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CONVEX- AND SOLID-VOID MODELS FOR ANALYSIS AND CLASSIFICATION OF PUBLIC SPACES

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Abstract. In this paper a semi-automated morphological classification of urban space is addressed systematically by sorting through the volumetric shapes of public spaces represented as 3-dimensional convex and solid voids. The motivation of this approach comes from a frequent criticism of space syntax methods for lacking information on how buildings and terrain morphology influence the perception and use of public spaces in general and streets in particular. To solve this problem information on how façades relate with streets and especially information about the facades' height should be considered essential to produce a richer and more accurate morphological analysis of street canyons and other open spaces. Parametric modelling of convex voids broadens the hitherto known concept of two-dimensional convex spaces considering surrounding facades' height and topography as important inputs for volumetric representation of urban space. The method explores the analytic potentials of 'convex voids' and 'solid voids' in describing characteristics of open public spaces such as containment, openness, enclosure, and perceived enclosure, and using these metrics to analyse and classify urban open spaces.

Keywords. Open public space; convex voids; solid voids; user-guided feature recognition.

1. Introduction – problem and proposal

In the analysis of public space a frequent criticism of common methods such as Space Syntax is their lack of accounting for the effects of building heights, topography and other 3-dimensional factors, for example as pointed out by

Ratti (2004). The analysis proposed here problematizes the space syntax convention of 'convex spaces' while acknowledging their importance in the classification/characterisation of open urban spaces (whether public, semi-public or private). It proceeded from the observation that the spatial characteristics of individual spaces are important even before considering them as parts of a network of traversable streets, plazas, etc. This led to the fragmentation of the 'convex spaces' defined by space syntax into individual volumetric particles – 'convex voids'. These contain information about facades' heights and differences in elevation, and they can be joined according to different criteria that may be chosen: maximum visual field, direct connectivity, relative proximity, etc. – criteria also potentially including height-based factors. The re-joining of individual 'convex void' particles into 'solid voids' can thus be done in ways which tend to reproduce the conventionally accepted classes/categories of open urban space – such as streets and squares – or by using different criteria, to group them in other ways that can possibly lead toward other interpretations. Also, patterns of repetition or similarity can be revealed which are important to understanding the urban fabric.

The observed characteristics of individual spatial volumetric particles – 'convex voids' – and their collection into classes/categories of open space can engage with questions such as what are the intended, possible, and probable uses (functions) of spaces, as well as what different human activities and behaviours might be engendered, promoted, hindered, etc. by spaces having different qualities and quantitative characteristics (Whyte, 1980; Hillier and Hanson, 1984). Thus, many various factors ranging from simple size and shape (Chaszar and Beirão, 2013) to more complex issues such as degrees of containment, openness/enclosure, perceived openness/enclosure, visibility, perceived accessibility/connectivity, etc. can usefully constitute the first level(s) of spatial classification. Many of the requisite evaluations and comparisons of spaces can of course be performed 'manually', as they have often in the past (Moudon, 1997), but these processes can be augmented and extended by means of computational tools allowing the processing of greater amounts of data, generally with greater speed and in greater detail [1].

A subsequent level of complexity analyses the relations of open spaces to each other, first with reference only to their immediate neighbours and later still to consideration of entire open space networks. The focus on individual spaces versus spatial networks is to some extent a matter of whether the emphasis of study (and eventual intervention) is on regarding urban space as a stage primarily for movement about the city (especially vehicular movement) and/or more stationary activities.

In any case, rich and flexible methods of urban open space representation are needed which are capable of responding to such questions, and we next describe our work in developing proposals for such representations. We present our procedure for constructing a 'convex voids' model of central Lisbon as well as calculation of several spatial characteristics derived from that model: containment, perceived containment, openness, perceived openness. Furthermore, through combination and comparison of those measurements we proceed with feature recognition for two urban typologies: 'largos' and riverside open spaces. Exploration of other individual spatial characteristics and their measurement, as well as network analysis through construction of the 'solid voids' model will be the subject of future investigation.

2. Representation of public spaces – construction of analytic model

Void space analysis of urban structures/fabric poses numerous challenges in representation due to the ambiguities of delimiting voids. One common approach (Hillier and Hanson, 1984) is that of using 'convex spaces' as basic units from which to build up more complex structures – urban spaces. A fundamental question, however – even if 'convex spaces' are accepted as a valid starting point – concerns how these spaces should be defined, for example what should be their granularity in terms of size, level of detail, etc.

The main issues stem from (1) the usual ambiguity that the convex space representation has, especially regarding urban space representation, and (2) the incompatible representation of streets in a grid where the representation of a street in one direction always dominates over the other, even when both directions form well defined streets. More specifically:

(1) Although the rules for defining a 'convex map' are clearly stated in the literature, issues of interpretation mean that any two persons will draw a different convex map if they do it on their own. However, they may agree on a compromise map which includes a common agreement on the interpretation of spaces (Ratti, 2004). Agreement on the definition of convex spaces plays therefore an important role in the process.

(2) Even considering that an agreed interpretation of public open spaces will allow stabilizing a convex map into a common working representation, still, such a model fails in providing representations that allow the common perception of streets in a regular grid. In other words, in a grid, two streets cross in a common space that belongs to both streets. In a convex map those crossings will belong to a single convex space and therefore to a single and supposedly the most important street.

Our proposed representation enables analysis to start from a representation which allows for crossings to be identified as areas that ambiguously belong to both streets. The classification procedures will later enable distinguishing the importance or hierarchic structure of all streets or other spaces that by means of visibility, openness, accessibility or other factors seem to obviously constitute a single (if not unique and exclusive) spatial entity.

The question of representation method is relevant for various reasons, including factors such as how much effort/computation the representation requires for its preparation, as well as how the method of representation affects the subsequent analyses and thus influences the insights gained from them. In our work we have examined various ways of deriving void space representations from available data, and we summarize some of our findings here.

2.1. GRANULARITY OF CONVEX SPACE & DRAWING TOLERANCE

The question of granularity arises from the reconsideration of space syntax 'convex spaces' in order to improve them. Even though convex in a plan representation such as a convex map, space syntax's set of 'fattest convex spaces' ignores the changes of space heights and surrounding topography that can significantly influence the visual fields which are claimed to be fundamental for space syntax analysis. Our approach accounts for significant changes in façade heights, such as those between streets segments and crossroads, aiming to define 'convex spaces' at a scale from which it is possible to reconnect them in various ways depending on selected criteria. Accordingly, the convex street segments, as well as crossroads, are understood as separate 'convex voids' giving the possibility of identifying them individually and/or joining them into complete open urban spaces – streets, squares, and other types and sub-types.

The next issue relevant for construction of an analytical model is the drawing tolerance that would allow a necessary abstraction of the considerably uneven urban structure of Lisbon. Therefore, we defined the limit of 1,00 m as the minimal change in shape of buildings or other boundaries that would influence the definition of convex void.

2.2. FROM 'CONVEX SPACES' TO 'CONVEX VOIDS' – HEIGHT CALCULATION AND ADJUSTMENT FOR PERCEPTION

As mentioned earlier, our approach aims at improving the concept of 'convex spaces' by moving it to a three-dimensional realm where surrounding objects' heights have a generative function. Volumetric representation of 'convex voids' uses extruded solids whose height is equivalent to the average height of surrounding buildings. (See also 'containment' in section 3.) For computational reasons the surrounding facades without any height, such as in between two squares or in street crossings, were given a negligible height of 5cm. This serves to avoid issues arising from computations with 'zero' values or extremely small ones affecting numerical accuracy in mathematical operations, as well as allowing visual checking of the model without adversely impacting the spatial characteristics developed.

Since urban voids do not have obvious physical limits, their analysis differs significantly from analysis of buildings. They can be defined on different levels of abstraction and derived from various delimitation rules. The most abstract representation as explained in definition of ‘convex voids’ uses strictly the geometry of urban forms without accounting for human perception. When we include the fact that human experience is by visual field extended out of the abstract geometrical delimitations of ‘convex voids’ we understand that a volumetric height calculated as the average of the adjacent buildings facades’ heights (here referred to as ‘containment’, see Section 3) should also account for information from neighbouring spaces. For that reason, the factor of correction of convex voids’ height is established.

The first model built using the above described methodology shows a few spaces that, although logical in terms of methodological consistency, fail to capture human perception in those spaces. For instance, the solid voids representing street crossings within the regular grid clearly show a very shallow solid void. If we consider that these spaces connect street segments on every side, corresponding to a space that has total connectivity with the neighbouring spaces (openness=1) this means that a such space should be perceived as totally open and not as enclosed space [2]. Still, in narrow streets the street crossing enclosure is not so much defined by the openness to the neighbouring street segments but perhaps more by the edges of the buildings defining those street segments. Such perception obviously reduces as the size (area) of the space rises; let’s say that in a street crossing between two very large streets the closure effect of buildings with the same height will be obviously much lower than in the narrower streets. Considering this we defined an adjustment factor that raises or lowers the ‘convex void’ height depending on the voids’ sizes. Such a factor typically raises the height of street crossings and lowers the height of enclosed street segments, while having only a minimal effect on larger spaces [3]. (Figure 2 in Section 3 gives a view of the model showing the adjusted ‘convex voids’).

3. Identification of typological classes/categories

The analysis of urban open space proceeding from a ‘convex void’ representation lends itself to identification of spatial types at both the ‘convex void’ level and at the level of more complex ‘space void’ agglomerations, where the former analysis to a large extent enables the latter (Figure 1). ‘Convex voids’ can be assessed via a series of measures described below both as simple, preliminary studies of a given urban fabric model, and as compounded criteria. These result in the emergence of spatial configurations and characteristics corresponding to types captured even in common parlance, for example the ‘largo’, which is the name given to a space that is a particular hybrid of street and square. The selection and compounding of criteria can proceed along various (possibly complementary, not exclusive) lines, such as ‘clustering’ or ‘user-guided feature recognition’, as discussed more extensively elsewhere (Chaszar, 2011; Chaszar and Beirão, 2013).

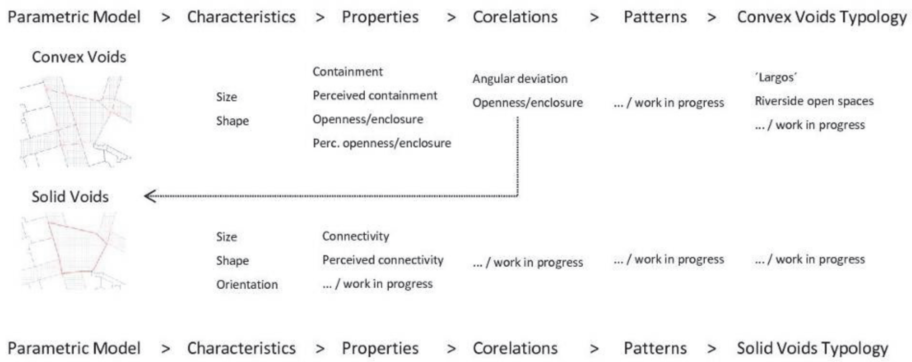

Figure 1. Diagram of relationships among ‘convex voids’ (simple) and ‘solid voids’ (aggregated) characteristics, properties, correlations, patterns and typologies.

3.1. CONVEX VOID CHARACTERISTICS AND PROPERTIES

Size – Size based analysis results show patterns which already give some insight to the structure of urban open spaces. For example, major focal points such as large 'praças', parks and open riverside areas, are immediately distinguishable from smaller squares (e.g. ‘largos’, ‘becos’, etc.) as well as from almost all streets and intersections [4]. Districts are also distinguishable to some extent through the number and distribution of smaller and larger spaces. (E.g.:Alfama (medieval area) ≠ Baixa (regular grid))

Simple shape – Simple shape based analyses such as aspect ratios already present a potentially more refined classification of spaces. Combination of these (2D and 3D) shape results with size of course creates potentially still greater differentiations, such as by further subdividing the categories of streets, intersections and squares suggested by the initial size-based results.

Containment – This measure, represented by height of ‘convex voids’, gives us an idea about the overall containment of an open space. Very low values indicate wide spaces with few or very low adjacent facades, such as ones next to the river, city viewpoint or on the edge of urban tissues. The middle values are mostly connected to the planned urban squares and common streets. Observation of the measure of containment of Lisbon shows the

Figure 2. Partial map of study area showing convex voids' 'perceived containment' values, ranging from least (blue) to most (red) contained.

alternation of feeling tightness and broadness characteristic especially for the old part of the city.

Perceived Containment – Generated from the adjusted heights of 'convex voids' (see Section 2.2), this analysis results in a less differentiated spectrum of space types – as expected due to the 'blending' effect of the adjustment – but meaningful differences and similarities are still discernible. Due to the small granularity of spaces in the medieval area the adjusted heights of convex voids clearly reveals the spaces that are very tightly contained.

Enclosure/openness – Enclosure/openness results are derivable from 2D (plan) data where open sides of spaces are assumed fully open and all others fully closed (or partially penetrable, not part of the present study). It shows us the permeability of the space perimeter, that is, the degree to which it prevents or permits movement to an adjacent space (Figure 3).

Perceived Enclosure / Openness – Perceived enclosure/openness is a percentage of a convex void's faces that is overlapped by surrounding ones.

Figures 3 & 4. Maps of 'openness' and 'perceived openness' values for urban open spaces in the study area, ranging from most (white) to least (black) open.

The value of enclosure 1 would indicate that the space is surrounded only by buildings while a value of 0 that it is completely open, i.e. surrounded by other totally open convex voids (Figure 4). This measure not only shows the relation of a space to its immediate neighbour(s) but also the potential of the space to be experienced as separate and distinct (if enclosure is high) or as a 'transitional space' and a part of the spatial sequence (if enclosure is low).

Further basic metrics of 'convex voids' – in some cases applicable also to compounded 'solid voids' – defined but not yet implemented – are described in the following section.

3.2. EMERGENCE OF SPATIAL TYPES FROM COMPOUNDED CHARACTERISTICS

While a simple analysis along a single dimension of 'convex void' properties can already reflect similarities and differences significant in the roles of various open spaces, more often it is necessary to consider multiple criteria in identifying commonly recognised or otherwise important classes of space.

Some examples from the current study include 'largos' and riverside spaces. In the case of 'largos', a combination of *shape* (longish), *size* (medium), *containment* (high) and *openness* (medium) generally characterises the type, while reduction along the *containment* dimension shifts it to 'rossio', a type more frequently associated with the periphery than the centre. The search for riverside sites might contrastingly proceed from characteristics of larger *size* (though they could also be small in rare cases), low *containment* and high *openness*. However, as one might guess by the nomenclature, a riverside site may be more effectively identified by its proximity (usually adjacency) to a river, in which case a topologically based search accounting also for relationships of neighbouring spaces seems more effective.

Within the observed case study of Baixa Chiado of Lisbon, our method showed possibilities of recognition of common used morphological classification through empirical definition of domain of values of convex and solid voids' characteristics (openness, containment, etc). This showed that in the portuguese language different terms that are used for squares, such as *praça, largo, terreiro, rossio,* are etymologically rooted in an ontology of urban space and place that our method succeeded in capturing.

4. Discussion and further work

The results obtained so far suggest that analyses of open urban space represented as 3D 'convex voids' can give insights regarding the structure of urban fabric and also in the identification of spatial types. The analyses and properties on which we focused until now are essentially related with the search and identification of spatial types which includes the referred methods within the field of urban morphology studies. The introduction of the theme of connectivity through ‘solid voids’ will bring the research closer to the field of space syntax by reintroducing the theme of movement underlying the combination of properties of openness and perceived connectivity.

We note that the presentation and interpretation of results above generally involves the issue of presenting smoother distributions/spectra vs. sharper groupings/bins/clusters. User-guided feature recognition (Chaszar, 2011) favours the former, allowing users to recategorise as wished using meaningful distinctions and exploration, whereas clustering, etc. tend to favour the latter, but both may suggest also categorisations previously not considered (e.g. based on coherence and gaps in distribution) (Chaszar and Beirão, 2013).

Also, extension of this proposed ‘convex void’ approach suggests further work including the following items: 1) Network analysis through construction of ‘solid voids’ model that would re-join the ‘convex voids’ and reconstruct bigger spatial entities through application of connectivity rules and recognition of transitional spaces. Those ‘transitional spaces’ that are characterised by low enclosure can be seen as emergent phenomena depending upon factors (characteristics) such as location, size and connectivity – especially considering these in relation to other spaces, not only as to a particular space itself – which make a space a candidate for 'transitionality' without wholly determining it (neither necessarily nor sufficiently). 2) ‘Solid voids’ models could be reconstructed using different criteria), so configurations such as groupings of space according to the 'axial lines' convention of 'space syntax' methods can emerge from chains of smaller spatial units formed according to more or less rigorous rules. Future work also projects development of additional measurements, for both ‘convex-’ and ‘solid voids’ models, such as: a) *connectivity* (differing from enclosure/openness by accounting for impedances to access, not only to vision); b) *perceived connectivity* (based on 3D enclosure/openness data, due to non-visibility or non-perception of some barriers to movement) and c) *orientation*, that can further distinguish between otherwise identically (or very similarly) -sized and -shaped spaces, and that also gives some insight into district definition even without reference to size or shape, using factors of solar and wind exposures.

5. Conclusion

The presented method for open urban space representation via three-dimensional ‘convex voids’ is an introduction to a broader metrological tool, here focused on central Lisbon’s open urban spaces in order to describe and assess them on several levels. Through development of the conceptual model of ‘convex voids’ are discovered possibilities of measuring individual and intrinsic spatial characteristics such as size and shape and spatial properties of containment, perceived containment, openness, perceived openness and others. Further, through combination and comparison of these properties, and through their application using clustering and feature recognition, open spaces’ typologies, patterns, repetitions and different spatial configurations can be categorised and further explored.

Endnotes

1. Although some evaluations relatively routinely performed by the human eye and brain are as yet intractably difficult to implement as executable instructions to a computer.
2. Note that spaces with openness equal to 1 should have a solid void of 0 height; however, these spaces are represented with the negligible height of 5cm which keeps the model’s consistency avoiding the computation of null values and allowing the solid void analysis.
3. The equation considers the difference between the area of the vertical faces of a space A (A_A) and the average surface area of adjoining space vertical faces (A_v) divided by the space A perimeter (p_A). This gives the gross height correction value gh_A. If added to space A’s void height this value would level space A’s void by the weighted average height of space A and neighbouring spaces. The height correction value H_A is then obtained as a function of the area of space A:
   $$H_A=gh_A*(3/\sqrt{(9+x_A)}) \qquad (1)$$
   where x_A represents the area of space A. If we consider a hypothetical space of null area, the relation will be $H_A=gh_A$, meaning that the closure feeling is the same as the average of the closure on neighbouring spaces, and as the area x_A rises the H_A value decreases assuming very small values for very large spaces but keeping relatively high corrections for small spaces. The value H_A is then added to the void of space A. The value H_A may be positive or negative depending on the neighbouring spaces.
4. The surfacing of these spaces is of course indeterminate without reference to non-geometrical data (though in some cases parks and squares may be differentiated if topography is more accurately represented), so the ‘praças’ are not distinguishable from small parks, but the larger parks are larger than the largest squares.

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