yield different results in a study of segregation or neighbourhood effects.

Thus far, the discussion has been based on the claim that *k*nn-induced areas can reasonably represent 'true' neighbourhoods, a viewpoint that is not supported by all studies. However, the zoning effect of the MAUP remains regardless. Strictly speaking, it does not depend on whether physical structures are considered important. The key argument is that the circular form of individual neighbourhoods, implicitly assumed when setting out from Euclidean distance to neighbours (as is usual in *k*nn), is just one possible zoning method among many others. For the same reason, the UGCoP will also persist. *K*nn is not the only method for producing scaled contextual areas to extract factors from (as Malmberg *et al.* 2014 did), and applying the same idea to alternative aggregation methods may well yield different results.

Next, the claim that *k*nn enables the measurement of urban phenomena at several levels of scale will be problematized. Setting out from a single location, this premise works fine on less detailed *k*-levels. However, the smallest geographical units of a grid (i.e. the grid squares) are defined by areal size rather than population (which is the backbone of *k*nn). As pointed out by Nielsen and Hennerdal (2017), a consequence of this is that the size of the grid squares and their population density will limit the measurable degree of detail in terms of *k*-levels. In a semi-central city district such as Södermalm (Figure 1), where 300–400 inhabitants tend to reside within each 100×100 m grid square, any *k*-level below this number of neighbours will still refer to the same specific grid square. Using 250×250 m grid squares will shift the problem from $k=300$–400 to about $k=2000$ in this example. Thus, the scale effect of the MAUP partially remains (as long as data are supplied in grid-based formats). However, as will be argued below, the use of gridded data results in more significant problems when more than one location is added to the analyses.

***K*nn and the physical urban environment** – This subsection will elaborate on factors not directly related to MAUP or UGCoP. First, a direct consequence of geographically varying population density is that the limit of the lowest measurable *k* will also display spatial variations. For example, in Skår (Figure 2), whose population density is less than a tenth of Södermalm's (Figure 1), *k*-levels as low as $k=20$–30 (compared with $k=300$–400) can be measured in a 100×100 m grid. Thus, *k*nn certainly does not enable any exact comparisons between different settings (e.g. cities or countries) at detailed *k*-levels. (This problem is not relevant in studies setting out from EDs, etc., as the size of those spatial units are defined by population.)

Moreover, the difficulties in making comparisons between geographical settings are aggravated when taking into consideration the claim in some studies that *k*nn, better than predefined areas, represents the realities of the people under study. One attribute of *k*nn is that various bespoke neighbourhoods at

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the same *k*-level may display different spatial sizes. This fact has occasionally been explicitly observed (e.g. Malmberg & Andersson 2015; Sleutjes *et al.* 2019; Andersson *et al.* 2023), and Malmberg *et al.* (2018) highlight possible effects over time (where the spatial size of a bespoke neighbourhood at a certain *k*-level may be altered due to population change). However, I would like to draw attention to the concrete manifestations of the relationship between area and population.

As shown in the figures, cities contain variations within their fabrics, which constitute an important factor behind varying population densities and thus behind the varying geographical sizes of *k*nn-induced neighbourhoods. If these areas are supposed to reasonably represent 'true' neighbourhoods (or if this is at all desirable), anyone agreeing that the variations in the urban fabric are reflected in the ways in which the individuals residing there perceive and use their neighbourhoods, should find the variations in the spatial sizes of *k*nn-generated neighbourhoods worrying.

Although $k=400$ in all five cases represented in the figures (i.e. in parts A–E in Figures 1 and 2), the $k=400$ neighbourhoods of grid squares C and E are 21 and 45 times larger, respectively, than the $k=400$ neighbourhoods of grid square D (or A). Based on these differences in mere size, it can be questioned whether these areas are really perceived as being on 'the same level of scale' by their inhabitants or whether they have equivalent functions in their inhabitants' lives.

The claim that *k*nn belongs at an *analysis scale* may seem to sidestep these arguments about variations in size. However, several studies that I understand to adopt such a position present these variations in size as a drawback or limitation of the *k*nn method (e.g. Rogne *et al.* 2020; Wimark *et al.* 2020; Haandrikman *et al.* 2023). To me, this indicates that, for results to be relevant, areas created by *k*nn at the *analysis scale* need some form of connection to the *phenomenon scale*.

Put another way, an argument missing here is what constitutes *a specific level of scale* (beyond the same *k*) for the inhabitants in a location? Based on the literature discussed above, my presumption would be that people's living milieus consist of more features than just their neighbours and that the physical environment plays some role here (cf. Wimark *et al.* 2020).

Second, *k*nn buffers are constructed in a similar manner regardless of the study area (e.g. country, region, or city), whereas a set of 'neighbourhoods' that accounts for physical structures would vary geographically according to those structures. Consequently, the effects of modifying one set of areal units into another will also vary with the changing urban landscape. For instance, there is reason to believe that a *k*nn-induced area of 21 grid squares delimiting a city comprised of continuous urban fabric (e.g. Figure 1) would differ far less from an alternative based on physical structures than 21 grid squares representing the $k=400$ neighbourhood of grid square C in Figure 2, which cuts through distinct homogeneous and physically separated areas. If physical structures are considered relevant for *k*nn, this also becomes a drawback of this method of aggregation.

Third, the attribute of *k*nn that makes it possible to avoid hardcore border drawing is an obvious advantage in central parts of cities, as these parts of cities commonly consist of continuous urban fabric (Figure 1). However, it becomes problematic farther out, where physical barriers function exactly like hardcore borders for the studied populations (Figure 2). Thus, in order to reflect the physical realities (e.g. rivers, railways, main motor traffic thoroughfares) that are perceived by and hinder mobile inhabitants, these de facto borders would need to be considered to the same extent as spurious borders need to be ignored.

Fourth, only residing populations have hitherto been considered in *k*nn, even though the social interactions claimed to be captured may also involve other people present in the surroundings. The inhabitants of grid square E in Figure 2 may well meet and interact with people working in the same (or adjacent) grid squares, as well as with people from other parts of Gothenburg that are shopping or using the service facilities there (cf. van Ham & Manley 2012; Kwan 2018). However, this limitation of *k*nn is not inherent to the method, but rather a consequence of a lack of spatially detailed data on other populations.

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CONCLUSIONS AND POSSIBLE WAYS FORWARD

The great advantage of *k*nn-indiced neighbourhoods is that they set out from individual coordinates and consider the populations of these coordinates' immediate surroundings. Thus, *k*nn may offer an unbeatable resolution and creates nuances in study results through its ability to simultaneously reveal several scales. Another positive aspect is that samples large enough for statistical analyses and individual confidentiality can easily be achieved by adjusting the *k*-level. However, despite claims to solve or circumvent geographical problems, such as MAUP, it has been argued here that these issues largely persist in *k*nn-based urban studies. Additionally, it has been argued that they tend to oversimplify or ignore the physical complexity of cities. The present study argues that the main shortcoming of *k*nn is that the resulting bespoke neighbourhoods are implicitly assumed to consist only of neighbouring residents at various Euclidean distances. However, there are many barriers criss-crossing the urban landscape to various extents, and many buildings host activities other than residing. These barriers and other activities may influence the residing population and their geographical contexts; thus, they contribute to various kinds of segregation, neighbourhood effects, and so forth. To represent 'true' neighbourhoods in the best possible way or to address the issue of poor correspondence between *analysis scale* and *phenomenon scale* (depending on one's perspective), and to reflect de facto borders, these aspects of the varying urban landscape need to be considered in future *k*nn-based studies.

One of the few studies based on *k*nn-induced neighbourhoods that consider the physical environments is a work by economic historians Hedefalk and Dribe (2020). These scholars employ several indicators of the built environment in or close to bespoke neighbourhoods at various *k*-levels as control variables in regressions. However, such an approach does not really consider the location of the built structures in relation to the construction of urban subareas.

An alternative way to consider the physical variations within a city has been presented by Knies *et al.* (2021). These researchers set out from UK census output areas (OAs) of a few hundred people but argue that, when these areas are combined to form units at larger *k*-levels, the similarity between OAs should be given priority in the merging process in order to reflect the identification processes of the inhabitants. Therefore, OAs sharing LSOA (lower layer super OAs; the subsequent, less detailed, level of the U.K. census geography) are merged first. Any kind of geo-data indicating physical and mental barriers – or predefined areas that consider barriers and other structures – could be used similarly to how LSOAs are used in this study when grid squares are merged to form larger *k*-levels.

The Flow version of the EquiPop software includes a 'spatial friction' function for considering physical structures in the urban landscape in a more precise way. Thus, using this function, difficult-to-cross barriers in the landscape can be added to the data on populations of grid squares; and as a result, bespoke neighbourhoods will expand more slowly in some directions from the unit of reference upon which a bespoke neighbourhood is constructed (see Östh & Türk 2020 for an introduction). To the best of my knowledge, this function has not yet been employed in a published study. In a timely fashion, Kramer (2017) developed a method of testing where physical objects function as hard boundaries.

Yet another approach for considering the physical aspects relevant to the lives of inhabitants in *k*nn-neighbourhoods would be to employ suitable areas identified in big data. Then, the restricting role of urban barriers would not be taken for granted, and the focus would be on where people may meet, be influenced by, and influence others (e.g. Järv *et al.* 2015; Brindley *et al.* 2018; Shelton & Poorthuis 2019). The importance of various kinds of physical (and mental) barriers in the urban landscape would then be revealed by the analysis rather than based on an assumption (cf. Poorthuis 2018).

Finally, if we are to consider the physical variations in the urban landscape – irrespective of how this is done – then the limitations

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of *k*nn must be both acknowledged and considered in studies. First, Euclidean distance to neighbours is not the only method for creating bespoke units. Second, employing gridded data results in a loss of precision. The numbers of inhabitants in a grid cell limit the *k*-level of detail that is meaningful to analyse. Third, as demonstrated in the figures above, physical manifestations of the urban landscape are unique to each location, to some extent. Therefore, the MAUP, the UGCoP, and difficulties in measuring segregation, for example, in exactly the same way in different cities, are not (only) a matter of method. The complex physical structures of cities are primary sources of many difficulties in geography, including those discussed in this paper. Thus, although these problems may perhaps be clarified or diminished by methodological developments, they will hardly be solved in such a way. We have to put up with both MAUP, an ever-varying urban landscape, and other difficulties.

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