Mapping Socio-Spatial Relations in the Urban Built Environment through Time: Describing the Socio-spatial Significance of Inhabiting Urban Form

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Abstract This chapter introduces Boundary Line Type (BLT) mapping, a vector GIS based cross-culturally and diachronically comparative method, used for mapping the socio-spatial significance of urban built environments. This new research method is related to other methods currently used to study contemporary as well as historical urban built environments such as urban morphology, space syntax, and GIS based approaches. BLT mapping uses GIS technology in order to apply an ontology of formal boundary conceptualisations expressing the constitutive differences among the materially constructed subdivisions which shape built environments and are inhabited by urban society. This ontology resulted from a firm socio-spatial theoretical grounding (Vis 2013a, 2013b, forthcoming) and is here operationalised on the basis of contemporary, historical, historically reconstructed, and archaeological ground-level city plans of the historic city of Winchester (UK) and Chunchucmil (Classic Maya, Mexico). The research processes of data preparation and the analytical mapping of BLTs by identifying them in empirical data contexts are presented. This alerts the prospective user to the challenges and practical measures involved in using spatial datasets of different origin. The interpretive opportunities of the resultant formal redescription of the urban landscape and the potential of the BLT data structure for both advanced spatial analysis and visualisation is explained. Facilitating this interpretive and analytical mapping practice is expected to stimulate future research to systematically explore society-space relations as manifest and developing in cities over time and in socio-culturally contrasting urban traditions. Devising and conducting this methodology advances the qualitative GIS research agenda for the spatial humanities and social sciences by marrying theoretically informed ideational concepts to quantifiable empirical units of information.

Introduction

Recent years have seen a distinct rise in the use of Geographical Information Systems (GIS) for the historical study of cities. The urban branch of the broader emerging practice of historical GIS, is taking advantage of the flexibility in data collation and integration offered by a digital database based environment over draughting plans on paper (Lilley, Mapping Medieval Chester). Despite GIS's geostatistical and geoanalytical underpinnings, historical GIS is aimed foremost at locating historical sources, data and events on a map to visualise them in spatial distributions, which may help to explain historical processes and relations (see Gregory and Ell 2007).

Urban examples of such digital mapping practices show a similar preference for locating the past on historical plans, often in relation to the current city plan (e.g. Frank 2013; Locating London's Past; Paris Cityscape on MapApp; Tokyo Cityscape on MapApp; Jensen and Keyes 2003). Many projects are not primarily concerned with creating a reconstruction of the urban environment that is as accurate and historically sensitive as possible. *Mapping Medieval Chester* (Faulkner), *Mapping Medieval Townscapes* (Lilley, Lloyd and Trick 2005), *Pompeii Bibliography and Mapping Project* (Poehler), *Alpage* (Noizet and Costa; Noizet and Grosso 2011) and a GIS for medieval Antwerp (Bisschops 2012) are excellent examples of the meticulously detailed reconstructed plans that can be achieved using digital tools. These open up promising future directions for social and spatial research based on such data. Inspired by the possibilities enabled by historically regressive sequence mapping of cities, this paper aims not to present another example of this particular practice, but to introduce a new mapping method which exploits the best level of historically or archaeologically reconstructed spatial data that could be achieved for the comparative socio-spatial study of the physical characteristics of the built environment through time.

As demonstrated by historical GIS efforts, historians, akin to human geographers (see Jones et al. 2009), usually map to spatially visualise what happened where and investigate resultant locational relations. Instead, in social scientific archaeology or historical geography one might want to ask: *how* was it where something happened? This addresses the pertinence of revealing the affective qualities and affording particulars that characterise the location and spatial situation in which something occurred, next to questions that just determine where something occurred. Fletcher (2004) expressed a similar concern from the perspective of materiality in space, wanting to ask what it is the material does to create what actually happened in collision with social action. Both questions are part of studying the relationships between society and space, which according to Griffiths (2013) is one of the main reasons for historical science to engage with the geographical practice and theory of GIS. Furthermore, Griffiths (2013: 154) argues, history's foci on the study of maps as cultural objects and historical space as representation have "created something of an epistemological blind spot for historians wishing to access and substantively describe 'spaces of practice' produced by everyday activity." The material implications of the proposed line of questioning, cf. the discipline of archaeology, would thus prepare the historical fields for uncovering the entanglement of living in the material spatial world over the long term. Such endeavour would contribute to answering Lilley's (2011b) alarm over historical geography's neglect of the Middle Ages and Jones' (2004) stressing of the benefits of extending human geography's temporal frame of reference beyond the recent past.

This perspective would enable one to explore and better understand how the experiential and affording[1] structure of an urban built environment developed as a social reality and what the compositional properties were in which this structure was originally encountered. Effectuating such research requires a general conceptualisation of the socio-spatial significance with regard to inhabiting and developing the built environment, incorporated in the basic physical characteristics composing urban landscapes. In other words, a conceptualisation making explicit the spatial and material features affording urban life and development to take place in a time-space specific way in each city. Formulating the theory and conceptualisation necessitated by this objective has been the subject of earlier research (Vis 2013a, 2013b, forthcoming).

Founded on an interdisciplinary body of thought on physical affordance and social experience Vis (2013a) establishes that the boundaries by which the physically constructed composition of the built environment emerges would merit a further formal ontology. Vis (2013b) discusses how a theoretical conceptualisation of encountering, physically transforming, and inhabiting a built-up social and spatial world as a constitutive process in combination with a rigorous conceptualisation of the empirical information conveyed in configurative spatial layout data on the built environment can lead to an ontology of boundary types. These so-called boundary line types (BLT) (Table 1) are based on an abstract intellectual understanding of the differentiation between subdivisions and by their very definition simultaneously ensure their empirical identification in each specific urban situation. Vis (forthcoming) finalises and illustrates the formal definitions of these BLTs in expectation of a wider application and operationalisation in comparative urban built environment mapping processes. Within this appropriately themed volume, this chapter contextualises the method and discusses how to put BLT mapping into practice on the basis of archaeologically and historically acquired plans of urban built environments. The spatial data resulting from this practice enables a visual redescription of urban built environments on the basis of a rudimentary understanding of the socio-spatially affording characteristics of its physical presence, while the data structure is suitable for an array of spatial analyses in the future. This chapter will discuss how these methodological processes operate, but will not present the full analyses of any case study.

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[1] Affordance is a concept derived from the work of psychologist James J. Gibson (1979) on perception, which entails the quality of things and the environment which allows individuals all possibilities to act upon them. Here affordance is used in conjunction with the affective qualities of the experience of encountering things and/or the environment.

As mentioned previously, BLT mapping is intended to work as a comparative method and therefore should be applicable to the full breadth of urban built environments that societies have produced in the past and present. This is not to say that any comparison is inherently useful, nor does it preclude the possibility of even the most random comparison leading to a more profound understanding of inhabiting a specific built environment. Simultaneously, as the product of a high level social theoretical treatise, despite directly informing the empirical reality of urban data (cf. Smith 2011a), the understanding generated will be limited by an essentially human level of generalisation tied to its constitutive perspective on emplaced social and environmental interaction (Vis 2013a, 2013b). The BLTs "operate firstly as distance setting, creating a personal territory; secondly choosing activities and project participation, negotiating the abilities and constraints; and thirdly the adherence to context, depending on the constitution and perception of (aggregate) entities. These spheres of significance intrinsically combine the social and spatial." (Vis 2013a: 26) The BLT concepts are a critically realist outcome of iterative abstraction (see Sayer 1981, 2000; Yeung 1997; Wallace 2011), which acts as a fundamentally human and social 'underlabourer' (cf. Pratt 1995) to undertake more detailed socio-cultural and historical investigations into the contexts of the inhabited built environment. Mapping BLTs therefore amounts to mapping the socio-spatial relations immediately afforded by and encountered as occurring in the physicality of the built environment: this process emphasises degrees of spatial dependence rather than detached spatially independent social activities (see Sayer 2000).

Predominantly, this chapter will make explicit the socio-spatially analytical mapping method in historical context arising from these thoughts, which retains the researcher in charge over the digital technology used (cf. Griffiths 2013). Therefore much space will be dedicated to the way the source data is prepared and the interpretive decisions made that allow the spatial data captured in GIS to preserve immediate access to the largely intellectually and empathically qualitative theory, which enables their individual identification. In doing so, GIS initially becomes an exploratory tool in which formally fixed conceptual data informs further insights into and precise contextualisations of the socio-spatial significance of inhabited built environments instead of a technological 'black box' (cf. Griffiths 2013; Lilley 2012).

Context of the method

From the vantage point of comparative methods, it no longer matters that the settled world has known wildly differently shaped urban landscapes. Consequently, within this paper the mapping of BLTs will be discussed in relation to two very distinct test cases. These test cases, Chunchucmil (Classic Maya lowland, Yucatan, Mexico) and Winchester (1550-present, UK), have been selected on the basis of the basic quality of the data available and their arbitrarily contrasting general configurative characteristics. The Maya culture area is known to have been the home to a low-density (tropical) agrarian urban tradition (see Isendahl and Smith 2013; Fletcher 2009; Graham 1999), while Winchester is a typical historical English (and western European) example of a densely settled urban landscape based on a persistent medieval pattern with Iron Age and Roman antecedents (see Conzen 1960). High-density urban settlements have become the default of the globalised western city, but low-density urbanism was until recently (pre-European, 19th century) also a tradition widely found in Africa (Smith 2011b).

The method of mapping boundary line types does not stand isolated in its efforts to capture social and spatial, or historical and spatial, information on the basis of built environment layout ground plans.

Urban morphology and town-plan analysis

Town plan analysis took a firm hold in geographical practice on account of Conzenian urban morphology (Moudon 1997; Whitehand 2007). Its combination of streets, plots, uses and fabrics, was grounded specifically in spatial and historical rather than immediately social interests. Town plan analysis aimed to reveal the building history of the shape of a town based on historically and spatially coherent plan units, which are somewhat subjectively identified by the researcher (see Conzen 1960, 1968, 1981; Whitehand 1981; Lilley 2000; Conzen 2004). It thrives on large bodies of social and economic historical sources and a degree of intuition, which are an intrinsic part of the spatial presentation of the research outcomes in its resultant urban mappings. It structurally connects historical context to the processes that shape urban space to create a townscape created out of the town's plan, building fabric and land utility. The town plan in turn is composed of three elements: the street pattern, the plot and aggregate blocks, and the buildings and their block plans (Conzen 1968). Yet, ultimately the analytical unit of urban morphology, the plan unit, is a relatively coarse spatial reference, which cannot reconstruct a town's precursory phases in great detail.

Not all historically conjectural or regressive sequence mappings of urban plans result from urban morphology, but the research practices which Conzenian urban morphology sprang from (see Lilley 2000), seem to have paved the way for the more general acceptance of recent historical practice. The work of Keene (1985) on medieval Winchester, drawn upon in this chapter, Keene and Harding (1987), Dean (2012a, 2012b), and Bisschops (2012), amongst others, demonstrates degrees of similarity with urban morphological regressive mapping practice, as most specifically morphologically practiced by Lilley (2000, 2011a) and Lilley, Lloyd and Trick (2007). As Bisschops (2012) points out, his practice uses both historically intensive regressive mapping and the 'cross-section method' inspired by Keene (1985). This approach allows series of properties to be mapped with reasonable accuracy, while anchoring incidental properties or buildings within each sequence of properties (cf. the notion of plot series, Conzen 1960).

The aim in this type of work tends not to be the historical explanation of the origins of the formation of the urban form and building fabric of the town as in traditional urban morphology, but to reconstruct the town plan for a specified moment or period in the past. This is then used to geographically locate and position (social) historical sources to the spatial shapes and references created, now greatly aided by the data management technology within GIS. Urban morphology, in part, may help create a skeletal plan for earlier phases of a city often on the basis of the first accurate urban plans from the 19th century. More advanced, intensive historical and archaeological methods (Lilley 2011a; Bisschops 2012; Dean 2012a, 2012b) of working backwards, processes of careful cartographic reconstruction, are needed to approach approximately complete and reasonably accurate snapshots representing the historical town. This practice has only been developed within western European contexts. In that area the reconstructed plans resultant from regressive sequence mapping of urban layouts form a methodological prerequisite for the analytical socio-spatial mapping method presented here, especially where ongoing cities inhibit large extents of archaeological mapping.

Space syntax

Perhaps the best known analytical approach to ground plan configurations is the family of theory and tools going under the header of 'space syntax' (Hillier and Hanson 1984; Hillier 2007; Bafna 2003), which is increasingly claiming its place in archaeology (Thaler 2005; Van Nes in prep.; Morton et al. 2012a, 2012b, this volume; Fisher 2009; Stöger 2011; Paliou and Knight 2010). There are several important similarities between the methodology presented here and urban space syntax, which are not purely coincidental or to be ascribed to using a significantly concurrent dataset. Both emphasise topological information and both seek a social understanding of certain structural properties of the built environment's configuration. However, space syntax privileges the open spaces left within the built-up morphology, which logically leads to movement across space as the most successful area of space syntactic research: navigational (pedestrian) movement in particular (Bafna 2003; Morton et al. 2012b, this volume; Craane 2009).

Space syntax tools, on an urban level[2], calculate probabilistically or rule based spatial patterns across its 'open' space, afforded by the configuration. It is this space syntactic pattern, an abstraction derived from a simplification into convex spaces rather than the original empirical reality of the shape of the configuration that is analysed to produce an array of values (see Batty and Rana 2004). Space syntax in general is often strongly linked with arguments in spatial cognition (see

[2] Space syntax incorporates a family of analyses, which also includes a strong branch in interior spaces, based on graph analysis (Hillier and Hanson 1984). Incidentally, in archaeology syntactic analyses of interior space are arguably yet more wide-spread than urban analyses (see Fisher 2009).

Bafna 2003) and omits a clear incorporation of phenomenological or individually experiential aspects of built environment configurations (see Griffiths and Quick 2005), except for the development of space syntactic viewsheds (isovists) (see Franz and Wiener 2008). Moreover, the theoretical underpinnings of space syntax do not intrinsically include a historical or constitutive grounding. These are important reasons for Griffiths (2005, 2011), to urge a careful and critical use of space syntax only in historical research.

It is worth bearing in mind that space syntax was born out of attempts to understand "the influence of architectural design on the existing social problems in many housing estates that were being built in the UK" (Pinho & Oliveira 2009: 110) and therefore to better inform urban design practice (Hillier and Hanson 1984). In general space syntactic analysis comments on the probability of the built environment configuration affording lively or less lively streets, which is often connected to economic viability (e.g. Chiaradia et al. 2008; Narvaez, Penn and Griffiths 2012; Griffiths et al. 2010; Valente 2012). The probability of liveliness is associated with the cognitive readability or intelligibility of space for way-finding argued to be tied to global and local integration measures (Van Nes in prep.). The separate sides of the street in some analyses have an abstract presence restored through the measures of the 'constitutedness' of streets, expressing the quantification of buildings opening out onto the street (e.g. Van Nes and Lopez 2007; Palaiologou and Vaughan 2012). The prevalence of the street as a clearly defined space is also found in urban morphology and in both cases limits the potential comparative application of the methods. Maya cities, for example, are known to have few clear streets (Magnoni, Hutson and Dahlin 2012), while there exists much open space that is organised differently.

As will be demonstrated, the BLT mapping presented here, adheres to the original physical morphology of the configuration, maintaining much of the material spatial information. It is based on constitutive theory and is directly experiential in its use of Gibsonian affordance (Vis 2013a; Vis 2009; see Gibson 1979) rather than using it for cognitive assertions. It seeks to elicit the features that afford opportunities for further socio-spatial development and use through time by inhabiting it. BLT mapping socio-spatially conditions and contextualises the encounters or actions that could take place within each emergent location. Although the boundary method necessarily is inclusive of interconnectivity and affordance of movement across the built environment, it does not make any probabilistic claims about that movement itself. Instead, the potential for movement or any other use becomes qualitatively characterised and its socio-spatial position within the configuration contextualised in formal socio-spatial descriptions of each space. This may narrow down likely functions within space (various actions are possible in the same space, cf. Sayer's (2000) spatial independence), but does not express the probability of something occurring within a specific space. After all, BLT mapping is limited to the conduciveness of the physical characteristics of the distinctions making up the built environment and not, like space syntax, to a pattern of its linked open spaces.

Historical objects of urban fabric

A final methodological development of relevance here is championed by Lefebvre and others (Lefebvre, Rodier and Saligny 2008; Lefebvre 2009; Rodier et al. 2009; Lefebvre 2012). They have been building a conceptual ordering of the urban fabric that emphasises temporal dynamics and function (the underlying theoretical model goes under the name: OH_FET) for storing and analysing urban archaeological information. This practice is based on a conceptual model hierarchically composed of simple and (aggregate) complex objects elucidating the intricate formation and use of architectural complexes in an urban setting (Lefebvre, Rodier and Saligny 2008; Lefebvre 2012). It focuses on eliciting the historical rhythms of built space in development. Following Galinié, Rodier and Saligny (2004), the method is based on accepting the assertion that any understanding of the dynamics of urban fabric over time necessitates the conceptualisation of a constituent object of the urban fabric which compiles all knowledge about its transformations. This gives rise to the 'historical object' an initial interpretation meeting three fundamental criteria: 1) location and surface area (where is it?); 2) date, duration and chronology (when did it exist?); 3) function, social use, or an interpretation (what is it?) (Lefebvre, Rodier and Saligny 2008; Lefebvre 2009; Rodier et al. 2009). Lefebvre (2009) explains that any modification of these three criteria causes the disappearance and creation of a new historical object or interpretation. Theoretically this is a logical consequence of the aggregate complexity of historical objects. It should be noted that this endeavour includes more information sets than the socio-spatial significance pursued by BLT mapping, together with the ultimate goal of understanding the dynamics of urban formation. To that end, detailed temporal information is the driving force for generating analytical spatial units, while it remains unclear what the meaning of these features is.

Lynch (1981) insightfully remarked that many building notions conflate the space it represents with the type of use associated with it (e.g. a church). Inevitably, the social use types found in Lefebvre (2009) and Rodier et al. (2009) are largely examples of such notions. They combine established cultural interpretations, which exist only in relation to specific cases and could additionally be dependent on historical periods. This will often preclude broad comparative application. Another problem is the desire to treat temporal intricacy on a similar level as spatial complexity, as this would require equal information across the whole urban space for each unique moment of (spatial or functional) transformation. This introduces a laudable pursuit of a research aim privileging temporal dynamics over the more conventional time-slice or snapshot approach. Yet, this concern runs the risk of overlooking that equal historical information is required across the whole of the research area at each separate instance of change within it, which is rarely the case and thus introduces conceptual anachronisms or conceals inevitable extrapolations. In contrast, time-slices are necessarily coarser and more conjectural, but in their atomic assumption[3] of the (historical or reconstructed) urban plan (see Vis 2013b), they are better suited for spatial analysis. The discrepancy between methods is caused by disaggregating complex historical objects into more temporally specific features. Logically such an approach is naturally better suited for intensive studies of smaller urban areas, as demonstrated by Lefebvre (2012).

The boundary method, however, does not emphasise temporality, but rather the social reality of physical space at certain moments. Due to the method's comparative aims, categorising particular functions or uses of space is refrained from. As reconstructed time-slice plans in the historical dimension are accepted, it does not fully depend on equal historical information. Instead, a moment is chosen for which the best consistent information is available or for which conjectures are justifiable across the area as a whole (cf. Lilley, *Mapping Medieval Chester*). The BLTs focus on the spatial embeddedness of occupying (thus using) spaces within the built environment at any such moment. In contrast to Lefebvre and consorts, with this approach, temporal details are lost. BLT mapping thus privileges the general social dynamics of physical space over those of time, although its theoretical basis ensures a historically constitutive understanding of the conditions of living in the built environment. The aims of urban morphological approaches, space syntax and OH_FET adaptations all differ quite specifically, while maintaining some degrees of similar reasoning and practical compatibility with the boundary method as outlines in this paper.

Mapping boundary line types (BLTs)

Mapping BLTs is an analytical and interpretive process, which requires high quality source material. As mentioned before, within this paper the process will be demonstrated by using two test cases: Chunchucmil and Winchester. Not only are the cities themselves enormously different, the source material available also represents two distinct disciplinary products. The test case in Chunchucmil relies fully on archaeological material from over a decade of intensive surface surveying on site (Hutson et al. 2008), while the Winchester test case relies on material meticulously compiled and integrated from extensive medieval historical and cartographical research (from here: 1550s) (Keene 1985), the first edition large 1:500 scale, OS survey city plan of 1872 (from here: OS 1872), and the current large scale OS MasterMap (from here: MM). Their selection thus serves the double purpose of explaining the variants of the BLT mapping practice depending on historical and archaeological source material, while at the same time explicating the comparative potential of the method.

[3] Assuming a time-slice is atomic explicates its momentary indivisible nature as a whole. A time-slice is an abstract entirety which is immediate and inseparable: no time passes, everything occurs at once.

All maps are necessarily selective representations of spatial information and never an incontestable truth (Wood 1992; Monmonier 1996; MacEachren 2004; Lilley 2011a, 2012; Gauthiez and Zeller this volume, Beisaw 2013). In the method at hand GIS software is used to create the spatial data (maps) appropriate for the current purpose (city ground-level outline base plans). The base plans upon which BLT mapping can be applied are interpretively derived from original mapping sources. Chunchucmil's source material concerns an archaeological plan, prepared in Adobe Illustrator software. Following archaeological practice, this depicts all that was observed and identified as archaeological features. Winchester's source material concerns a historically reconstructed and conjectured plan of the property boundaries in the 1550s, a scan of the historical sheets of OS 1872, and MM: the current Ordnance Survey large scale standard. The purposeful character of each of these maps is distinct, according to the differing aims, selections and technologies of the mapmakers. They need to be especially prepared not only to be imported into a GIS environment (here: ESRI ArcGIS), but to establish an equal and comparative foundation of the selected spatial data (see Vis 2013b).

The idea of a (ground-level) base plan as an initial stage of practice features in various kinds of urban analysis. Urban morphologists would prepare a base plan on the basis of a good quality 19th century map (see Conzen 1960; Lilley 2000), and in space syntax the base plan drawing typically separates open (street) space from blocks of buildings (Hillier and Hanson 1984; Van Nes in prep.). For BLT mapping the base plan follows from an interpretive process of decision making on the nature of the physical distinctions of the constructed subdivisions that shape the built environment's composition (Vis forthcoming). The subdivisions are only represented by their outlines (i.e. their empirically recognisable boundaries) and not by the internal and functional designs of the emergent areas (Vis 2013b, forthcoming). Inevitably, this process in part relies on professional judgments on what to include and what to exclude, as elaborated in the examples below.

This is the first time BLT mapping of the urban built environment has been put into practice. What is reported on is a digital adaptation of the process. However, during the initial trials of the mapping process it was first tested with pens and semi-transparent paper (i.e. manual GIS layers), to see if and how the source material would be suitable for this work. The presented method is aimed primarily at what are known as 'legacy datasets': basically extant maps and spatial data produced in earlier projects and/or for other purposes. Being able to work with legacy data greatly increases the wide application and flexibility of this method. Yet, one is also confronted with issues concerning the nature of the spatial data that may not be immediately appropriate for all aspects of this method.

The workflow could be summarised in the following steps, further discussed below:

1. Acquiring or assembling and converting the source material (typically legacy spatial data and/or maps);

2. Creating equivalent spatial information by mapping (tracing) the outlines of main features contained in the source material;
3. Case specific conjecturing to resolve data gaps and revising the resultant outline base plan;
4. Remapping the base plan by identifying the BLTs.

Chunchucmil site plan

The archaeological plan of Chunchucmil was originally acquired in digital format from Scott Hutson, University of Kentucky, who directed and completed the mapping project on Chunchucmil over the past few years, taking over from Bruce Dahlin. Frequent contact with Scott was invaluable to using the still unpublished map (Hutson, Magnoni, Dahlin in prep.), which necessarily depicts archaeological interpretations of the features mapped, and gets to grips with the empirical situation encountered on-site which the map does not convey. Hutson et al. (2008) demonstrate that dateable artefact assemblages show a relatively equal period occupation across the full surface of the site (5^{th}-6^{th} century, Classic). There is a central barricaded portion that indicates Terminal Classic and later reuse of the monumental core (Dahlin 2000), with little activity elsewhere. Therefore, knowledge about the palimpsests and possible anachronisms of the remains observed is limited. Where a mapped feature is cut by another, thus making the former largely obsolete, here only the latter is taken into account. The resultant reading of the site's plan should be seen as a rough approximation of a final stage of maximum occupation throughout the site.

Chunchucmil's plan is prepared as an 'ai' (Adobe Illustrator) extension, which is dedicated to adaptable graphic presentation rather than (geospatial) data storage. Unfortunately, this file format cannot be directly imported in ArcGIS. A laborious conversion process for rescuing legacy Illustrator data, set out in Wunderlich and Hatcher (2009), was roughly followed. This involves, amongst other steps, manually separating out layers of disparate digital information (e.g. lines and text) and automatically densifying the distribution of anchor points (vertices) along lines to preserve software generated shapes. The route to ArcGIS proprietary shape file ('.shp') format then requires AutoCAD file formats (a hereditary '.dxf' exchange format (2000/LT2000) was used, which proved more stable than newer versions). Though this format should suffice for direct import into ArcGIS or freeware programmes like QGIS, such conversions produced compromising results. It was found that MapInfo's Universal Translator tools get reliable results (first to proprietary '.tab', then from '.tab' to '.shp'), which lead to directly usable shape files. Both a raster image — for visual clarity aiding the reading of the new vector data, especially needed since Illustrator annotations did not make it through the conversion successfully — and the shape files of the original plan were imported as GIS layers.

In order to inspect the converted data quality visually, the shape files and raster image ('.tiff') need to be geographically related to each other. This is achieved by projecting and georeferencing the data. Although several GPS points were taken across Chunchucmil (Hutson, personal communication), the inherent error margins associated with such points, would result in unequal placement and georectification between the data layers. Therefore only the site's centre GPS point was used. This point forms the centre of a derived 250x250m grid over the core of the site, for which the coordinates can be calculated. When separating the layers in Illustrator, this grid was transferred into each layer. In doing so, the raster image could be precisely georeferenced according to the on-site grid system. Subsequently, the calculated coordinates allowed exact spatial adjustment (placement) of each vector data layer on top of the image. Then it is possible to inspect visually, per individual detail, whether the conversion is complete and if not, to reveal any missing data.

Chunchucmil base plan

From now on the work becomes dedicated to selecting the basic spatial data that is conceptually required for the BLTs to be identified in the next stage. The theoretical conceptualisation of filled space and the inhabited built environment (Vis 2013a, 2013b) necessitates a reduction of information to the physically binding built boundaries, which also function as empirical counterparts to conceptual 'sites of difference' (cf. Abbott 1995). These physical distinctions separate spaces into discrete subdivisions (see Vis 2013b for the underlying progressive processing of spatial-physical information). Since the Chunchucmil plan now exists as vector data, the process of creating a base plan of outline features is predominantly limited to using the 'tracing' function in ArcGIS editor. In addition, regular editing tools were used for conjecturing any apparent gaps in information (see below).

Tracing the lines interpreted to be outlines revealed some issues with the data structure and topological integrity, most probably resulting from the initial drawing of the map in Illustrator.

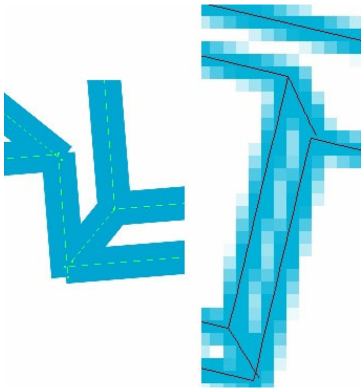

Fig. 1. Illustrator data (left) and converted ArcGIS shape files on top of raster image (right). (Image appears courtesy of the Pakbeh Regional Economy Program with help from S. Hutson.)

Visually presentable figures would in minute detail reveal line constructions that were unsnapped or simply did not match the features contiguous geometry (Fig. 1). Tracing requires continuous lines. Despite these errors usually measuring no more than a few centimetres or even millimetres in real space, literal copying of the data would not produce usable outline data. This means that the process of tracing outlines also required additional editing for cleaning up and sometimes redrawing features, ensuring a proper structure for the outlines represented by a single polyline. At times, features of different layers representing two classifications of information (e.g. architecture and boundary walls) would come conspicuously close to connecting, yet virtually never would these features truly connect. As a rule of thumb, detached mapped features of equal or differently interpreted classifications would be connected within the GIS layer (polyline feature class) used to prepare the base plan if approximately under 80cm of width. Any analogous gaps of larger width or conspicuously positioned would be connected in a separate conjectural layer.

Conjectures were also used more progressively after having traced all originally observed features deemed to represent outlines. As expected in even the best archaeological information, the fragmentary nature of material remains means that various, clearly unintended, gaps in the data persist. The theoretical foundation requires all the integral subdivisions of the built environment to be present as a base layer of information, so such remaining gaps needed to be critically filled with harsher interpretive conjectures. As to date no other example of a Classic Maya site is known to manifest such a constellation of elaborate house groupings, pathways and boundary walls in the areas outside of the monumental centre (see Hutson et al. 2008; Magnoni, Hutson and Dahlin 2012) conjecturing analogically is largely out of reach. Therefore a rather bold approach to conjecturing was decided on. Fragmented buildings would be finished continuing the shapes suggested in the observed remains. Fragmented boundary walls are completed exclusively with straight lines (without crossing any other tracings), directly connecting two ends of mapped lines of the same class or onto another feature, using parallel and perpendicular alignments (see Fig. 2). Especially in the highly non-geometrical urban form of Chunchucmil, straight lines emphasise that these conjectures are not intended to represent informed reconstructions of the actual features' shapes. They rather complete the spatial data by reconstructing close approximations of the likely topological relations that would have existed between subdivisions. This unavoidably compromises the morphological integrity of the data, but to suggest actual knowledge of the features amounts to over-interpretation. Conjectured information can always be retrieved as this is kept as a separate dataset (see Fig. 2).

It should be understood that these crude conjectures are a requirement of the conceptualisations behind the mapping practice being discussed. It is not suggested here as general archaeological practice and is not a necessity for each form of interpretation on the basis of the plan (as demonstrated in Magnoni et al. 2012). Nevertheless, for any future topological spatial analyses, the conjectures are necessary. In Chunchucmil's case, the complementary conjectures went through three iterations. The initial phase concerned the coarse connecting up of features on screen. Then a revision was carried out based on the principle that directly or indirectly all spaces within an urban environment must be accessible. In other words, how is one able to traverse the site respecting the actual physical barriers mapped? This intuitive patterning was carried out on a high-resolution printout of the map with a semi-transparent overlay. The possible lines of movement and flow across the site were drawn. So the conjectures were adjusted to enable or better facilitate necessary traversing. A final revision is a side effect of the actual process of BLT identification, which would point out any subdivisions where a specific discrete outline was commonsensically expected, but absent (Fig. 2)[4].

Since the Chunchucmil's base plan aims to convey the most basic physically constructed subdivisions, archaeological artefacts, stelae and quarries are generally not included, unless a quarry seemed suggestive of possible incorporation as part of a (conceptual) boundary. Querns or *metates* within gaps in walls are taken as an indication of a probable passage way because the arduous task of grinding in all probablility had a social element to it (Hutson, personal communication). Bedrock, however, is included as these outcrops of the natural soil would have impeded thoroughfare and are often incorporated in boundary walls and even minor architecture. One should always be mindful of the possibility that consciously or subconsciously, readily perceived or concealed, subjective patterns could emerge from the underlying decisions and rules of thumb regarding outlines and conjecturing.

[4] It is important to note that all conjectures can be retrieved from direct comparison with the traced data of the original plan. It is likely that more means become available to improve on the conjecturing (or reconstruction) process in an informed way if additional research is carried out, thus further giving reasons to revise and adjust insights derived from the current iteration.

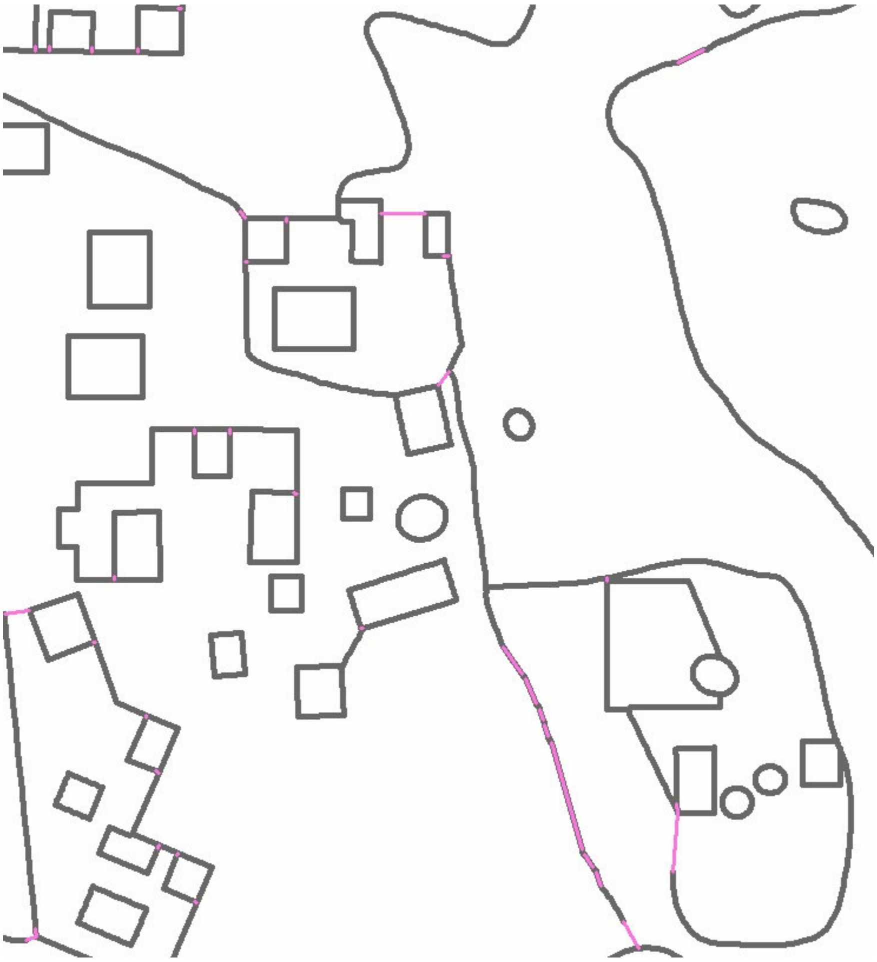

Fig. 2. Outline features (in grey) and minor and coarse conjectures (pink). (Image prepared from original data courtesy of the Pakbeh Regional Economy Program with help from S. Hutson.)

While the base plan consists of tracings of originally mapped outlines and conjectures, there is an intellectual aspect to boundaries that is not immediately represented. This is the ‘virtual boundary’ (see Table 1). A fiat boundary is understood to be present, but is not physically there (see Smith and Varzi 1997; Smith 2001; cf. Vis 2013b for a treatise on how fiat and bona fide boundaries are used in understanding spatial data). For Chunchucmil’s boundary walls, it would be a logical expectation that there were (possibly closable) openings in them which allowed people to access the areas they circumscribe. However, in order to create discrete outlines as well as accounting for possible data gaps, these openings would have been connected up by conjectured lines. There is no way to distinguish on the basis of the mapped material remains whether any opening was intended, destructed, deteriorated, caused by decayed perishables (e.g. incorporated cacti), or removed (by animals or humans) after abandonment, etc. (Hutson, personal communication; Becker 2001; Demarest 1997). At the same time there is no real necessity for each wall or distinction to complete a circumscription contiguously. Indeed, in Chunchucmil several platforms tying building groups together would gradually descend into the ground, creating a ramp for probable unimpeded access (Hutson, personal communication). Virtual boundaries, though not themselves a BLT (Table 1), are thus used to mark-up situations in which it is likely that missing physical information would not have detracted people from contextually recognising the spatial distinction at that location. This enables further discrete subdivisions to be mapped (Fig. 3). Note, however, that although virtual boundaries would note places of unimpeded access, entrances (represented in Table 1 by two separate BLTs) do not only operate on virtuality, nor do virtual boundaries only occur on the basis of conjectures.

Although an outline base plan is necessary for BLT identification, it cannot be assumed that the prepared base plan will contain all the lines as present after the full BLT identification process. Identifying BLTs, although bound to adhere to their definitions (Vis forthcoming), is still an interpretive practice on top of the base plan. While 'dangling' physical distinctions do not immediately cause a discrete subdivision, in preparing the base plan these would still be included, as final informed selections follow from the BLT identifications. In some cases these dangles originally traced from the site plan may be decided to not support a fully-fledged subdivision. They then become obsolete, as feature specific to the internal and/or specifically functional arrangement within subdivisions. Furthermore, it can be decided that virtual boundaries should be adjusted to support a commonsensical or more basic boundary line structure. Nor does a base plan necessarily include all the virtuals, as the most regular virtuals result from applying the BLT definitions themselves. In other words, a full base plan can actually only be derived after all BLT identifications have been carried out. All unique BLT identification polylines form a full and selective outline base plan (Fig. 3, 4).

In Maya settlement archaeology, Becker (2001) strongly argues for the existence of perishable boundary walls and (formal) hedges. Although predominantly stone and rubble were used in Chunchucmil, it is entirely possible that what we no longer see, could have perished. Much of what may have perished could have made internal divisions of activity areas within the bounded areas of boundary walls (*albarradas*) (Becker 2001; Manzanilla and Barba 1987; Hutson et al. 2007; Hutson et al. 2008). Similarly, various structures within groups of buildings could have been perishable (Becker 2001; Magnoni, Hutson and Dahlin 2012). Here, if nothing at all was mapped, no additional conjectures are invented. However, there are ambiguities such as the 'screen walls' connecting structures in building groups in various Classic sites, mentioned by Becker (2001; Tourtellot III 1988) (see Fig. 4). These could easily be confused with remnants of communal platforms. In such cases the expert opinion of the mapmakers indicating where they identified a platform or group on the plan (by annotating it) is cautiously followed. Although Magnoni, Hutson and Dahlin (2012) offer a population estimate which is partly based on the count of residential structures (following the method of Rice and

Culbert 1990), for the purposes here the different structures which will be part of the building group are not considered per function. Becker (2001) gives a good overview of what functional structures could entail, but also how few of them are systematically identifiable. Various fragments of albarradas can also be found ‘dangling’ inside house-group-lots. These dangling lines may well form part of internal arrangements in concordance with the activity areas and perishable boundaries. With this in mind, these dangles can be excluded from the base plan. The activities together are part of the same, larger, socio-spatial system mapped by the outline.

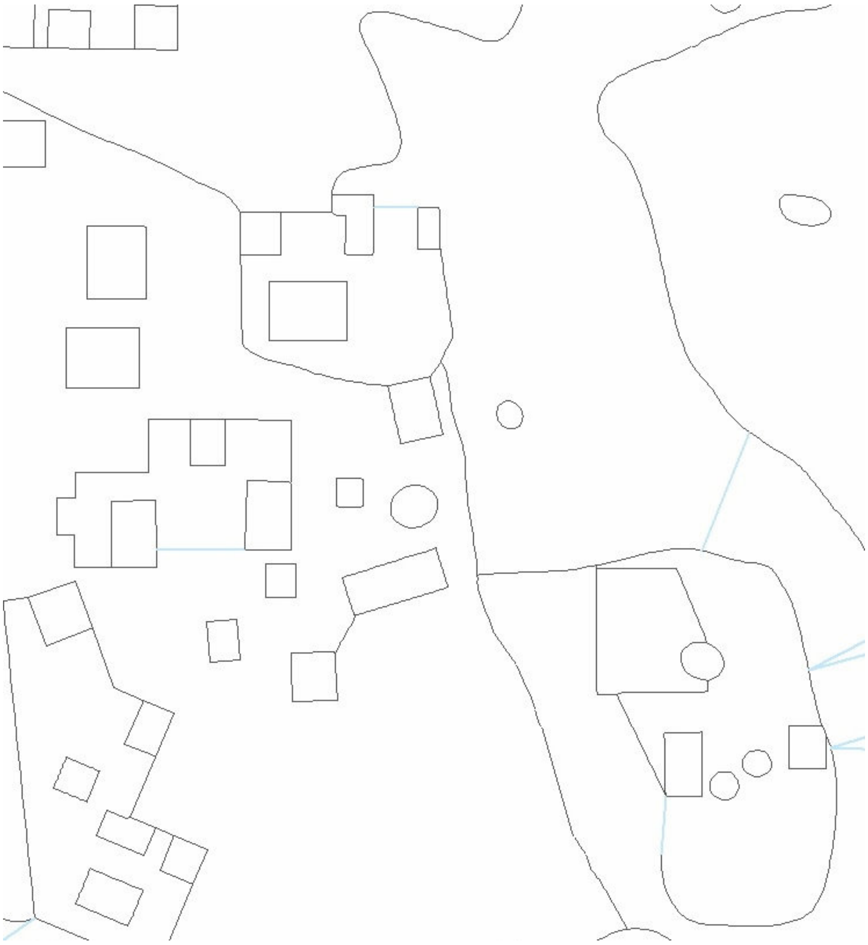

Fig. 3. Chunchucmil’s outline base plan (grey) with several virtual boundaries (light blue). The virtuals on the right hand side would not have originally been included in the base plan. (Image prepared from original data courtesy of the Pakbeh Regional Economy Program with help from S. Hutson.)

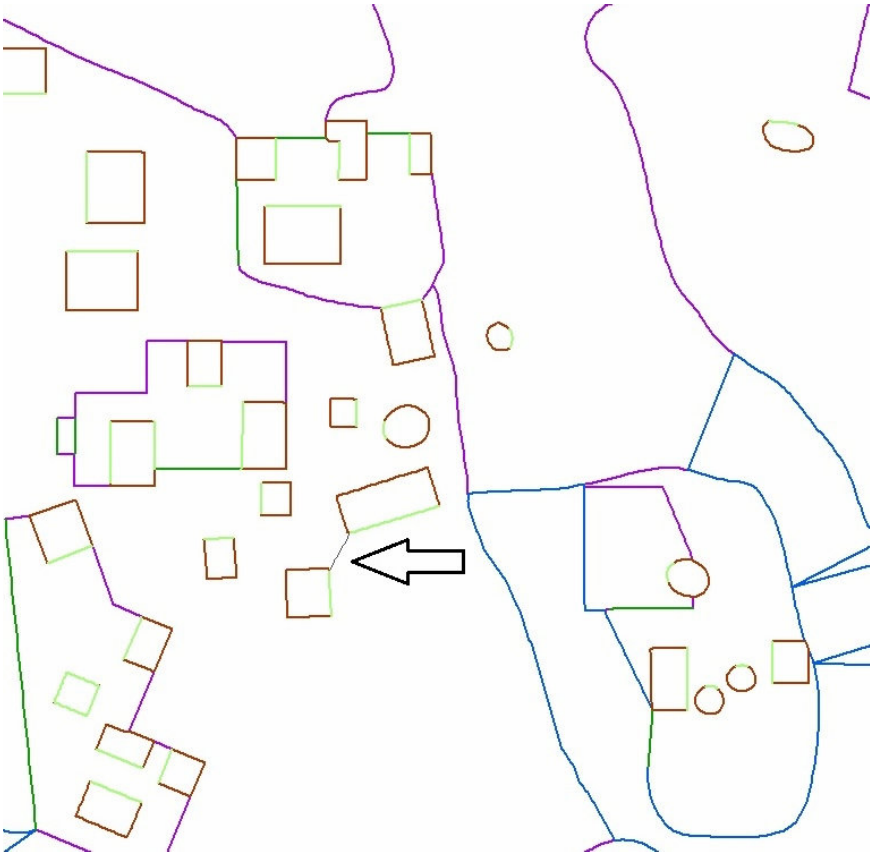

Fig. 4. The arrow indicates a line which was previously part of the base plan and could not successfully be completed into a full subdivision. Sometimes buildings could have a wall between them because of the wind (screen wall), thus a functional feature not fully separating anything socially. (Image prepared from original data courtesy of the Pakbeh Regional Economy Program with help from S. Hutson.)

Chunchucmil BLT identifications

Despite using digital tools, creating the base plan is mainly a manual process within the GIS environment. BLT identifications in turn are based on manual tracings of each instance, individually and entirely; a BLT is successfully recognised within the base plan. For the base plan to be effectively supportive of this work, one needs to ensure topological integrity throughout the dataset.

ArcGIS has developed the ‘topology toolbar’ for the purpose of ensuring topological integrity. For this to work it is most convenient to merge any separate layers composing the base plan into one comprehensive dataset. Within ArcCatalog any feature class (layer) in a geodatabase can be subjected to a topological rule set. When validated, any errors can be inspected and corrected within ArcMap. The topology rules first let one set a cluster tolerance, simplifying the data structure (any features below a measured threshold are regarded the same), and further allow one to make sure the data does not contain any unintended dangling lines, unsnapped vertices or nodes, intersections, unwanted duplication or coverages, unconnected polylines, etc. Despite functional limitations[5] this semi-automated process both speeds up subsequent work and improves the immediate quality of derivative data. Any unfinished but suggestive subdivisions kept in the base plan as well as any 'edge effects' (unfinished subdivisions truncated by the test area selection) can be marked as exceptions in the correcting process. The cluster tolerance should be a measure commensurate with the precision achieved in the mapping resolution. For Chunchucmil 10cm was selected, which might be smaller than the actual mapping resolution achieved on-site, but which would retain most of the interpreted shapes (e.g. curves) generated from the observations in Illustrator (see the above comment on densifying anchor points[6]).

As boundary mapping is based on outlines, all layers will always consist of polyline features. The paramount difference with the data structure of the outline base plan and each separate layer conveying a BLT is that each polyline feature in the BLT layers must convey a BLT identification in its entirety. In contrast, for the base plan the only truly important characteristic of the data structure is that, when maintaining topological integrity, all lines shaping the outlines are there. In other words, each separate feature in each BLT layer is a complete meaning carrying empirical identification of a material socio-spatial occurrence at the time represented by the plan.

The BLTs (Table 1) are numbered according to an order which is principally a logical order for carrying out the BLT identification process. As the ontological primacy of the solid dominants was established (Vis forthcoming), the first stage of BLT identification would see the researcher create a visualisation resembling a figure-ground plan, mapping out the built volumes from the open spaces (see Trancik 1986). This follows from Type 1, closing boundaries, creating a materially closable extraction from its surroundings (i.e. a complete structure or building). After identifying Type 1s, one would continue perusing the configurative relations to their surroundings and from this and the shape of the Type 1s, start

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[5] It is also possible to set topological rules before mapping and check up on data created in a (semi) live way, whilst editing the data. This could be more efficient if most eventualities are known upfront. Likewise topological rule sets can be adjusted if it is found that the rules do not adhere to the intended logic. Unfortunately, topological rules appear unable to handle composite rules regarding more than one feature class (layer) at once, but can only run multiple questions simultaneously, each treating a single layer. Complementary coverages can be checked by using tools for selecting on location.

[6] Of course the simplification process is not 'intelligent'. Though accuracy to about 10cm is maintained, at very large scales, some shapes might have become altered counter intuitively, e.g. right angles might have become slightly flattened and curves less smooth. Unwanted changes can be manually adjusted.

identifying facing boundaries (entrances, Type 2). Taking in more of the surrounding configuration incrementally, Type 3s, associative boundaries, can be identified as bounded areas in direct association with a single Type 1. Type 3s could get a Type 4 (entrance, or extended facing boundary) in direct relation with a Type 2, to extend a mediated relationship of the Type 1 with its surroundings. If no Type 3 can be found, within most built environments a Type 5-9 could be expected (Fig. 5). Note, however, that while Type 1s need at least one Type 2 to socially partake in the configuration and avoid a negative definition (Types 11-13), beyond this there is no necessity for any specific BLT to occur in the direct vicinity. The definitions will allow the successful identification of each specific BLT that does occur as part of the outline base plan in which Type 1s and 2s are now defined.

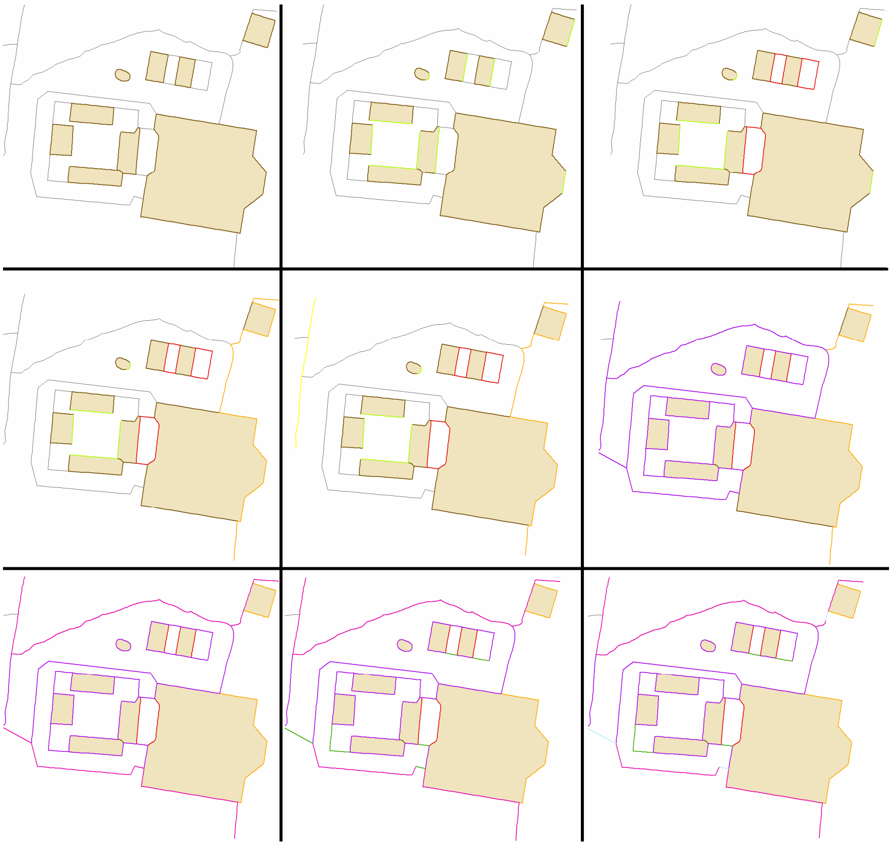

Fig. 5. The BLT identification process in nine stages on the basis of the Chunchucmil outline base plan (black). From left to right, in order of the BLT identification added: Type 1 (brown); Type 2 (light green); Type 3 (red); Type 6 (orange); Type 7 (yellow); Type 8 (purple); Type 9 (pink); Type 4 (dark green); virtual boundaries (clear blue). For visual clarity Type 1 has been converted into filled polygons. Note that BLTs that surround features get both an inner and outer identification. (Image prepared from original data courtesy of the Pakbeh Regional Economy Program with help from S. Hutson.)

The limited area in Fig. 5 demonstrates there is not a one-to-one relationship between a BLT identification and a line of the base plan. All segments of lines are identified as two or more BLTs (see Vis forthcoming). This reflects the binary character of any boundary, which can be approached from either one of its sides, thus affecting the role or significance it has for the person located in space.

From a purely intellectual point of view, the BLTs that do not circumscribe a subdivision but qualify the relation between two subdivisions, i.e. Type 2 and Type 4, including the virtual boundaries, should be drawn twice. Ultimately each entrance or virtual qualifier of a boundary is part of each colocated BLT (e.g. the reciprocity of any passage or doorway). This would essentially duplicate identifications at such places. However, for both visual and analytical purposes this is unnecessary in the spatial data. The length, construction and location of any such boundary could be recognised and utilised from the single identification of such boundary qualifiers.

If the data resulting from the BLT identifications should be used for computational spatial analyses or converted into other formats, then it is paramount that the BLT feature classes are checked against an appropriate topology rule set as discussed before. Fortunately, the polyline features are a flexible format, which can easily be processed into closed polygons, which would enable any investigation or visualisation on the basis of areas rather than boundary lines, while vice versa the intricacies of the BLT data structure cannot be automatically preserved. Computational spatial analyses are not part of this current paper, but are pursued in the continuation of this ongoing research.

Chunchucmil BLTs

Identifying BLTs effectively does rely on a series of informed professional judgments based on rules of thumb on how to read the plan. Entrances are especially tricky to positively and exclusively identify. The nature of the archaeological map is such that from the piles of rubble and debris from which the mappers were able to estimate structures, it would typically not be possible to also define their entrances. This leads to the use of an analogical rule of thumb by giving preference to buildings facing each other (directly and indirectly) as found throughout the Classic period in the Maya area in plaza and platform groups (see Becker 2001, 2004). Additional entrances may depend on any associated boundaries in their configurative complex (see Table 1). Alternative locations for entrances are identified when the spatial context displays a great measure of orientation elsewhere rather than in a facing fashion between buildings. Hutson (personal communication) suggested that small structures in the middle of plaza groups could have been entered from any side as they could have served as elevations to address audiences.

It could generally be assumed that platforms are accessible from all angles as they are low enough to mount without too much trouble. Similar to encountering a low fence, however, it would be logical that there are preferred places to access a platform. In many cases the platforms have been mapped as if they gradually descend into the ground (see also Fig. 5), as confirmed by a detailed excavation of a platform group (Hutson, Personal Communication), on one or more sides. Caution is necessary as a discontinuous platform outline could have a number of other causes besides those of intentional architectural construction. Subsiding platform sides in conspicuous locations within their context are taken as an indication for places to ascend onto or to access the platform. In instances where there is a full outline (possibly including a conjunction with albarradas), a wider opening between buildings or orientation towards the surrounding configuration is accepted as the indicator of an access way.

As a rule of thumb, albarradas are regarded to be physically impermeable, but similarly mitigated, due to heights lower than the human field of vision and the conspicuously fragmented and often virtual nature of their course, which occurs even in well preserved areas. Impermeability is thus mitigated by probably wide and/or multiple passages. Only albarradas mapped over a complete circumscribing course could become identified as enclosing boundaries (Type 7), which is also considered for rare high platforms, the outlines of which are often formed in conjunction with structures, with a probable formal entrance.

The parallel definition of Type 5 is applied in a very relative sense, sometimes including mirroring lines and contextually derived directionality. This means that two lines forming a relatively narrow (in context), but irregularly shaped corridor in a mutual linear orientation are likely to be defined as a type 5, broadly applying empirical parallelism. Type 5s running long contiguous courses are rare in Chunchucmil. The decision between a Type 5 or Type 9 is subjective to the degree that the researcher needs to judge when the general observed parallel structure is sufficiently lost.

Though Type 6 depends on opening out onto a few Type 1s, it is set apart from Type 8 because of its integration and sense of local centrality. It would seem that plaza and platform groups make good candidates for Type 6s, but usually their bounded area is spatially removed from the ‘open’ flows of traversing the site from anywhere within the spatial system. Generally identifying a Type 6 is closely associated with nearby or connected Type 5s and Type 9s, along which Type 8s would often be laterally placed.

It has been suggested that chich mounds (low piles of rubble) might be the foundations of (perishable) buildings (Magnoni, Hutson and Dahlin 2012). Indeed, the placement in association with building groups of (circular) chich mounds is conspicuously alike the round buildings mapped as architecture. Therefore, in revised iterations, such round buildings have been treated as outlines of buildings, unless their situation within their surroundings seemed to suggest otherwise or their shape seemed illogically irregular for a structure. As a rule of thumb chich mounds with dimensions similar to round buildings and placed detached from albarradas — ancient buildings do not typically straddle albarradas (Magnoni, Hutson and Dahlin 2012) — are identified as Type 1s.

Winchester materials

In contrast to a lost urban tradition like the Maya, British urban history appears remarkably well-known (see Palliser 2000; Clark 2000; Daunton 2001). A wealth of historical records is typically available to retrieve various narratives behind British urban settlements, often even in considerable detail. However, as many cities are ongoing places continuously being developed over time, historians have struggled to put the intricate structure of material urban space into their research of the past (Bisschops 2012). Methods of reconstructing bygone phases in urban development on the basis of (property) records have been successfully developed since the 1980s (Keene 1985, Keene and Harding 1987). More recent projects are constantly improving the accuracy and detail of these kinds of studies (Lilley, Lloyd and Trick 2005, 2007; Lilley 2011a; Lilley, *Mapping Medieval Chester*; Gauthiez and Zeller this volume) by employing new digital technologies. However, Dean (2012b) has recently demonstrated that the established urban morphologically based practice of reconstructing and conjecturing an urban plan sequentially may contain unexpected significant errors, which come to light when combining these mappings with archaeology. Users of historically derived conjectural sequence plans should therefore be critically aware of the inherent and inevitable discrepancies introduced by the methods producing these plans.

The fact that Winchester is still a small but thriving present-day city, confronts the boundary mapping methodology with a different dimension in which to work. Keene's (1985) seminal work on medieval Winchester[7] provides a basic level of urban mapping which can serve as a basis for the detailed resolution boundary mapping requires. Keene (1985) produced three sequences for the Middle Ages: 1300s, 1417, and 1550s, on the basis of records of medieval properties or burgage plots. To demonstrate the principle of BLT mapping through time, here only a small section is taken back to 1550s.[8] This is complemented by the current (2011) MM data for Winchester and OS 1872, published during 1871-1872. Needless to say, there are various highly detailed maps from the 1870s onwards, which could

[7] Biddle's 1976 edited volume on early medieval Winchester does not contain mapping material to a similar level of detail, which reflects the increasingly fragmentary nature of the archaeological and historical records required for sequence mapping.

[8] The 1750 Godson survey was also considered for preparing an additional time-slice. However, after appropriate digitisation and georeferencing of this plan from the two copies in the Bodleian Library's collection, it soon transpired that not only the historical survey technology, style of depiction, and imprecise edge matching of the printed sheets, would make a topographical challenge, but also the detailing the detailing of the plan left many building and plot details ambiguous. This rules out the opportunity for a direct translation into realistic and accurate individually reconstructed topographical features. Although the Keene (1985) plans also lack part of the a priori level of detail required for BLT mapping, his two large comprehensive volumes give much detailed background on how to interpret the plans. It is possible that with appropriate historical research, the Godson survey could make a suitable basis for an additional historical section of the city in the future.

give a much greater temporal resolution. This temporal specification could be the subject of future research.

The acquisition of MM is completely digital and can easily be imported into ArcGIS proprietary vector formats. OS 1872 is also acquired digitally, but as a raster image geoTIFF (indicating a basic level of geoprocessing is performed on the image, projecting, locating and scaling it). The Keene plans did not exist in any digital format prior to this research. The original plans appear in sections at a 1:2500 scale. Although these could be scanned and stitched together, it seemed worthwhile to trace down the originals. These are kept by the Winchester Excavations Committee (curated by Martin Biddle and Katherine Barclay and in the care of the Winchester Research Unit) in the depot of the Winchester City Museum. The originals consist of large sheets of film on which the line drawing of the map was draughted. Rather than sectioned in the small portions of the book, these sheets represented the medieval city in five parts: the walled area, and the north, east, south and west suburbs. The large scale of these original sheets as well as the less fragmented and unannotated nature of them, seemed qualitatively more advantageous to work with than scanning the images in the book. Digitising involved large roller scans of each of the map sheets at high (400-600 dpi) resolution, resulting in huge raster files. Despite the initial advantages of using these large film sheets, the consequential large file sizes caused various issues in the subsequent processing. This involved the cleaning up, enhancing and precise stitching of the five different sheets in Adobe Photoshop. To keep the files manageable a resolution of 400 dpi[9] was deemed sufficiently sharp for the definition of the line drawing at full scale.[10]

The next stage of importing and georeferencing them in ArcGIS was carried out in direct reference to MM, assuming the current mapping standard to be by-and-large the best available. This was preferred over setting up a proper set of control points with dGPS (cf. Lilley 2011a), as error margins between these points

[9] The originals produced with the help of Geoff Denford, Winchester City Council (Winchester Museum Service), were at 400 and 600 dpi, while additional scans on a larger scanner were made at the University of Portsmouth thanks to Katherine Barclay at 500 dpi. Although the quality of definition on the 500 dpi scans was superior, the lower resolution determined the quality of the final stitched scans, which were visually improved with image processing and filtering in Photoshop thus ensuring readable solid lines, suitable for semi-automated vectorisation (see below).

[10] It should be noted that the Keene plans were prepared in reference to the then current OS city plans of the 1970s, which used planimetric technology closer to present standards (Keene, personal communication). In addition the 1872 OS plan and the 1750 Godson survey were used as points of reference for shaping features in the built environment. The film sheets were all in relatively good condition, but there is no accounting for any errors resulting from 40 years of ageing of the physical material, although flat roller scanning should ensure an accurate reproduction of their current condition without photographic lens distortion. Finally, accuracy is compromised by the stitching process, which is a simplistic visual weighting of the matching errors between the edges of each sheet using graphical tools in Photoshop, which inevitably retains small mismatches. An alternative would have been to vectorise the images and use ArcGIS computational tools to match the edges of the matching vector files.

could cause unwanted discrepancies between MasterMap and each historical layer. Instead, with the aid of Keene (personal communication) historically persistent points in the environment were identified, documented as spatial data, and photographed on site for future reference. Logically fewer points were available throughout all periods from the 1300s as the built environment developed. These points served as a basic set of control points[11], also for the 1872 OS plan. In the georeferencing process the basic control points would achieve enough initial accuracy to carefully select a series of additional points that were clearly related to the historical plan at hand. This improved the relative accuracy, using higher order georectifying warps.

For the 1550s plan, the approach chosen first involved vectorising the raster with a semi-automated process using the ArcScan suite in ArcGIS. Although this also features a fully automated tool, the results of this process left much to be desired. The semi-automated tracing of a two-tone raster image (i.e. classified in two categories) with polylines works somewhat more quickly than an entire manual redraw. The downside is that the thickness of the scanned lines can cause minor ruggedness in the shape of the resulting polylines. For future reference, Keene's (1985) historical conjectures were vectorised in a separate dataset from the features that were deemed certain. Rather than georeferencing, the process of geographically relating the vector data to another dataset is called 'spatial adjustment', but operates on largely similar principles to those in raster georeferencing. Because snapping exactly onto nodes is possible in both the vectorised 1550s data and OS MasterMap, a more accurate placing can be achieved. Any certain identical points can subsequently be selected as 'identity points' where ArcGIS would virtually nail the overlaying sheet to the underlying location. Using rubbersheeting, greater local accuracy on the basis of additional points can be achieved without ever moving these 'identity points'. In this way the vectorised 1550s data could create a more precise initial match to the OS MasterMap data.

[11] In addition, the geographical representation of listed buildings and monument sites was obtained from Winchester City Council (courtesy of Ian Scrivener-Lindley and Tracy Matthews). These polygons and points were prepared on the basis of MasterMap, and so would relate exactly to the source data. Unfortunately, heritage listings serve a policy purpose of protecting and managing the sites. This means their shapes cannot be trusted to convey any historical reality. Furthermore, in Winchester the heritage records, often of a dubious and dated standard, have not been fully integrated across the various systems that have existed over the years and do not include archaeological excavation plans. Only limited cautious use could be made of these records, using online resources such as Heritage Gateway and National Heritage List for England. In practice, where possible, Keene's (1985) words were preferred over the listings, but the records were used to indicate plausible historically persistent features.

Winchester base plans

To demonstrate the applicability of BLT mapping through time and on historical material, a small area around Winchester's former East Gate and bridge was chosen to test the principles. The current MM version[12] represents the large scale mapping standard for the UK. Nonetheless, using MM for creating outline features and eventually identifying BLTs is perhaps less straightforward than one would expect. As is the case with all maps MM presents a selection of mapped features. MM should satisfy policy and legal use requirements as well as depicting the physical layout of a place. It omits entrances, and many comprehensive buildings consist of several polygons of which it is unspecified as to how they compose an internally divided whole (as opposed to usual archaeological ground surface mapping). Although the OS Address Layer 2 will give an indication of the location and number of addresses at an approximate location, which helps the interpretation of the physical and social reality, this does not generate the aggregates of polygons which represent each building completely. MM combines a mix of uses in one map, keeping track of a feature's development, extensions and adjustments. It offers a very basic and generalising degree of land use classification, and will often, but not always, indicate the provenance of a feature as either 'natural' or 'man-made'. At the same time most man-made open surfaces are merely described as 'multi surface' or 'general surface', which does not reveal much of what is actually mapped.

This illustrates that even when working on the present, interpretive rules of thumb are necessary to work with the mapped material. Fortunately, we have more resources at our disposal which can shed light on the present social reality of the physically built-up city. MM was used in conjunction with Google Street View, Google Maps, Bing Maps[13], and Ordnance Survey's Imagery layer (vertical aerial photography). Although this can clarify a lot of what is represented in MM, including revealing minor discrepancies, there are still aspects of the built environment that are largely inaccessible. This mostly concerns the backs of buildings and their gardens, or small alleyways, or legally and functionally restricted areas. For comprehensiveness only a dedicated urban survey might be able to remove most gaps left despite cross-referencing various sources. Again, to acquire an immediate feel for the quality and appropriateness of the data, it is enlightening to perform an initial run on semi-transparent paper.

Creating outlines on the basis of MM required intensive cross-referencing of various sources — photographic sources often being the most intuitive — to choose the lines which truly conveyed outlines that physically exist and are not part of internal design or composite functions in any area. In exceptional instances

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[12] MasterMap can be updated up to every six months. This data was downloaded end of October 2011, with the Ordnance Survey Imagery Layer (OS official aerial photography) and Ordnance Survey Address Layer (2) arriving on disc in April 2012.

[13] Online mapping and imaging resources can be updated without prior notice. The work on Winchester took place between May 2012 and April 2013.

original MM lines received minor amendments to more precisely convey the actual physical difference on the ground. The greatest ambiguity is undoubtedly associated with separating buildings by internal divisions and likewise, with complex plots and open areas at the back. At the same time, the general assumption held that in inaccessible areas all lines of MM would be physically recognisable on-site, so they could all potentially be used to convey outlines. Inevitably, some of the outline features on the base plan were therefore interpreted with potential BLTs in mind. MM itself is topologically integrally developed by the Ordnance Survey. Nonetheless, the tracing of lines in MM is a manual process, so as described, before a topology rule set should be enforced on the outline base plan.

The georeferenced OS 1872 plan likewise introduced its own interpretive difficulties and ambiguities. First OS 1872 was prepared and published over a two year period in which the city was rapidly developing. The seams of the separate sheets of the plan therefore do not always match both due to their separate publication and small differences between the original paper documents. In vectorisation these discrepancies are interpretively weighted to permit mapped features to retain relatively regular shapes. The resolution and definition, as well as the detailed symbology of the OS 1872 plan made it unsuitable for using the semi-automated raster tracing in ArcScan.

Unfortunately, digitised historical OS plans are not delivered with a legend of the symbology and abbreviations used. Although Oliver (1993) mentions the existence of coloured versions of the OS 1872 city plan, these were not available via EDINA's Historical Digimap services. This means the plan is a simple black and white affair, where it is often ambiguous as to what kind of (physical) distinction is made with each single solid line. Coloured plans normally convey differences between built-up areas and open areas as well as to a degree the materials used (Oliver 1993). From comparisons between maps of the same era at the same scale (several can be consulted online at the National Library of Scotland) and an extensive list of abbreviations used in various OS mapping projects over the years (available online at the National Library of Scotland), intensive studying of OS 1872 leads to relatively accurate reading.

OS 1872 was clearly aimed at a comprehensive representation of the physically present features of the city. The general resolution for detailing was 15cm (Oliver 1993), which offers greater architectural detailing than MM. In addition, functional furnishings of the city were often also mapped. Strangely, contrary to Oliver's (1993) supposition, gates and doorways are not consistently featured on OS 1872, while archways (in walls) do appear. Vectorising towards an outline base plan thus involves selections and interpretations (e.g. excluding the furnishings and some architectural details). As with MM, accuracy cannot be guaranteed for areas around the back of buildings or within larger building complexes which are too compositely mapped to make certain inferences on what each line conveys. Likewise, separately mapped extensions were interpretively incorporated or divided into discrete buildings with internal divisions. Outbuildings are particularly complex as they are numerous in the Victorian city. Rather than each separate rectangle, clusters of outbuildings were given an area outline. As vectorisation relied on manual editing, features of OS 1872 that came tantalisingly close to an extant line in the MM base plan were traced from the latter, which would be deviated from when different shapes and orientations occur.

The base plan of 1550s firstly comprises the spatially adjusted vectorised plot based property plan itself, including Keene's historical conjectures. This dataset offers a much more simplistic foundation, as no unnecessary or confusing detail was included in the historically self-selective reconstructive mapping process. The challenge here is rather the reverse. The limitations of the topographical reconstruction on the basis of the historical records (see Keene 1985; cf. Bisschops 2012) cause many unaffordable gaps inhibiting it to serve as an outline base plan for BLT mapping. Most conspicuously, buildings are not mapped at all, except for those with public and administrative functions. More importantly, as the plans are property based, the physical distinctions of any further subdivisions within any property are not mapped and sometimes simply unknown. This means a rather crude level of conjectural mapping is required to add the missing detail of the built environment to merge into a comprehensive outline base plan.

Keene's (1985, Fig. 155) work conveniently includes a plan for each historical snapshot selected, indicating the built-up and probable built-up frontages along the streets. This is used as a basis for deciding whether a building needs to be conjectured. As for the actual shape of a building there is no pretention that this reflects reality. Lewis, Roberts and Roberts' (1988) book *Medieval Hall Houses of the Winchester Area* shows three examples of shops surveyed in the city of Winchester, which were between approx. 10 and 15m in length. These dimensions are taken as a rough maximum for typical buildings, also comparing internally to the more detailed knowledge of smaller separate properties along the High Street area. Without any readily usable direct sources to base morphological considerations on, at this stage it was deemed more important to ensure that the topological distinctions were made than to be concerned about their appearance. Keene's abstracts of compiled historical records on the properties in his gazetteer are used to find clues about any multiple buildings, plots or gardens being part of a single property. Often the evidence for this is scant or even entirely absent (which is also the origin of some of Keene's own conjectures).

As an example, Fig. 6 shows the clear difference between the west and east sides of the northern end of current Chesil Street. The west features large subdivisions on sizeable plots, because no further evidence was available and the suggestion was raised that this area could have hosted a few substantial medieval buildings. The east, however, has been subdivided into smaller built environment features, because there was no special indication of substantial buildings and the one historical building still in existence (The Old Chesil Rectory) was indicated to feature two tenements with a probable communal arched entrance (Keene 1985). The neighbouring plots in that sequence feature frontages (probably built-up, according to Keene) with comparably dividable dimensions (4 or 5m each). On the opposite corner towards the north, there is an indication that at some point during the late medieval period there could have been six shops occupying this site. In these cases, the open areas behind the buildings are not subdivided as they could well have been shared.[14] Open areas are only subdivided if prompted by Keene's (1985) discussion of the records.

Despite the conjecturing efforts, the exact same level of detail cannot be expected on the basis of 1550s as from either MM, OS 1872, or an archaeological plan. It would be a gross over-interpretation to start conjecturing absent outbuildings or morphological details. This means that in any comparative work with more detailed material, the simplified composition of buildings and open areas should be taken into account.

Fig. 6. An example area of the Winchester 1550s base plan data with initial building and plot division conjectures shown in pink. The great contrast between the large and small buildings is a reason for concern about its historical accuracy, but is still in keeping with the scarce information available for this area. (Image prepared on the basis of original plans reproduced courtesy of the Winchester Excavations Committee ©.)

[14] Little is known about the actual (physical) subdivisions of open areas associated with buildings in the medieval period. Archaeologically there could have been fences, paths and hedges, all used to section off small bits of space. In any case, it seems likely the medieval city saw a variety of plot divisions and shared open areas (Dean, personal communication), which is also suggested throughout the discussion of properties in Keene's (1985) gazetteer.

All base plans will need to be checked and corrected on topology before being used for BLT identifications.

Winchester BLT identifications

There is no need to repeat the explanation on the general process of BLT identifications as this was described for Chunchucmil before. No fundamental differences occur with a historical European example (see Fig. 7, 8, 9). The rules of thumb applied, however, depend on the particular context and nature of the source material.

One aspect particular to working diachronically is to ensure that in the few cases where a boundary outline would remain in exactly the same location through time, any concurring BLT identification on that location should be identical to the more recent phase. This helps to keep the data clean by eliminating confusing uninformed differences. Most instances concern historical building frontages, which also retain the same doorway.

As noted before, the areas around the back of buildings cannot satisfactorily be assessed. This means there is little secure information on back entrances in each time-slice. In general the assumption is then made that back entrances are necessary for structures which have a plot around the back. Unless the shape and mutual orientation of the outlines and further identified BLTs suggests differently, the back entrance is conjectured in rough opposition to the front entrance. Only in complex buildings and contexts or on the basis of actual additional information, would more entrances be identified. It should be noted that because many entrances are conjectured, like in the Chunchucmil case study, their dimension is less relevant than their existence topologically. The width of entrances is at best indicative.

Working on urban built environments more familiar to the researcher means that there is a greater immediate understanding of what could be expected. This applies especially to outbuildings, garages, sheds, follies, etc. (absent in 1550s). In Chunchucmil all architecturally mapped structures and architecture ended up with Type 1 identifications, while at the same time many actual outbuildings could have perished. This may have included examples of what in western and globalised cities would be considered (functional) outbuildings. However, in Chunchucmil and indeed the Maya culture area in general, buildings tend to occur in groups on shared open areas. These open areas would usually be identified as a Type 3 or a Type 8, depending on a one-to-one or one-to-many building(s) relationship. In western and global cities outbuildings are typically understood as auxiliary to and under the exclusive influence of the main structure they are in constellation with (a single socio-spatial system). It therefore seems detrimental to go against that intrinsic understanding and consequently identify most gardens as a socio-spatially distinct Type 8, while there is still only one main Type 1 which determines the association.

This is why outbuildings in Winchester (MM and OS 1872) are treated as sequential occurrences of Type 3s or 8s even if materially they could be closable like separately inhabited or occupied structures. In Chunchucmil the groups of Type 1s are typically larger than two and extensive research suggests that they are inhabited by multiple nuclear families (Johnston and Gonlin 1998; Magnoni 2007), meaning that with greater confidence their associated open areas justifiably end up a Type 8. The advantage of this practice is that visually and computationally the BLT data is still easily simplified to generate aggregate outlines of a Type 3s or 8s cluster, which could stand on the same level as badly preserved archaeology or self-selective historical reconstructions. Since it might be more difficult to repeat the entire interpretation process to add detail later, maintaining auxiliary buildings is preferable to omitting them initially. Additional information from other sources could in any future research be stored in the attributes of the BLTs as well.

Boundaries of unoccupiability (Type 11 or 12) are primarily based on MasterMap's proprietary 'natural' or 'man-made' designations. On OS 1872 they are based on the symbology, and on 1550s they are limited to bodies of water only.

Due to the style of OS 1872, the nature of outlines often does not reveal itself clearly until the BLT identifications disentangle all the lines. This means that similar to the iterative revisions of conjectures on Chunchucmil's plan, the OS 1872 base plan is more invasively revised during the BLT identification process than is the case for either MM or 1550s. At the same time the additional architectural detail and pathways in parks and gardens available on OS 1872 only, give an extra certainty for conjecturing any entrances.

Garden plots situated like housing plots without a directly associated building on site are quite particular to the medieval period in Winchester. Though justifiably identified as opening boundaries, Type 9s, they are something of an oddity. Due to their open character these gardens are logically a Type 9, but the known function is quite distinct from parks or other open areas. This difference is similar to the distinction of an agricultural field and a park, which resonates well considering garden plots could have been used to grow crops rather than serving a more modern leisure function. Besides built-up frontages, Keene (1985: Fig. 155) also identifies likely 'open ground', which seems to indicate land without any particular identified use, which roughly follows the general plot pattern. With the current BLT ontology it is impossible to differentiate between these and so-called garden plots. Despite differentiation of what is typically regarded as open space in urban studies (Stanley et al. 2012; Smith M.L. 2008), functionally Type 9s will have a protean referral record. Although spatially often unidentifiable, from a social perspective the ambiguity due to the lack of a predominant socio-spatial occupation, could justifiably render any unused space (e.g. fallow) a Type 10.

Fig. 7. Example of the BLT identification process in nine stages on the basis of the Winchester's MasterMap outline base plan (black). From left to right, in order of the BLT identification added: Type 1 (brown); Type 2 (light green); Type 3 (red); Type 5 (blue); Type 8 (purple); Type 9 (pink); Type 4 (dark green); Type 11 and 12 (grey); virtual boundaries (clear blue). For visual clarity Type 1 has been converted into filled polygons. Note how the triangles of road segments are exclusively virtually bounded. (Based upon Ordnance Survey mapping. © Crown Copyright 2013. All rights reserved. An Ordnance Survey (EDINA) supplied service.)

Fig. 8. Example of the BLT identification process in nine stages on the basis of the Winchester's OS 1872 outline base plan (black). From left to right, in order of the BLT identification added: Type 1 (brown); Type 2 (light green); Type 3 (red); Type 5 (blue); Type 8 (purple); Type 9 (pink); Type 4 (dark green); Type 11 and 12 (grey); virtual boundaries (clear blue). For visual clarity Type 1 has been converted into filled polygons. (Image prepared on the basis of original scans © Crown Copyright and Landmark Information Group Limited 2013. All rights reserved. 1872.)

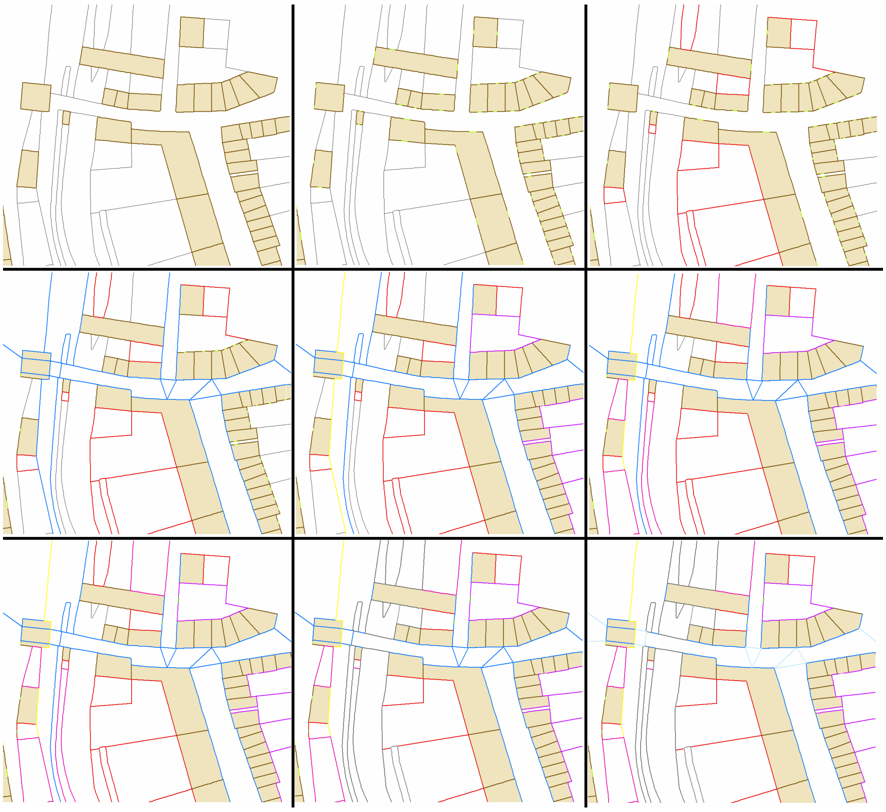

Fig. 9. Example of the BLT identification process in nine stages on the basis of the Winchester's 1550s outline base plan (black). From left to right, in order of the BLT identification added: Type 1 (brown); Type 2 (light green); Type 3 (red); Type 5 (blue); Type 7, 8 (yellow, purple); Type 9 (pink); Type 4 (dark green); Type 11 and 12 (grey); virtual boundaries (clear blue). For visual clarity Type 1 has been converted into filled polygons. Note the effects of the city wall (Type 7) and the medieval encroachments on the river along the bridge. (Image prepared on the basis of original plans reproduced courtesy of the Winchester Excavations Committee ©.)

Interpretative and descriptive merits

Now we have seen the application of BLT mapping in an archaeological and alternative urban tradition as well as in a historical example of an ongoing urban tradition, a brief discussion of the merit of this intensive mapping method is in order. This will be done by focusing on the identification of one BLT: Type 8 (mutual boundaries).

Type 8's definition pertains particularly to the nature of an area that is formed and occupied by an aggregate socio-spatial system composed of a specific selection of materially secluded socio-spatial systems (occupying physically segregating structures). As noted before, Chunchucmil's urban environment, and indeed Classic lowland Maya urbanism, is characterised by house or building groups in a variety of constellations. It is therefore hardly surprising that Type 8s end up as a part of a large number of well-dispersed sizeable areas. However, BLT mapping not only confirms on a spatial and physical level what can generally be asserted by looking at plaza and platform groups, it also makes explicit how they are composed and how they are connected and situated on a social and spatial level within the urban environment as a whole. It specifies that only very few open areas pertain singularly to a structure (Type 3) within Type 8s. Adjacent Type 8s furthermore create larger clusters of groups together with their shared spaces, around which, by and large, circulation spaces guide further open interaction opportunities. It also demonstrates that plazas and platforms, distinct from Type 8s as identified in many plaza groups, should in the majority of contexts not be confused with current ideas about urban squares, which often form locally central parts of circulation. Instead, that role often appears to be played by opening boundaries (Type 9s), while square like areas (Type 6s) are a much more specific occurrence.

Type 8s in Winchester are of interest, initially because comparing with Chunchucmil, present-day Winchester is largely devoid of Type 8s in favour of a multitude of Type 3s. When they do occur, they are often set back from the more open circulation systems. Their boundaries therefore only represent the first point of interaction with the secluded socio-spatial systems (Type 1s) grouped by the Type 8 in a restricted way. This latter observation holds true for both OS 1872 and 1550s (Fig. 8 and 9). Both these historical situations show a mix of a Type 8 and Type 3 pattern, where in OS 1872 fewer Type 1s participate in Type 8 constellations. Type 8s also appear marginally less frequent, yet possibly more evenly distributed than on 1550s.[15] OS 1872 is therefore suggestive of a transitional stage in which associated open spaces become increasingly secluded.

This preliminary observation of a possible urban historical process in Winchester's built environment, uncovered by the BLT identification process, benefits from an analogy with historical research to test the reliance on exclusively empirically mapped information. Daunton's (1983) spatially sensitive quotidian study of the form and formation of the Victorian city, confirms that the careful reading of OS 1872 can be trusted. The British Victorian city saw a marked shift from shared open areas to increasingly individual open areas, even to the point where policy measures were put in place for the construction of urban residences including such open areas. Although Daunton's discussion focuses on an area of Newcastle and although the changes emerged more quickly in various guises in large urban settlements, the move towards more privately allocated open space instead of accessible open meeting spaces seeped into the provinces over time (Daunton 1983). It is therefore very likely that 1870s Winchester was a Victorian city in transition. The socially interpretive and descriptive use (cf. Griffiths 2013) of the BLT identi-

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[15] As noted before, this could partially be due to the way the historically reconstructed map and lack of documentary detail was treated in the outline base plan.

fications comes into its own here. The virtual boundaries, for example, give the researcher the interpretive flexibility to mark the difference of an incomplete separation between individual buildings' open areas. They offer a stage in between Type 8s (mutual boundaries) and fully fledged Type 3s (associative boundaries).

For all of these socially positioned and spatially situated occurrences of Type 8s, or indeed any BLT identification, applies that their description is only completed by all other BLT identifications of which they are part. They are incrementally contextualised within a completely marked-up dataset of a built environment. Despite bringing to bear a novel essentialist ontology onto the built environment, it could be argued that, due to superior understanding of western and globalised society and its urban forms, this method adds little to the initial socio-cultural understanding of the structure of a particular urban space. The advantages offered by BLT mapping should rather be sought in the opportunities it creates for the resurging research interest in comparative urbanism (Smith 2012; Smith and Peregrine 2012; Stanley et al. 2012; Taylor 2012; York et al. 2011; Ward 2010; Fletcher 2009; Yoffee 2009; McCafferty and Peuramaki-Brown 2007; Nijman 2007; Briggs 2004; Robinson 2004).

The enigmatic and irregular nature of the Maya urban tradition has caused havoc to their study as cities (Sanders and Webster 1988; Chase, Chase and Haviland 1990; Graham 1999; Smith 1989, 2003; McCafferty and Peuramaki-Brown 2007). Although the idea of low-density urbanism has existed for decades, it is only recently that archaeological examples like the Maya are receiving more structural attention directed at the analysis of the pattern of urbanism they represent (Fletcher 2009; Isendahl and Smith 2013; Arnauld, Manzanilla and Smith 2012). As demonstrated here, the boundary mapping method is able to contribute to the opportunities for analysis referring to urban form or the configuration of the built environment in particular. In the Maya area it offers a mapping which could further formalise, specify and spatially contextualise work on neighbourhood clusters (Ek 2006; Hare and Masson 2012; Lemonnier 2012) or political modalities (Bazy 2011). Furthermore, its topological data structure (see below) intrinsically provides the basis for many additional lines of questioning spatial patterns and connectivity (cf. Morton et al. 2012b, this volume, applying space syntax), or further specifying and investigating possible alignments across Maya settlement layouts (cf. Bevan et al. 2013). In addition, the outline and BLT specifications, open further directions for discussing Chunchucmil in relation to Becker's (2001) settlement layout models (cf. Magnoni, Hutson and Dahlin 2012) and attributed with additional material and architectural information, this could be connected to considerations of labour investment (Folan et al. 2009; Guderjan 2007).

Thus BLT mapping allows initial explorations of alternative urban traditions where extant methods have difficulty engaging with the structure of their built environments as they were developed for globalised cities. The boundary method is devised for it to work equally across all built environments. Despite this flexibility, it fulfils the requirement of a more rigorous and formal method on the basis of a directly empirically translated theory (Smith 2003, 2011a; Smith and Peregrine 2012, Joyce 2009), which sits next to perhaps overly formal and socio-culturally embedded or prescriptive current methods to study urban form. A western medieval city like Winchester, relying heavily on a street network and a Maya city composed of intricately linked series of variably characterised and embedded open space are descriptively and formally mapped on exactly the same basis. This allows for a meticulous exploration and description of the socio-spatial affordance of inhabitation in physically developing configurations of subdivisions, contextualising and situating each specific location on the same grounds.

Diachronic and spatial data structure

Bisshops (2012) rightly notes that digital maps of contemporary urban situations are not suitable for plotting and attributing medieval historical data onto them. These modern maps contain much irrelevant information and fail to represent the spatial situation for the historical moment of interest. Therefore these practices offer little opportunity to question the relationship between society and space in the past, let alone elucidate socio-spatial processes through time (cf. Griffiths 2013). Relating the built environment of the past rigorously to the present, however, would enable a study of the social materialising processes of the mutual constitution of the city and its inhabitants.

For comprehensive visual inspection alone, the images throughout this paper have demonstrated the need for a better way to visualise the mapped BLT information holistically. Naturally, where the data available for a case study allows, the resultant data structure emerges diachronically and thus could be compared and analysed across time. Figure 10 shows the outline base plans for the same area in Winchester as used before for the three time-slices (1550s, green; OS 1872, blue; MM, red). Where most diachronic images in historical GIS are raster based and thus require semi-transparent layers on which point data of events can be distributed (e.g. Paris and Tokyo Cityscapes on MapApp), here the vector topology of the data simultaneously provides both a spatially clearer and perceptively more complex image. It is easier to see specific relations in small areas than it is to get an overall impression of the processes going on. If this is true for the relative simplicity of three time-slices, it would most definitely require other measures when thirteen BLT layers per time-slice are added.

Importantly, however, the BLTs convey what occurred in the composition of the city's built environment itself and how the development of this has manifested itself as is relevant to and constitutive of its inhabiting urban society. Conceptually and experientially the structural composition of the built environment does not adhere to the graphic area pixels of a raster image, but naturally relates to topological relations along lines forming composite subdividing polygons (areas). Deriving specific spatially contextualised insights on urban configuration formation requires a vector GIS data format. Yet, working with BLTs through time effectively necessitates advanced spatial analysis and associated visualisations to obtain significant information coherently.

Fig. 10. All outline base plans are overlaid on top of each other in the same Winchester area: MM (red); OS 1872 (blue); and 1550s (green). Note that the major changes from 1550 to 1872 are formed by the removal of the city wall, widening of the bridge, and the intensification of built-up space, e.g. along the river. In addition, it can be seen how the major changes from 1872 to the present concern infrastructural adjustments to street lines, some major new buildings and a cleaning up of the mishmash of development along the west bank of the river. At the same time some of the plot boundaries along Chesil Street are amongst the most persistent features. (Partly based upon Ordnance Survey mapping. © Crown Copyright 2013. All rights reserved. An Ordnance Survey (EDINA) supplied service; partly based upon original plans reproduced courtesy of the Winchester Excavations Committee ©; partly based upon original scans © Crown Copyright and Landmark Information Group Limited 2013. All rights reserved. 1872.)

By conducting the mapping processes in a GIS, but on a conceptual basis, an intricate spatial data structure emerges. This data structure would not normally be at the disposal of historical or social scientists studying material characteristics of urban space together with the relationships between society and space at large. It offers the flexibility to incorporate various degrees of socio-cultural, functional, or time-space historical specification as attributes in the GIS, moving into ever more casuistic applications. This can be achieved on the basis of three units: either per BLT identification, per completely described subdivision, or per specific BLT combination at each unique topological segment (see Fig. 11). Such attribute specifications would never detract from the intrinsic socio-spatial significance conveyed by each spatial data element.

The redescribed built environment plan falls apart in the combinations of colocated BLT identifications along each unique segment of boundary outline. These smallest elements pertain to an essential understanding of the social significance of the presence of that distinction as a site of difference (cf. Abbott 1995). The occurrence of each combination of BLTs gives rise to an additional emergent categorisation characterising a chosen urban built environment. An initial downside is that rather than representing readily perceived socio-cultural or functional spatial categories, these pieces of line complicate the image of the built environment we have, despite allowing precise socio-spatial assessment. Tools for the spatial analysis of these new layers of significance within our data are needed to aid us in exploring large and complex built environment configurations and extract any patterns emerging from the intrinsic characteristics of the particular built form. The analysis of the rhythms and patterns in the composition and interconnectivity created by the smallest meaningful elements of topological segments could reveal aggregate levels of coherence inherently present in a city.

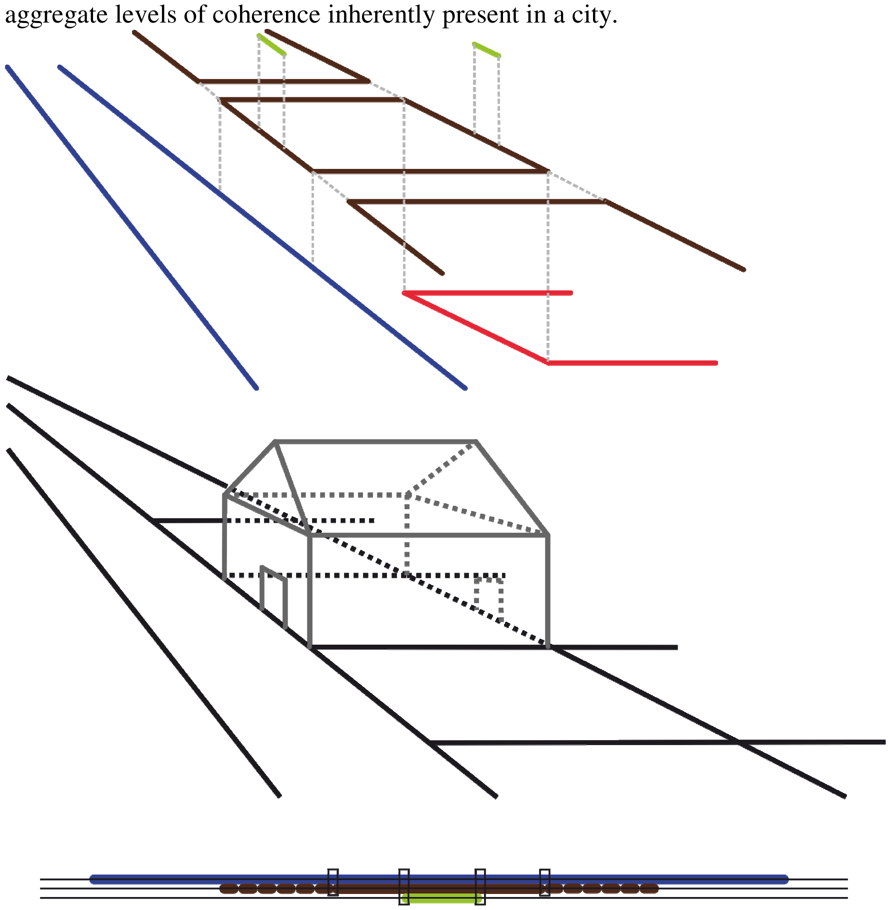

Fig. 11. A schematic representation of the GIS data structure resulting from conducting BLT mapping. The 3D terraced house (grey) on a street represents a simple empirical reality in a usual globalised urban built environment. The base plan (black) results from the physical subdivisions recognised on ground level. In colours above all BLT identifications that would operate on the rectangle of the house in the depicted situation are shown in layers: Type 1 (brown); Type 2 (green); Type 3 (red); Type 5 (blue). Note how only the identifications of the Type 1 of the house's outline and its entrances are completely drawn. Below, the boundary outline of the front of the house is presented as overlaid GIS layers (in thin black lines). The rectangles represent all the nodes operating at the front of the house. Note how three complete socio-spatial descriptions of boundaries emerge: the doorway itself, left of the doorway, and right of the doorway. All are topologically distinct and unique boundary segments.

Future potential of BLT mapping

Despite the need for computational spatial analytical tools to help navigate and order the complexity of the resulting datasets, BLT mapping provides a means to not merely assess the changes and development of urban form *per se*, but the specific socio-spatial characteristics of developing urban forms. That is, the boundary outline itself could change, but even when the outline stays the same, the BLT identifications along the line could change. This offers a key to a more detailed understanding of urban development and to a recognition of socially significant patterns within those processes in each particular case.

An additional advantage of the boundary mapping method is that the resultant spatial data does not abstract or simplify the representation of urban built environments into something that cannot be combined with other extant methodologies. For example, its outline base plans could be adopted as the basis for a space syntactic study, while the intricate data structure could be invested with urban morphological attributes to add layers of information to the research without losing its fundamental socio-spatial bearing. This is important as it has been noted recently that integration of urban morphology and space syntax, or space syntax and GIS, are quite complicated to achieve despite commonalities (Kropf 2009; Pinho and Oliveira 2009; Jones et al. 2009; Griffiths et al. 2010). Although there are undoubtedly various practical complications, the structure of the spatial data generated in boundary mapping seems conducive to integration, because most elementary characteristics of urban form are maintained rather than transformed. Parallel ontologies or typologies of urban tissue and architectural textures (cf. Kropf 1996, 2009, 2011), a functional and scalar typology of urban open space (cf. Stanley et al. 2012), or meaning carrying elements in buildings and planning (cf. Fisher 2009; Smith 2007) could be incorporated, by attributing either topological boundary segments, completely described subdivisions, or individual BLTs.

Flexibility of the method is also found in the source materials used. This paper has demonstrated that in general archaeological survey plans, modern, historical, and historically reconstructed plans can be successfully subjected to BLT mapping. Some of the decisions and assumptions made in this process differ according to that source material, which does not obstruct the method to progress to create fundamentally equal data across cases. Nonetheless, it also demonstrates that the archaeological focus on observing and documenting physically present information makes a better natural fit to this method's requirements and provides important correctives on historical conduct (see Dean 2012b). And within archaeological conduct several alternative mapping practices exist. Not only excavation plans (in other Winchester areas considerable excavation data is available (Keene, personal communication; Scobie, Zant and Whinney 1991)), but also the data produced by various remote sensing techniques reach levels of definition which produce urban plans of sufficiently good quality (see Benech 2007; Maschek, Schneyder and Tschannerl 2011; Paliou, Corsi and Vermeulen 2012).

As an analytical mapping practice within a GIS environment acting as research tool, BLT mapping perhaps does not aim to push forward the theoretical basis of GIS in particular (cf. Haçiguzeller 2012; Gillings 2012; Kwan and Schwanen 2009; Leszczynski 2009), but rather forces GIS to work in a qualitative and theoretically informed way (cf. Hu 2011). It is founded on a framework of human and social understanding structurally coupled with the affording nature of material presence (cf. Gillings 2012; see Vis 2013a). It is historically sensitive in both theory and practice. Requiring first the empirical materiality of space through time, the main gist of the spatial turn in historical sciences — reading spaces as produced in a Lefebvrian irreducible and imaginable way (cf. Griffiths 2013; Arnade, Howell and Simons 2002) — is incorporated in its descriptive and analytical potential. Mapping boundary line types is inescapably a method for the qualitative social scientific use of GIS.

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Table

	Boundary line type (BLT)	Empirically identifiable principle	Social relation to interaction opportunities	Exemplary indication (for western or globalised cities)
1	Closing boundaries	Operates on the basis of seclusion of a continuous spatial arrangement from the surrounding configuration with the material property that the boundary can be closed off towards its outside, thus making it a dominant. It is also a solid (i.e. no internal arrangement of outlines)	Interaction opportunities are quite stringently internalised as distinct from the outside, though there is a mutual (in)direct orientation between the solid dominant and the surrounding configuration	These boundaries typically circumscribe buildings of any sort or size
2	Facing boundaries	Operates on the principle of the orientation for soliciting interaction from the surrounding configuration	Is the site of solicitation of interaction with a dominant	These boundaries represent the doorways or entrance ways into a building
3	Associative boundaries	Operates on the basis of dependence on a single dominant. It is directly associated with and, in a conjunction including possible other (in)directly	Interaction opportunities are mediated between the openness of the surrounding configuration and the related dominant	These boundaries are typically associated with gardens or any plots and surfaces belonging to a specific building

		associated boundaries, with which it forms an adjoining configurative complex		
4	Extended facing boundaries	Operates on the principle of orientation in an uninterrupted connection to a facing boundary by dependence on any boundary associated with a dominant	Is the site of indirect solicitation of interaction with a dominant, proceeding is no necessity	These boundaries are typically associated with garden gates or courtyard entrances, etc.
5	Directing boundaries	Operates on the basis that it directs interaction along opportunities for further boundary crossings in parallels	Interaction opportunities are directed along the boundary crossings that constitute its sides, connecting all sorts of bounded spaces	These boundaries are associated with the street network, access and pathways
6	Disclosing boundaries	Operates on the basis of guiding interaction towards opportunities for further boundary crossings in multiple directions rather than a single particular direction with necessary (in)direct connections to solid dominants	Interaction opportunities are freely organised, yet directed in multiple directions which in several cases will eventually lead to soliciting interaction with solid dominants	These boundaries are associated with square-like spaces in well integrated urban situations with several associated buildings
7	Enclosing boundaries	Operates on the basis of se-	Interaction opportunities	These boundaries are

		clusion from the surrounding configuration with the material property that the boundary can be closed off towards its outside, making it a dominant while containing solid dominants	are restricted by solicitation between the openness of the integration within the boundary configuration and the configuration with solid dominants that it circumscribes	typically associated with city walls and gated communities
8	Mutual boundaries	Operates on the principle that it is simultaneously associated with or encompassing a distinct subset of several solid dominants with which it forms a configurative complex	Interaction opportunities are indirectly directed to several solid dominants and mediated between the openness of thoroughfare	These boundaries are associated with a specific group of buildings without any preference as to which it provides access such as shared porches, cul-de-sacs and communal space in gated communities
9	Opening boundaries	Operates on the principle that it creates open, accessible connections towards its outside, while being an integrated part of the configuration	Interaction opportunities are freely organised, with no prerequisites for boundary contexts and the possibility of thoroughfare	These boundaries can be described as park-like spaces, e.g. garden plots, urban fallow, parking surfaces
10	Neutral boundaries	Operates on the principle of neutrality, which results from ambiguity and the absence of sin-	Due to the absence of a unambiguous relation to a residing socio-spatial system,	These boundaries tend to be the left over areas in less optimally used built envi-

		gular associations, can occur in virtually any context	crossing the boundary creates no difference from the surrounding non-dominant configuration	ronment configurations and also some delimited functional areas connected to streets (e.g. electricity supply)
11	Man-made boundaries of unoccupiability	Operates on the basis of negativity, can occur in most contexts	Negativity means there is no residing socio-spatial system, in this case because an area cannot be occupied by human beings	Structures that create a unoccupiable surface area, such as ponds, canals, architectural talus, narrow gaps, etc.
12	Not man-made boundaries of unoccupiability	Operates on the basis of negativity, can occur in most contexts	Negativity means there is no residing socio-spatial system, in this case because an area cannot be occupied by human beings	Steep slopes, natural bodies of water, etc., which are contained in the built environment
13	Not man-made negative boundaries	Operates on the basis of negativity, can occur in most contexts	Negativity means there is no residing socio-spatial system, in this case because it marks the end of the built environment	'Nature': wild or not fully cultivated areas
-	Virtual boundaries	Sites of distinction afforded by extant physical distinctions, human beings would have understood and/or experienced to	Can in principle be part of any BLT that is not closable or negatively defined	Locations of crossings from space to space are in principle unimpeded and predominantly unmarked such as openings in

		be a crossing from subdivision into subdivision without clear material markers imposed onto the surface		dry stone walls circumscribing fields, or a cul-de-sac connecting to a street with similar surface

Table 1: This represents an abridged version of the full definitions and description of the boundary line type (see Vis forthcoming), which has been adapted from Vis (2013b).

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