The Use of Morphological Description in Neighbourhood Planning: Form-based Assessment of Physical Character and Design Rules

Garyfalia Palaiologou[a]*, Taimaz Larimian[a] and Laura Vaughan[b]

Abstract

Despite ongoing efforts to encourage the use of urban morphology tools into current practice, uptake remains limited. Shortcomings are largely attributed to time and resource intensive methods of historical settlement transformation study. However, developments in quantitative morphological approaches offer new possibilities for efficiency and easier adoption of research tools in practice. This paper proposes the use of typo-morphology methods to inform the adoption of form-based design guidance in neighbourhood master plans. The aim of the study is to develop a comprehensive yet flexible method for form-based character assessment (FBCA) of residential streets. The resulting FBCA classification identifies streets where compliance with form-based design rules could be tightened. The FBCA method is empirically tested in the context of the local neighbourhood plan for Radlett, Hertfordshire in the United Kingdom, offering reflections from practice on the usefulness and limitations of the method.

Keywords:

character appraisal; spatial analysis; typo-morphology; neighbourhood plan; form-based codes; urban development; United Kingdom.

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[a] *School of Architecture, Building and Civil Engineering, Loughborough University, Loughborough, Leics, UK;*

[b] *Bartlett School of Architecture, University College London, London, UK.*

* School of Architecture, Building and Civil Engineering, Loughborough University, Loughborough, Leics, LE11 3TU. Email: g.palaiologou@lboro.ac.uk

Introduction

Morphological description can help to substantiate the spatial quality of physical settings (Sanders 2013, 117), manage the urban landscape (Gu 2010) and contribute to evidence-informed practice for achieving sustainable development (Marat-Mendes 2013; Lai et al. 2018). Despite on-going efforts in the field of urban morphology to translate its research methods into tools for practice, the field is yet to achieve systematic knowledge transfer to practitioners (Ünlü 2018). Amongst other reasons, the research-practice disconnect is attributed to the resources required and time-intensive study methods used by urban morphologists (McGlynn and Samuels 2000), which highlight the need for "an abbreviated research process that can be deployed with simplified analytical and prescriptive elements" (Talen 2014, 69; Sanders 2013, 116).

Quantitative approaches can offer to contemporary practice time-efficient methods and tools for simplified analytical and prescriptive tasks. A growing number of recent morphological studies make use of quantitative analysis of urban form which is based on measurable mathematical evidence. These studies have largely focused on the development of sophisticated quantitative analyses for research-driven inquiries and applications, thus are caveated as being complex for practice (Berghauser Pont 2018, 114). The FBCA method therefore addresses the need to recognise how quantitative methods could contribute to practice-driven objectives to support planning and design tasks. To this end, this paper engages with the following research questions:

- *Can simplified quantitative description of physical character be developed to encourage the uptake of morphological tools to inform form-based tasks in planning practice?*
- *What are the benefits and limitations of integrating quantitative assessment of built form into the mainstream neighbourhood planning process?*

This paper contributes to efforts for bridging the research-practice gap by testing the potential use of morphological assessment of physical character in defining form-based design guidance in neighbourhood planning. At the empirical level, the presented method can contribute to alleviate the tension between new and old developments by identifying the degree of control for form-based design rules of new developments based on the surrounding building arrangements. Methodologically, it adds to quantitative approaches by being practice-focused, sympathetic to local context and

scalable to the more urban built environments. The study makes a useful contribution in the development of automated quantitative typo morphology tools, that are appropriate to contemporary planning practice's needs for time-efficiency and qualitative stakeholder input.

To this end, the following study describes the use a typo-morphological approach (Gu, Li, and Zheng 2019) to respond to three objectives: (1) to propose form-based design rules to achieve continuity between existing 'ordinary' physical character and new development at the neighbourhood scale; (2) to meet the demands for efficiency in resources (skills, time and budget) in local planning practice; and (3) to support the use of the neighbourhood plan as a stakeholder-driven planning tool. The latter objective relates to a modern challenge facing planning practice – that of responding to public consensus (Talen 2009, 158). The proposed *form-based character assessment (FBCA) method* describes four tasks to identify levels of built form consistency in residential streets: qualitative surveying, representation, assessment of form-based variables, and street classification. Additionally, the method is refined and evaluated via stakeholder consultation and validation. The resulting FBCA matrix and street classification work as comprehensive and flexible point of departure for the specification of form-based codes (FBCs). The method is empirically tested in Radlett, Hertfordshire, a commuter village at the Green Belt fringes of north west London in the United Kingdom, to inform the process of drawing up a Neighbourhood Plan for Radlett – therefore, offering a tangible opportunity to reflect on the use of morphological description in practice and in stakeholder consultation.

As follows, the first section reviews literature on the contribution and gaps of typo-morphology to form-based planning practice. Thereafter, the research design and methods are introduced to propose the FBCA method as a tool which can resonate with planning decision-making at the neighbourhood scale. Following, we test the street-level FBCA method empirically. The concluding sections reflect on the challenges of quantitative character assessment and the contributions and limitations of this work, and identify next steps that could promote wider uptake of automated morphological assessment for the purposes of neighbourhood planning.

Literature review

Form-based planning practice

The form-based qualities of townscapes are a key factor in shaping the three-dimensional character of places and can influence living conditions on many levels, from sociability to public health (Talen 2009). This is evident in local environments where the application of form-based codes (FBCs) has been found to support liveable outcomes, for example, through the mixing of uses and shaping compact urban form (Talen 2013), walkability (Hansen 2014), and sustainable development (Garde and Kim 2017). Alongside these outcomes, modern FBCs seek to facilitate community involvement in the management of the built environment (Walters 2011, 207), and in practice they generate different types of neighbourhoods (Trudeau 2013). In other words, FBCs have the potential to create sufficiently flexible design frameworks that can produce "variety with harmony" (Carmona, Marshall, and Stevens 2006, 242). Thus, FBCs can help planning practice to manage the balance between continuity of physical character and alongside opportunity for change (Sanders and Baker 2016). Processes of urban densification, urban regeneration and rural development suggest a growing need for flexible yet locally informed guidance on how to achieve sustainable growth without damaging existing places and communities (Idziorek and Chalana 2019). The top-down vs. bottom-up tension in neighbourhood planning is particularly challenging if a resident-driven vision is to be delivered, and it calls for a better integration of planning outcomes and planning process to achieve a contextual approach (Talen 2019).

Character appraisals are tools to support the specification of contextual planning. To inform contextual FBCs, character appraisals need to consider not only visual or visible qualities of places, but also underlying form-based qualities related to the ways in which buildings demarcate the spaces in between them (Krier and Krier 1979). While character appraisals are an established component of supporting evidence in planning applications, there is no widely agreed approach to their execution. Methods and criteria used depend on planning priorities and values of local authorities as well as on the skills available to them (Mageean and Hulmes 2000). Larkham and Morton give examples of how "[p]ractitioners appear often to be identifying [character area] boundaries by a variety of quick approaches including personal knowledge, rapid reconnaissance, and

superficial cartographic convenience: in short, 'by eye'." (Larkham and Morton 2011, 135) The following sections discuss typological thinking in the field of urban morphology to highlight its contribution to form-based character assessment and its potential application in planning practice as a contextual framework for defining FBCs.

Physical character and quantitative typo-morphology

Typological thinking in urban morphology (Caniggia and Maffei 2001; Cataldi 2003) uses analytical tools that enable comparisons of physical attributes of building arrangements to reveal built form typologies based on underlying pattern, similarities and differences. It leads therefore to an assessment of physical character that can be used to inform place-based planning and urban design decision-making (Chen and Romice 2009). Typological or 'typo-morphological' studies identify physical character by analysing urban from in two ways (Moudon 1992, 342–44): (1) through the study of typological processes in urban development over time to identify morphological periods in urban landscapes; and (2) through the study of urban geometries in terms of form and spatial arrangement, which is categorised as a-historical 'space-morphology'. Whereas the value and usefulness of historically informed typo-morphology is acknowledged (Whitehand et al. 2014), its empirical application is compromised by its reliance on expert knowledge alongside the resource-intensive methods that are required for the study of 'morphogenesis' (i.e. of the formation and transformation) of the built environment (Samuels 2008).

Advances in geographical computational power has led to increasing popularity of mathematical approaches in the study of urban form, at least in academia (D'Acci 2019; Clifton et al. 2008). In turn, space-morphology takes advantage of increasingly available geospatial data and tools for spatial analysis; by using measurable quantitative evidence it reveals morphological patterns/typologies based on multiple form-based and spatial/configurational variables. These new generation 'urban morphometrics' are found to distinguish cluster areas of different historical morphological periods in nearly perfect accuracy (Dibble et al. 2017, 708), showing potential to also reflect a historical perspective. Quantitative approaches enable analyses with greater degrees of flexibility, precision and complexity and thus show wider scope to respond to the multifarious design and planning objectives encountered in practice.

However, quantitative morphological description remains far from being comprehensively used in planning practice. Berghauser Pont notes that due to its

complexity, the typical quantitative analysis "fits research purposes, but is less valid for practice" (2018, p.114). Other limitations include inconsistent terminology and confusion with regards to resolution of analysis in relation to scale of study (Fleischmann, Romice, and Porta 2020); as well as limitations of fitness of the various data mining processes depending on the study and the quality of the clustering (Schirmer and Axhausen 2019). Nevertheless, quantitative tools, if simplified, have the potential to inform evidence-based decision-making in planning and urban design practice, especially with regards to formulating contextual responses to local conditions. The practice-based approach which we adopted for the FBCA method, suggests that practice-driven objectives can help to mitigate some of these issues. As discussed in the next section, a focus on specific planning tasks – in our case, this task being the definition of form-based design guidance for neighbourhood planning – gives direction with regards to the relevant resolution and hierarchy for the morphological analysis.

Morphological resolution and hierarchy for neighbourhood FBCs

Geometric and quantitative analysis can be applied at different levels of detail or *resolution* to reflect different *hierarchies* amongst physical elements of settlement form (Kropf 1996; Osmond 2010). Morphological description can therefore support a range of planning tasks, at different scales and levels of management of the urban landscape. However, a clear association between planning tasks and morphological resolution or hierarchy is still lacking. Resolution is reflected in the number of variables considered to define typo-morphologies. For the specific objective of identifying form-based design rules to develop FBCs, a comprehensive set of variables would need to include typical characteristics that define building placement, height, width and frontage (Parolek, Parolek, and Crawford 2008, 12) (see also Appendix, Table A1).

The unit of analysis determines the hierarchical level at which morphological analysis would be conducted to identify typo-morphologies and subsequently to define the areas where FBCs would be applied. Furthermore, to assess character in a manner that resonates with both planning practice (objective 2) and public process (objective 3), it becomes important to identify a unit of analysis that makes sense administratively for the application of FBCs, but also in terms of experiential quality of what the locals themselves would recognise as their area's physical character. To this end, the assessment method in this paper focuses on streetscape and uses the street as the spatial unit of morphological analysis. Streets maintain a meaningful reference to human

perception, the way people see and use their environment, and the space-making qualities of built form (Marshall 2005). Whereas urban morphologists have previously proposed the role of streets in determining the character of places (Guy 2006; Oliveira and Medeiros 2015), despite some rare exceptions (such as the Plan for Bologna in 1975) and "although administratively convenient", streets are undermined in prevailing practice norms (McGlynn and Samuels 2000, 86). The FBCA method builds on precedent morphological studies to develop a street-level form-based character assessment of neighbourhoods.

The discussion so far has highlighted the scope for quantitative, automated approaches to inform form-based planning practice, as well as the limitations in terms of application. The FBCA method is a worked example of how a more focused approach can be taken that fits the typo-morphological requirements, but benefits both from relative ease of use, as well as appropriateness in considering the unit of analysis. The next section describes in detail the proposed method and tests it on the Radlett case study.

Research design and method

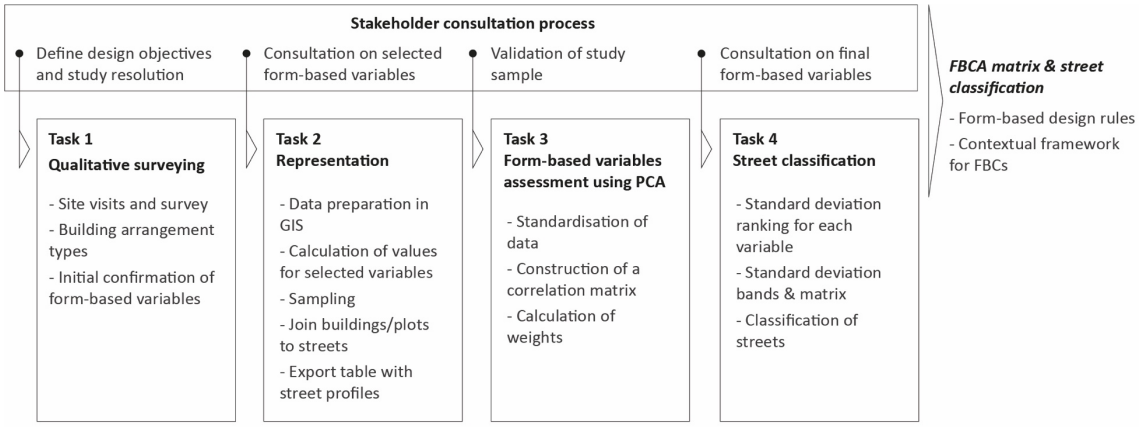
The research objectives frame the form-based character assessment (FBCA) method which results in four tasks to identify levels of built form consistency in residential streets. In response to *objective 1 – definition of form-based rules*, the study uses typo-morphological analysis to identify pertinent characteristics of urban form to guide future development. To this end, we adopt a definition suggested by Dibble et al. where physical character defines "a characteristic (or feature) of one kind of [urban form] that will distinguish it from another kind" (Dibble et al. 2017, 711). Therefore, the baseline criterion used for physical character is the distinctiveness of form-based variables (see below in task 3) and their consistency within a physical setting – in this case, streets (task 4).

In response to *objective 2 – resource efficiency*, the study opts for quantitative typo-morphological analysis of physical character rather than study of settlement morphogenesis (which would require historical analysis of the settlement development and transformation). The FBCA is conducted within a geographic information system (GIS) using spatial data (task 2), validated through qualitative surveying (task 1) and stakeholder consultation.

In response to *objective 3 – public consent*, the FBCA method adopts the street as a unit of analysis relatable to users (both cognitively and administratively) (task 4). In addition, local stakeholders and representatives from the planning process are consulted at critical decision-making points throughout the character assessment process. Stakeholder input aims to evaluate the proposed quantitative method at all stages and to develop an automated approach which is adjusted to the specific case study context.

The resulting process for the FBCA method is typical of the representation, analytical and descriptive steps used in quantitative typo-morphological studies (Gil et al. 2012), however, appropriated to conduct a simplified street-level FBCA, while maintaining stakeholder involvement. Figure 1 illustrates a summary of the four FBCA tasks and the stakeholder input that are described in detail in the following paragraphs.

Figure 1. Form-based character assessment (FBCA) method: outline tasks and stakeholder consultation process.



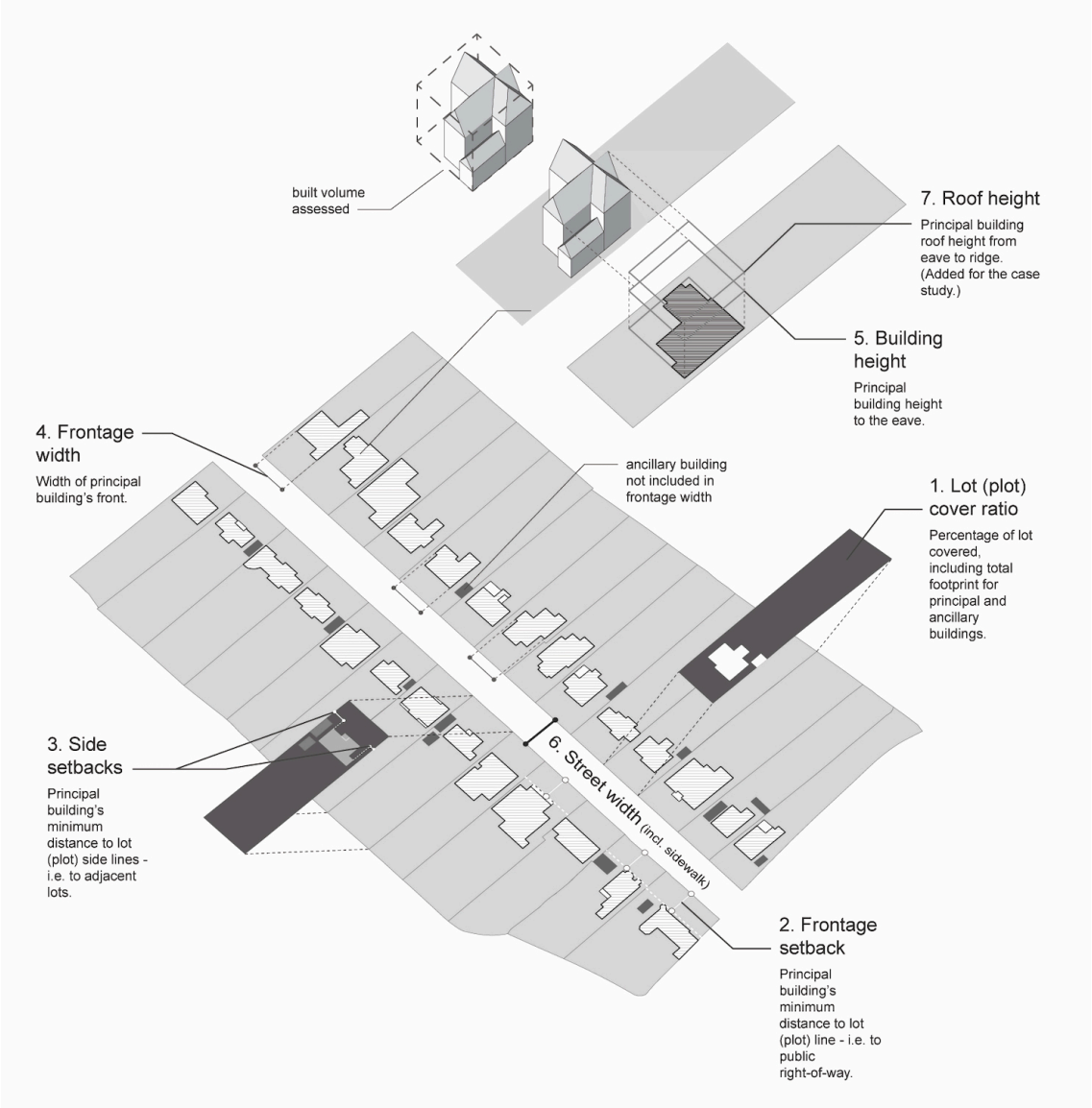
Stakeholder input and validation is an essential activity that underpins the character assessment process and supports the development of the neighbourhood plan as a stakeholder-driven planning tool. By stakeholders here we consider both experts involved in the planning process and lay audiences who live or work in the area. The aim is to receive validation of the quantitative results and to co-create the character assessment approach with and for stakeholders to strengthen its usefulness in the planning process. In this regard, consultation with stakeholders may take various forms, depending on the planning process requirements and public consent procedures involved in creating neighbourhood plans. Nevertheless, regardless of the planning practice context, the quantitative-driven approach requires qualitative validation by users to maximise its effectiveness and relevance. The FBCA method adopts a simple basis for stakeholder interaction, which includes the steering of objectives and

validation of results for each character assessment task: i.e. before task 1, to define the character appraisal objectives; from task 1 to task 2, to confirm the form-based variables which would be used in the analysis; from task 2 to task 3, to confirm sampling; and from task 3 to task 4, to confirm the form-based variables of special interest for the street classification.

Task 1 – Qualitative surveying: This task involves familiarisation with the studied built environment and is used to identify building arrangement types and validate the selection of the form-based variables which will be used in the FBCA to support the prescription of FBCs. A basic set of variables is identified as starting point, informed by common characteristics regulated by FBCs (see Table A1): (1) lot or plot cover ratio, (2) frontage setback, (3) side setbacks (distance to side plot lines) , (4) frontage width, (5) building height and (6) street width. The first three variables reflect the spatial arrangement within plots. The subsequent two variables are measures of building form and the final variable reflects the street geometry. In the Radlett case study, qualitative surveying additionally identified (7) roof height as a locally significant variable in terms of the building form proposition. (Figure 2) Although not the focus of this study, task 1 also enables an identification of streetscape design features including common building types, materials, vegetation and landscaping features etc., which are typically required in character assessments.

Task 2 – Representation (GIS processing and data sampling): This task involves the preparation of spatial and geometric data associated with the selected form-based variables (task 1) and its processing in GIS to enable the analytical phase (tasks 3 and 4). Datasets are first examined to identify residential streets and plots and remove outliers to determine the study sample. Next, plot-level and building-level data need to be linked to streets (the unit of analysis) to conduct the street-level study. For administrative convenience, the method adopts a boundary definition of streets by name. Spatial treatment, generation and processing of data involves manual processing and subjective decision-making (see the case study example in Figure 5) – a limitation discussed later in this paper. The output from task 2 is a quantitative description of each street profile which includes average, minimum, maximum, and standard deviation values for the form-based variables.

Figure 2. Diagram showing form-based variables identified in Task 1.



Task 3 – Form-based variables assessment (Principal Component Analysis): This task uses Principal Component Analysis (PCA) as a multivariate choice method to define objectively a real-valued function over the selected form-based variables. Namely, PCA is used to assign a weight to each of the seven variables. Given the small number of variables, PCA offers a simple method to assess their relative significance across the sample of streets. The main idea behind the PCA method is to reduce the number of attributes a dataset has, while maintaining most of the data information (Jolliffe and Cadima 2016). The steps of conducting PCA include (1) standardisation of data, (2) construction of a correlation matrix, and (3) calculation of weights, and are illustrated via their application in the Radlett case study, in the next section.

Task 4 – Street classification (Standard deviation ranking): This task identifies degrees of morphological consistency *within* each studied street for selected prominent form-based variables. The variables are determined by the PCA results (task 3) and the consultation with locals. Streets are ranked based on standard deviation values for each of these variables, then categorised in bands of high-medium-low consistency (low-medium-high standard deviation respectively). The rankings per variable are then combined to classify streets in groups of high consistency for all variables, some variables, or none. The outcome is a classification of streets and adjacent plots which defines various sets of form-based rules. Higher number of rules suggests higher scope for design control through the application of FBCs. Design codes can therefore use this classification to identify different combinations of variables of special interest within a streetscape, resulting in different degrees of intensity for design control. For example, streets with high consistency for all prominent variables show highest scope for design control, meaning that new development would adhere to its surrounding form-based rules (specified by the street profiles from task 2 which provides average, minimum and maximum values per street). Streets with high consistency in some of the prominent variables show average scope for design control, meaning that new development would adhere to its surroundings only in terms of the relevant form-based rules. The method is demonstrated in the Radlett case study.

The FBCA tasks are demonstrated and tested through case study research. The case study, Radlett village in Hertfordshire, UK, offers a useful test-case for typo-morphological analysis: at a first glance, the village shows little differentiation in terms of built form, with a limited range of building types and consistent parcellation of plots, blocks and built routes. Therefore, typo-morphology can help reveal a more nuanced character based on a deeper and systematic analysis of urban form patterns. Moreover, the research was conducted alongside the live planning process for drawing up a neighbourhood plan for the village and, thus, gave the research team access to real stakeholders and practice challenges.

Case study: testing the method in practice

Planning context

The Neighbourhood Development Plan (NDP) is a guidance planning tool for future local development and operates alongside the formal Local Plan (DCLG 2011, 12). The

creation of an NDP is typically carried out under the auspices of local councils and managed by a steering group of local experts, with the help of planning consultants (Parker and Murray 2011). The NDP needs to meet formal approval by a planning inspector as well as public consent. The process for creating an NDP for Radlett[2] was initiated by the local parish in July 2013 and the last public consultation took place almost six years later, in May 2019. The character assessment survey occurred between September 2015 and March 2016. The objective of the character assessment, set out by the local Steering Group, was to produce *measurable* and *material* parameters that define Radlett's urban physical character; a goal which was informed by residents' concerns that the disproportionate scale of newly built or re-developed homes was altering the townscape character and its verdant outlook (ADP 2019, 12, 14). Effectively, the character assessment directly informed the second out of thirteen in total objectives for the NDP Policies (*ibid.*, 27): "To meet new housing demand in a manner that is sensitive to the character of the village, guided by site-specific context analysis and the Radlett Character Assessment 2016. (Objective 2)"

Radlett: village profile

In the 2011 Census (ONS 2011), Radlett had a registered population of 8,163 usual residents living in 3,143 households. Building footprints cover approximately just 13.3% of the settlement area, and the village has a verdant character – a heritage strongly associated with the surrounding arable farmland, grassland and woods of the London Green Belt. Radlett gradually took on its current form throughout the 20th century, evolving from a medieval settlement that by the late 19th century comprised three estates (Kendals, Newberries and Aldenham Lodge) along with a few farmhouses surrounding an important regional road, Watling Street, and the housing and commercial developments created to serve the railway station (opened in 1868) (Figure 3). The Radlett (North) Conservation Area was excluded from this study.

[2] https://www.radlettplan.org/

Figure 3. Radlett, Hertfordshire: spatial history, showing plots with building development in c.1906-1939 and c.1924-1951. Topography geospatial data courtesy of Ordnance Survey (GB). Background historical map 1:2500 County Series 2nd Revision and 3rd Revision courtesy of EDINA Historic Digimap Service.

The Radlett area, c.1906-1939. The Radlett area, c.1924-1951.

Radlett was used as a case study for applying typo-morphological analysis not only due to its apparent morphological consistency, mentioned earlier, but also because of the village facing a pressing need for suitable new housing development within an area constrained by the boundary of the Green Belt. In morphological terms, the Green Belt acts as a long-term 'morphological frame' (Whitehand 2001, 106), meaning that further housing development in Radlett needs to occur through in-fill building in existing previously developed land, rather than extensions beyond its current planning envelope. Hence, the development issues facing Radlett and the role of form-based character assessment in supporting their management is a useful case study.

Form-based character assessment (FBCA)

Consultation with the Radlett NDP Steering Group was undertaken in various formats throughout the character assessment process. First, as previously mentioned, the objectives of the character appraisal were outlined by the Steering Group comprised of local residents. Two members of the group possessing planning expertise were actively involved, overseeing the process and co-ordinating with the Steering Group decision-

making at transition points between tasks. Members of the local community contributed to the qualitative survey by validating the mapping of historical building typologies (i.e. bungalows and chalets) (task 1). Consultation also took place in a workshop with all members of the Steering Group at the end of task 2, to confirm the sampling process and the shortlisted form-based variables. Results from task 3 were presented to a public audience at the local fair in November 2015, and final results (task 4) were shared with the local community alongside draft design codes in July 2017 at the launch of the Draft Radlett Neighbourhood Plan. Further consultation took place online as part of consultation on the Radlett Neighbourhood Plan itself.

Stakeholder involvement added a valuable contribution that helped mitigate some of the limitations of adopting an abbreviated and automated quantitative approach. Specifically, it took advantage of local knowledge about the area: experience of living there, as well as its material culture and local history. Given time constraints and resource limitations, local knowledge supported time consuming tasks such as the qualitative surveying, as well as to set out priorities for the analytical steps – for example, it helped to identify a reasonable set of urban form variables of interest which could be analysed within the time and budget available. Furthermore, stakeholder consultation was used to identify gaps in the quantitative datasets and also to confirm the practical meaningfulness of the quantitative results and their interpretation. Overall, stakeholder input helped the researchers to tailor the generic automated approach in response to specific user-driven requirements.

Task 1 – Qualitative surveying

Radlett is a low-rise settlement with typical building height between 7-9 meters. The traditional architectural language of Radlett buildings is characterised by half timbering techniques often with flint cladding, steeply pitched and gabled roofs, dormer windows and consistency in the use of materials. The survey and the consultation with the Steering Group added ‘roof height’ to the initial list of six form-based variables. In terms of building arrangement (i.e. excluding architectural style criteria), the survey found that the predominant morphology is detached buildings (58.3 per cent), followed by clusters of semi-detached (24 per cent) and terraced buildings (11.2 per cent) (Figure 4). To these standard categories, two building types of special interest to the residents were noted which are *bungalows* and *chalet bungalows* (6.5 per cent).

Figure 4. Radlett, Hertfordshire. Building arrangement for identified building types: detached, semi-detached, terraced, bungalows and chalet bungalows.

Task 2 – Representation (GIS processing and data sampling)

The character assessment survey covers the Radlett Built-up area[3] of approximately 300 hectares, in the southern district of Hertfordshire. Geospatial data and building heights for the Radlett study were retrieved from the EDINA Digimap Ordnance Survey Service via the local planning authority. Figure 5 illustrates the geospatial data used – existing and generated – for each form-based variable and the processing steps.

Next, data sampling was undertaken for plots and streets. Residential plots were identified to inform the specific objective about new housing provision, and outliers of large plot size were excluded; these plots coincided with large-scale housing development (e.g. social and sheltered housing schemes). The analysis excluded streets with limited access – i.e. private streets, very narrow pathways with no or limited visibility inside plots, and streets which could not be accessed in the qualitative survey

[3] The 'Radlett Built up area' is a statistical and spatial unit used in the 2011 Census, created by ONS Geography, with reference code 'GSS code E34003774'.

(nor via desktop study). In total, 2,553 residential plots were examined (i.e. 92 per cent of the population size) covering approximately 67 per cent of the settlement land. (Figure 6)

Finally, the sample of plot polygons (and building polygons within them) facing the same street were grouped and summary values (average, minimum, maximum, standard deviation) were calculated for the seven form-based variables per group/street.

Figure 5. Visual summary of editing of Ordnance Survey Topography geospatial data in GIS and CAD for variables' extraction.

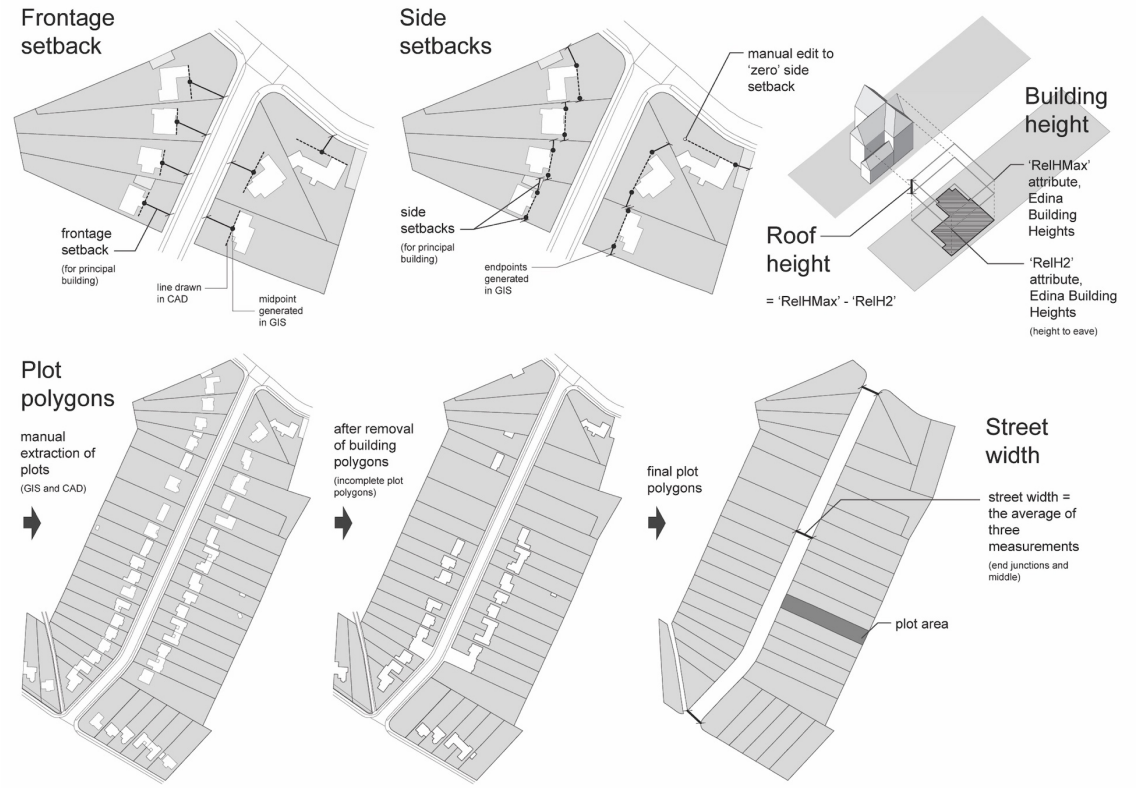


Figure 6. Radlett, Hertfordshire: showing plots and streets included in the study sample. Background map, Topography geospatial data courtesy of Ordnance Survey (GB). (Scale 1:15,000)

Task 3 – Form-based variables assessment (Principal Component Analysis)

For the PCA analysis we used *average* values per street for the seven form-based variables, i.e.:

- Average plot cover ratio
- Average frontage setback
- Average side setback
- Average frontage width
- Average building height
- Average street width
- Average roof height

Standardisation of data: The seven variables used in this study are not directly additive, because they have adopted different measurement units. Therefore, these variables have been converted into standard comparable units using equation (1).

$$x_{ij} = (X_{ij} - X_m)/\sigma \qquad (1)$$

$i = 1, 2 \ldots 7$ (Variable No.)

$j = 1, 2 \ldots 93$ (Street No.)

X_{ij} is the original value of the ith variable for the jth street, X_m is the mean, and σ is the standard deviation of the series formed by values of the ith variable for all 93 streets.

Construction of a correlation matrix: The first step in constructing the correlation matrix is to calculate the simple correlation coefficients of each corresponding pair of variables. Then for each column, the 'column-sum' of all coefficients is calculated. Finally, these seven obtained column-sums are added to calculate the grand column-sum (S). Table 1 shows the correlation matrix.

Table 1. Radlett, Hertfordshire: Correlation matrix.

	1	2	3	4	5	6	7
Average street width	1	-0.021	-0.167	-.271**	0.116	0.019	-.223*
Average plot cover ratio	-0.021	1	-0.193	-0.150	-.370**	-.426**	-.372**
Average roof height	-0.167	-0.193	1	.507**	.209*	0.016	.279**
Average building height	-.271**	-0.150	.507**	1	0.176	.245*	0.158
Average frontage width	0.116	-.370**	.209*	0.176	1	.464**	.358**
Average frontage setback	0.019	-.426**	0.016	.245*	.464**	1	0.060
Average side setback	-.223*	-.372**	.279**	0.158	.358**	0.060	1
Column sum of coefficients	0.947	0.636	0.656	1.184	1.291	1.095	1.218
Grand column sum (S)				7.028			

Calculation of weights: In this method weights are assigned in a way that they "maximise the sum of the squares of correlation" of the variables with composite index (Sharma, 2008, p. 90). Equation (2) is used to calculate the weight W1 (for variable x_1), and similarly for all weights $W_2 \ldots W_7$. The results of this part of analysis can be seen in Table 2.

$$W_1 = (\sum r_{xix1}) / \sqrt{S} \qquad (2)$$

Table 2. Radlett, Hertfordshire: Weights obtained from PCA.

Variables	Average street width	Average plot cover ratio	Average roof height	Average building height	Average frontage width	Average frontage setback	Average side setback
Weight	0.134	0.090	0.093	0.168	0.183	0.155	0.173

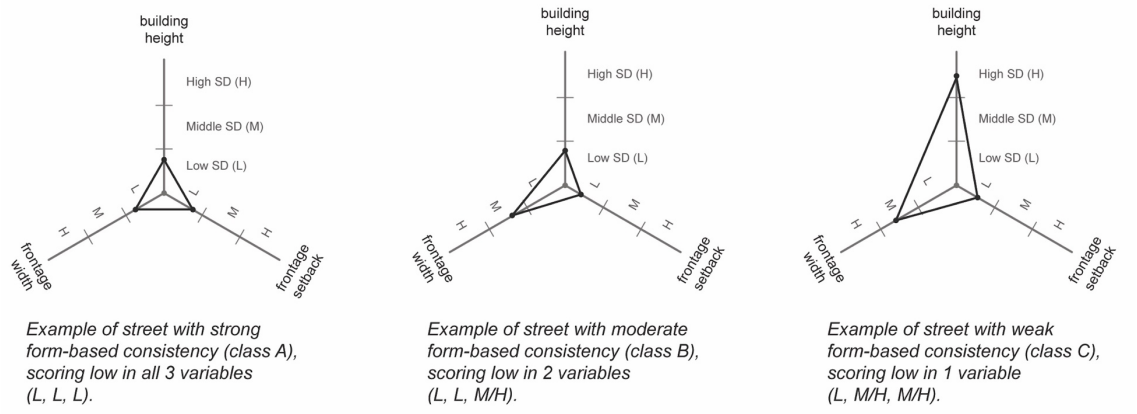
Task 4 – Street classification (Standard deviation ranking)

This step considered the four highest ranking form-based variables according to PCA weights. For the Steering Group, the average side setback (ranking second in PCA weight) was a variable of special interest which they wanted to strictly prescribe in the NPD Design Code for all future development. Therefore, the classification focused on the remaining three variables: frontage width, building height, and frontage setback. Streets were ranked based on standard deviation (SD) values for each variable (calculated in task 2), dividing the sample into three bands (low, medium, and high SD). Streets that ranked in the low SD band for all three form-based variables, are classified as morphological units of *strong form-based consistency* (class A, 16% of the sample); streets that ranked in the low SD band for two form-based variables are classified as morphological units of *average form-based consistency* (class B, 20% of the sample); and so on through class C (21%) where only one form-based variable was consistent within the street. Remaining streets (class D, 43 %) were defined as streets with diverse attributes. (Table A2 in the appendix.)

Results

The form-based classification resulted in the definition of a matrix for form-based rules, on a street-by-street basis (Figure 7). The matrix is proposed as a working framework for specifying combinations of FBCs resulting in various design control intensities. Based on the FBCA classification, design codes and policy recommendation for the Radlett NDP suggested scope for strict monitoring of change in streets which showed high consistency in relation to the identified form-based variables per class and street. Scope for flexibility in form-based rules for new development was encouraged in streets where the existing built setting did not have a consistent morphology. Figure 8 shows an example of how the street classification distinguishes street types within an area in Radlett. Figure 9 shows example 3D streetscapes and Google imagery of streets in Figure 8, for each category. The resulting classification, directly derived from statistical analysis of numerical variance, confirms what professional intuition can see and establish. The short-term practical usefulness of the method is evidenced in the mention of the FBCA in the Radlett NDP Design Code (Table A3 in the appendix).

Figure 7. The FBCA matrix: radial charts showing examples of street types with strong morphological consistency (class A), moderately strong (class B) and weak or diverse (class C).



Example of street with strong form-based consistency (class A), scoring low in all 3 variables (L, L, L).

Example of street with moderate form-based consistency (class B), scoring low in 2 variables (L, L, M/H).

Example of street with weak form-based consistency (class C), scoring low in 1 variable (L, M/H, M/H).

Figure 8. Plan view of Newberries area in Radlett, showing example street classification.

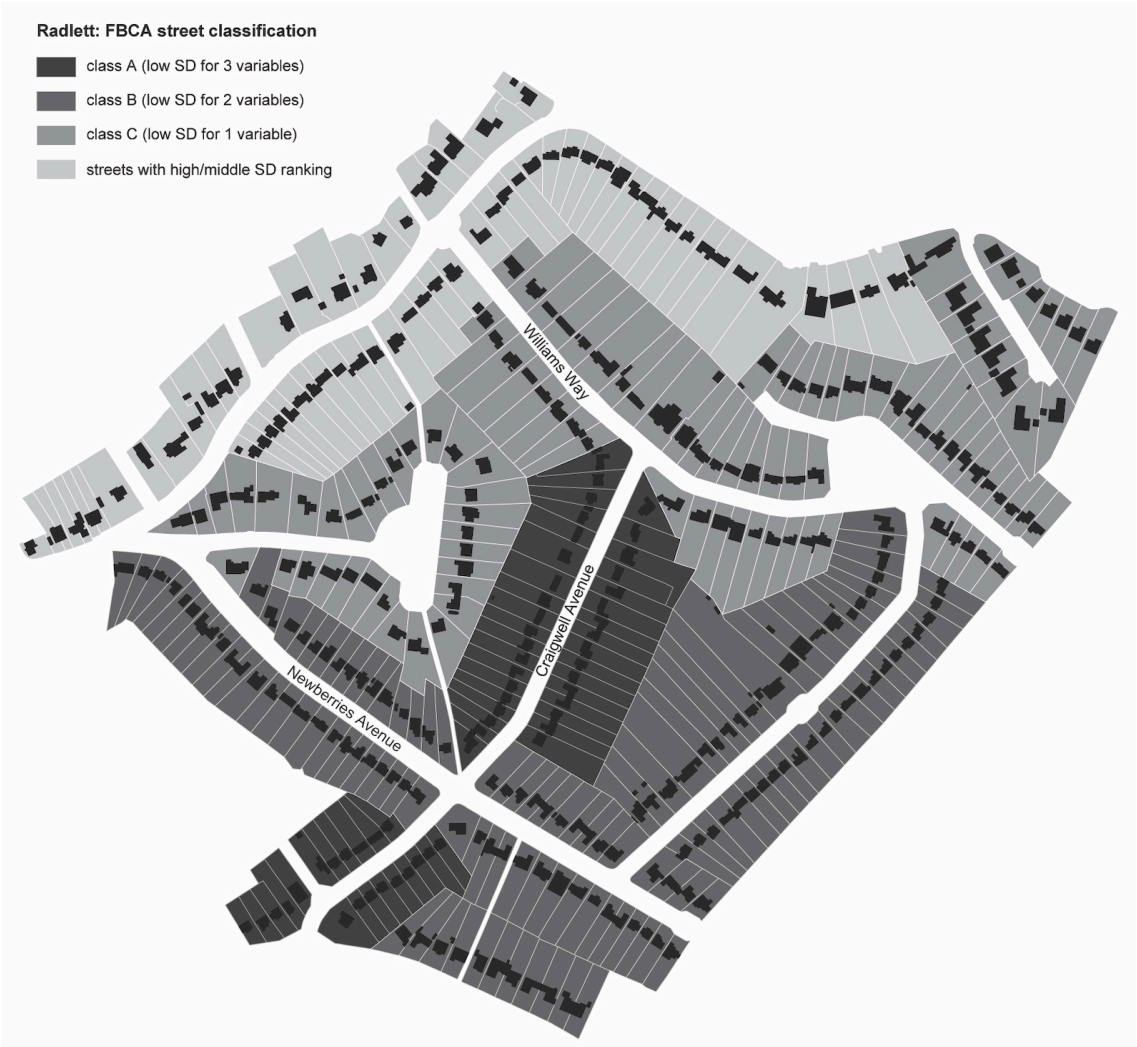
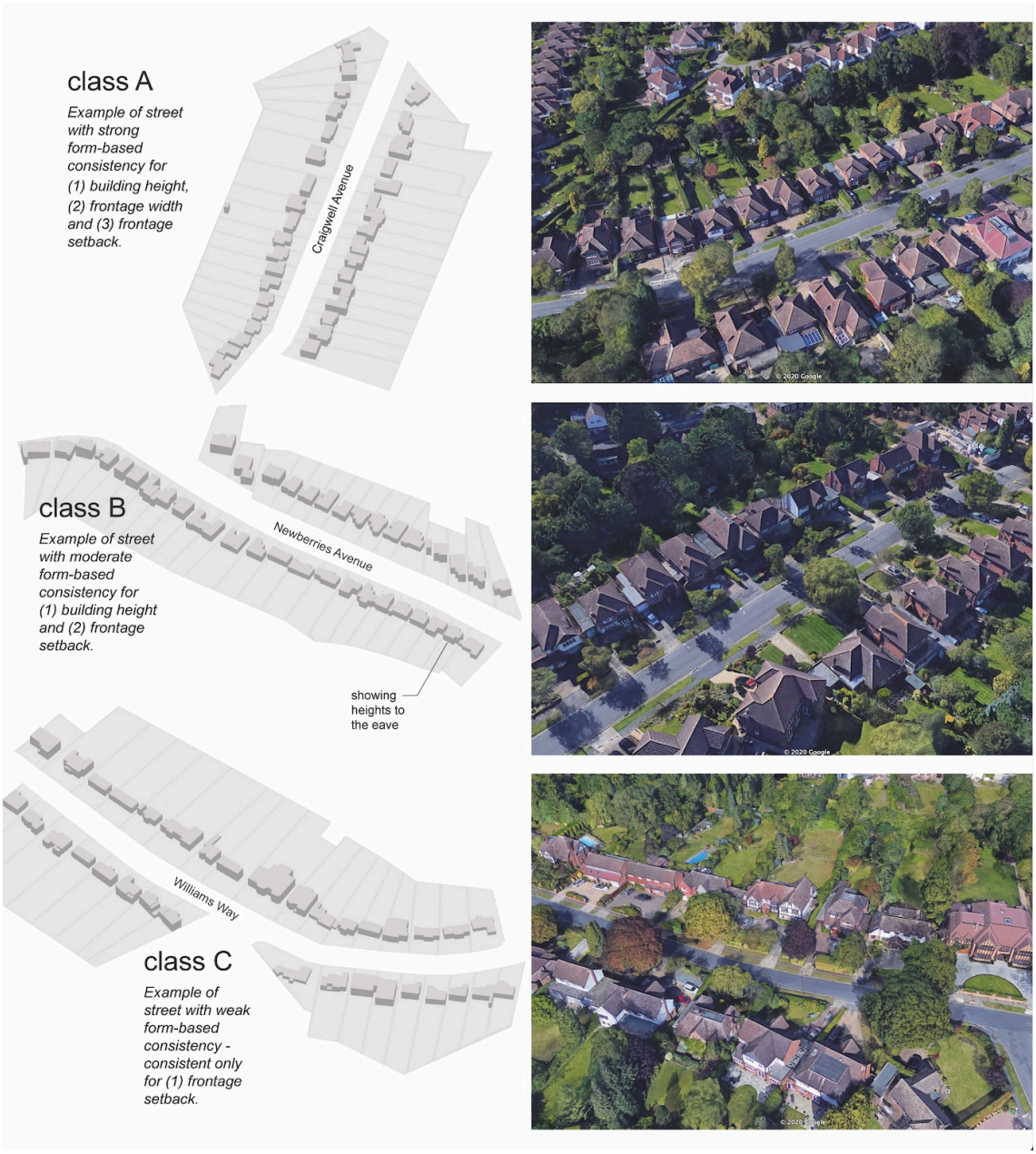


Figure 9. Example streetscapes: 3D representation of data and Google imagery.



Discussion

This study contributes to long-standing efforts to strengthen the uptake of morphological description in professional practice. The paper identifies a potential pathway for research-practice knowledge exchange within the remit of neighbourhood planning through the use of form-based character assessment (FBCA) as a contextual framework for FBCs. In response to the first research question, the testing of the FBCA method in Radlett suggests that there is scope for simplified and automated quantitative tools to inform practice. Benefits of the method include a place-based and stakeholder-

informed approach which results in a flexible form-based design guidance in neighbourhood planning. In response to the second research question, this section reflects on the research-practice exchange to additionally highlight a number of challenges that prevail beyond practical or methodological limitations. These include the interpretative act of linking the concept of neighbourhood character to a set of fixed form-based variables; and specifically, the implications of adopting simplified or abbreviated approaches in doing so.

First, the FBCA method considers the concept of physical character through the lens of form-based consistency while it seeks for flexibility within prescription. Therefore, it aligns with the notion of 'consonance' that seeks to achieve continuity in the urban fabric by interpreting an existing morphological language in new ways through design (Sanders and Baker 2016, 214). Nevertheless, physical character assessment which argues for consistency is also conceptually tied to the growing power of resident voices resisting neighbourhood change and is argued to prioritise a static version of 'existing' character for neighbourhoods (Dovey, Woodcock, and Wood 2009). This effect can be amplified when adopting a-historical approaches to the study of human settlements and urban landscapes (Scheer 2008). There are also limitations with using the typo-morphological approach which focuses on building arrangement, over the historico-geographical approach which considers both the natural and manmade landscape and thus strengthens ecological considerations. There is a risk here that professional practice then misses out on the more substantive contributions that the field of urban morphology can offer, especially with regards to the management of urban landscapes (Li and Gauthier 2014; Gu 2014).

Second, in the Radlett case study, we noticed hermeneutic junctures when considering the notion of form-based character and how it can be "created and reinterpreted through the planning process" (Davison, Dovey, and Woodcock 2012, 66). These junctures relate to decisions about the unit of analysis and support the observation that quantitative definition of typologies is scale-dependent (Schirmer and Axhausen 2015, 114). For example, the decision to measure morphological consistency within streets meant that physical character is defined regardless of the building type – i.e. terraced streets showing consistent form-based rules were classified as having 'strong character', but so did detached streets with similar degrees of form-based consistency.

Finally, the process of composing a neighbourhood plan increasingly involves public initiation, consultation and approval, and requires, in turn, formal planning

procedures that are accessible to lay audiences. Whilst technological advancements in digital mapping open the way for greater specialisation and integration of advanced digital tools into practice, these would require simplification and facilitation if they were to be broadly inclusive (Sieber 2006, 495). In the case of Radlett, the FBCA method helped to empower the residents' vision for the village by quantifying physical attributes of interest to them and in consultation with them. However, the process was conducted by experts and involved a level of trust and mutual understanding amongst the Steering Group and the researchers, but also a level of quantitative power which gives the experts an underlying advantage for driving decision-making. Whether abbreviated morphological studies, especially when achieved through quantitative-driven approaches, can enable a mutually beneficial integration of outcomes and process in neighbourhood planning in the way Talen (2019) describes it, is debatable. Still, if policy and strategic decision-making remains reliant on hard-based facts, quantitative tools in urban morphology can make a useful contribution in promoting management of neighbourhoods which is locally-informed through empirical evidence. The FBCA method confirms the 'communicative merit' of typo-morphology in enabling stakeholder participation in the planning process (Chen 2008, 131, 2010); yet, further research is required to deliver automated tools for morphological assessment that are participatory.

Conclusion

The form-based character assessment (FCBA) method provides a systematic approach to support neighbourhood planning with its common desire to protect character, alongside its need to adapt to change. It works at various levels – first, by focusing on form, the method allows for greater design freedom in terms of architectural standards, while considering local context (objective 1); second, by using simplified quantitative description it offers an abbreviated approach to typo-morphological study which reduces demand for time, expertise and labour resources (objective 2); and third, it is user-oriented by using the street as a unit of analysis and by considering stakeholder input and validation in the character assessment process (objective 3).

To encourage adoption in practice, the FBCA method outlines a quantitative typo-morphological approach and takes a useful step in the future development of automated spatial morphological analysis tools for planning and urban design practice.

It adds to precedent typo-morphological studies by focusing on a specific planning task: the assessment of physical character at the neighbourhood scale to define form-based rules and inform the specification of FBCs. The assessment process is abbreviated by adopting a quantitative approach over detailed historical study; the analytical process results in classification of plan units with administrative relevance (i.e. streets) when compared to typologies of blocks or street segments (e.g. Venerandi et al. 2016) which are more refined but can lead to more fragmented classifications. Furthermore, whilst still reliant on technical expertise, the FBCA method makes a contribution by articulating a clear role for stakeholders to be involved throughout the character assessment process.

Limitations and future research directions

This study has several limitations that, in turn, may represent potential directions for future research. The Radlett character assessment process involved a combination of GIS datasets from Ordnance Survey, desktop analysis and on-site survey. The use of secondary resources and the capability of GIS to generate spatial analytics enhanced the scope of the character assessment task significantly and allowed for a large area to be studied in detail. However, a considerable limitation is the time-consuming tasks of editing the datasets to achieve a high-resolution assessment. A useful next step would be to achieve advancements in automated morphological data extraction (e.g. Peeters and Etzion 2012) for relevant form-based variables (e.g. frontage widths and setback) in order to make the process resource-efficient, systematic (i.e. avoiding subjective decision-making in data processing) and more accessible to lay audiences. Relevant tools which have made progress in this direction are the Spacemate and Spacematrix systems (Berghauser Pont and Haupt 2005) and the City Induction model (Duarte et al. 2012) – yet these are primarily for GIS experts. The development of user-friendly capabilities for bottom-up GIS (BUGIS) (Talen 2000), to enable lay audiences to perform comprehensive morphological queries, remains a gap in provision.

Furthermore, the FBCA method is not intended to be a silver bullet for overcoming the multiple long-lasting challenges raised in the literature. Rather, it intends to contribute towards advancing the literature by proposing a more fine-grained and customised measure of physical character of neighbourhoods and to encourage uptake of typo-morphological tools into mainstream neighbourhood planning processes.

While we included a wide range of variables in measuring morphological features of neighbourhoods, the FBCA framework is not exhaustive. Future studies may seek to modify this framework or expand it with additional variables, contingent on the level of specificity or degree of design control when identifying morphological features of interest. The selection of variables in the FBCA method will depend on the nature of the investigation, the design objectives, and the desired degree of control for FBCs, or indeed the theoretical lens adopted in the study.

Similarly, the existing neighbourhood layout and street characteristics might require that measurements are aggregated separately for either side of the street. In Radlett, due to the average street width being 11 meters the analysis was applied both sides of the street together rather than the pertinent strip, for example. For wider streets or streets with very distinct form on either side it might be appropriate to analyse the plot series on either side separately.

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Table A1. Key examples in literature of suggested characteristics regulated by FBCs.

Author	**Form-based variables**
Parolek, Parolek, & Crawford (2008, 12), example by Grass Valley Development Code	• Building placement - Build-to-Line (Distance from Property Line) - Setback (side, rear) • Building form - Primary street/side street/corner lot built to BTL - Lot width - Lot depth • Building use - Ground floor, upper floor(s) • Building height - Minimum/maximum (principal/ancillary) - Ground floor, upper floors ceiling heights
Talen (2009, 145) – example by Duany & Wright	• Building function • Building configuration (building height and massing) • Lot occupation • Building Disposition • Setbacks – Principal Building • Setbacks – Outbuilding • Private frontages • Parking placement
Walters & Read (2014, 31-33)	• Street design and classification • Building height (principal/accessory) • Lot coverage (principal and accessory) • Building setbacks (principal/ accessory) • Frontage buildout (principal) • Building types and façade transparency

Table A2. Radlett, Hertfordshire: FBCA classification for morphological consistency for design features of significance per street. Showing a sample of streets with *strong morphological consistency* (class A), *moderately strong* (class B) and *weak* or *diverse* (class C).

Street-scale character, Radlett									
Street Name	**Design feature of significance**			**Street classification**		**Street Name**	**Design feature of significance**			Street classification
	Building height	**Façade width**	**Façade setback**				**Building height**	**Façade width**	**Façade setback**	
Abbey View		x		Class C		Church Close	x	x		Class B
Aldenham Road	x	x	x	Class A		Cragg Avenue	x	x	x	Class A
Athlone Close	x		x	Class B		Craig Mount			x	Class C
Barn Close	x	x		Class B		Craigweil Avenue	x	x	x	Class A
Battlers Green Drive		x	x	Class B		Dellfield Close	x		x	Class B
Beaumont Gate	x	x	x	Class A		Elm Walk	x	x	x	Class A
Beech Avenue			x	Class C		Faggots Close		x		Class C
Brook Drive	x		x	Class B		Folly Close		x		Class C
Canons Close	x			Class C		Gills Hill			x	Class C
Cary Walk		x		Class C		Gills Hill Lane	x		x	Class B

Table A3. From research to practice – short-term impact: Consideration of FBCA results and form-based design guidance in the Submission Plan (Regulation 16) and the adopted policy documentation for the Radlett NDP.

Radlett Plan, adopted policy			**Radlett Character Assessment (RCA) Report: Form-based assessment**		
Prefix	**Title**	**Policy theme**	**References to RCA Report in Submission Plan**	**RCA guidance**	**Supporting evidence**
HD					
HD1	Increasing Housing Choices	Housing demand and protection and enhancement of the verdant character of Radlett	"To meet new housing demand in a manner that is sensitive to the character of the village, guided by site-specific context analysis and the Radlett Character Assessment 2016 (Objective 2)"	General urban form and layout characteristics for residential plots	Tasks 1-3
HD3	Respecting and Enhancing Local Townscape and Landscape Character and Patterns	Townscape and landscape character and patterns	"Specifically, planning applications which impact on local townscape and landscape character should demonstrate how they respect and enhance this character in the vicinity of the site having regard to the Radlett Character Assessment that relates to the non-Green Belt, built area of Radlett as at 1.1.2019."	Streetscape morphology	Tasks 2-4
HD4	Development of Garden Land	Townscape and landscape character and patterns	"Garden land development will only be supported on existing residential sites where: a. the plot sizes respect the prevailing development on the site and in close vicinity of the site; b. the designs avoid shared-access tandem layouts to the front or rear, where possible; c. the designs respect the surrounding homes in terms of height, mass and bulk."	Plot outline and arrangement	Tasks 2-4
HD5	The Radlett Design Code	Townscape and landscape character and patterns	"This Design Code, informed by the Radlett Character Assessment, applies to all residential demolition/rebuilds, extensions and alterations to residential dwellings in the Radlett Neighbourhood Plan Area except in Conservation Areas and Green Belt sites as at 1st January 2019. Development proposals which respect the Design Code will be supported."	Streetscape morphology	Tasks 2-4