Abstract

The configurational approach to urban settlements seems to disregard the geometric features of their paths: in its topologic view, the morphology of streets and squares disappears so as to remain internalised within the variables which represent the configurational state of the system (Hillier, 1999). And that configurational pattern has been proved suitable to reproduce the distribution of centrality all over the settlement, with the most attractive areas (and therefore most crowded with shops and other urban activities) provided with high values of integration (Cutini, 2001a; Cutini, 2001b). All the same, when the analysis is applied to orographically strongly uneven settlements, the same functional prominence often appear to affect the steeper paths, while the level ones are frequently characterised by a poor presence of activities. An evidence like that, which furthermore seems to hardly conflict with the obvious expectations (a level path is certainly easier to go through and use than a steeper one), puts an unexpected question: is integration then depending on slope, and hence, more in general, is the grid configuration to be considered somehow influenced by the geometric (here orographic) features of the settlement?

Differently, the thesis of the paper is that in such urban settlements the slope of the paths, far from being its cause, is anyhow correlated with the distribution of integration. Such an assertion is tested in several case studies (among them Arezzo, Castiglione della Pescaia, Massa Marittima, San Gimignano, Siena, Vinci), corresponding to Italian historic urban settlements which were founded and arranged on high and steep rises. And those tests provide an outstanding confirmation to the supposed correlation: as a matter of fact, slope and integration do match, and then also slope and urban centrality result to some extent well correlated. Such a correlation will then be discussed, in order to understand what is likely to influence both the slope (that’s to say the way they are disposed) and the configurational value (that’s to say the way they are mutually connected) of urban paths. Not only does integration, hence, reproduce the internal geography of an urban settlement with regard to the distribution of activities and land use, that’s to say the way that settlement is used; it also can describe (roughly but constantly and reliably) the way an urban settlement fits the specific orographic condition of its site, that’s to say the way that use is actually made possible in the local geographic context.
Introduction

Going to the core of the question, studying the configuration of an urban settlement means to analyse a spatial system which is directly derived from the urban layout, so as to provide each single element of that system with a full set of variables, which identify the configurational state of the settlement. On such basis, to analyse the configuration of an urban grid means to define the characteristics of each of its spaces as they result from the relations which connect it to all the other parts of the grid; down to the facts, it means to define, for each single element of the system, a set of numeric values correspondent to its configurational indices; these indices, all together, are assumed to describe the configurational state of the system.

The configurational value of each element, which roughly corresponds to a portion (a single space) of the urban grid, is then obtained from the relations connecting it to all the other elements of the system (that's to say to all the other spaces of the grid). All in all, two fundamental questions arise from the matter: which kind of relation has to be selected so as to connect the elements of the system, and how to reduce the urban grid into a set of discrete elements, so that, structured by such relation, it can be assumed as a spatial system. Three decades of researches and experimentations have been producing several answers to such questions: among them, the axial map and the intersection between lines (Hillier, Hanson, 1984; Hillier, 1996), the visibility graph and the visual connections between vertices (Turner et al., 2001).

All these techniques appear to share the abstraction from the physical consistency of the grid, in that just the relations connecting each element to all the others, rather than its geometric or morphologic features, are what actually determine the configuration of the system and the configurational values of its elements. And just the measure of these relations, rather than other aspects, is what can be properly said the configuration of the urban grid.

On such basis, the geometric features of the grid simply do vanish, as substituted by the relation between its spaces. Or, what's more proper saying, such features do not really disappear: they rather just remain hidden inside the spatial relations, so to appear internalised within the spatial system of the urban grid, as well as to get implicitly reproduced by its configurational pattern (Hillier, 1999). This capability does actually appear a precious resource, making the configurational techniques suitable for managing also the morphologic aspects of an urban settlement, thus overcoming a typical fault of quantitative town planning models (Lee, 1971). As a matter of fact, the configurational techniques have been proved to be a useful and reliable tool, when applied to determine and reproduce the distribution of urban centrality, defined in terms of attractiveness towards activities: more in detail, the integration value (both local and global) was proved an outstanding indicator of attractiveness, since it results strongly correlated with the actual density of activities along the urban paths (Bortoli, Cutini, 2000; Cutini, 2001a; Cutini, 2001b). Such a result appears exceptionally useful, both to understand the inner geography of settlements and to predict and, even more, support the planning of their future developments.

So far, we've been talking of the spatial layout of the urban settlement, as it commonly appears described by its planimetric representation; yet, no effort was made towards the third spatial dimension, in order to take into account also the altimetrical variations within the urban grid. Do they influence the distribution of configurational indices? Or, instead, is such distribution unaffected by the orographic pattern, which can then be regarded as a mere morphologic aspect, with no
consequences on the actual use of urban space? Or, even, do altimetrical variations too result internalised within the configurational pattern of the grid?

Eventual effects of altimetrical variables are likely not to affect the configurational pattern of most urban settlement, when their inner geography, as it is in most cases, is characterised by a flat (or almost flat) geometric layout, so that we can easily overlook their third dimension and plainly focus only on their planimetric morphology and representation. No inferences, of course, could then be drawn out of researches around such urban settlements. Only orographically irregular settlements, frequently provided with significantly steep paths, will hence result suitable as a reliable field for studies on such matter: and, on this regard, Italian historic centres appears a precious and endless research field for such experimentations.

The ancient historic centres in Italy, in fact, were constantly settled over high and steep rises: the presence of several external threats (rival cities, foreign invaders, pirates incursions) and the absence of a strong unitary political power have been pushing up there, from the undefended and dangerous flatlands, any urban settlement since the fall of the Roman empire and up to the XIX century. More in particular, in the Middle Age, since the first recovery of urban life and settlements and up to the invention and the spread of the gunpowder of fire arms (that’s to say since the IX up to the XV century), the altitude and the slope were sought, selected and used as a territorial weapon against any external thread: the steepness did therefore become the natural ground for the arrangement of the inner geography of urban settlements (Detti, Di Pietro, Fanelli, 1968).

Since the last decades of the XIX century most of those settlement went atrophying, as population and urban life shifted towards the more accessible flat countries; so that they still remain today substantially unchanged by recent urban developments, as a precious material testimony of the way high and steep rises have been actually urbanized in the past and lived for centuries. Their presence does hence suggest us to investigate around some interesting questions. Is such arrangement somehow correlated with the configurational pattern of the settlement? Or, in other words, is orography too, beside the other geometric features, somehow internalised within the configuration of the grid?

**Case studies**

In order to verify the presence of any correspondence between configuration and orography, we’ve selected a sample set of historic towns which were all settled in Tuscany in the Middle Age, and that are all characterised by their position on high rises as well as by relevant steepness all over the settlement, as their paths result provided with slope mean values over 5 %. These are the selected settlements: Arezzo, Cortona, Massa Marittima, Montalcino, S.Gimignano, Siena, Vinci, Volterra: quite different physical and demographic consistency (population varying from few thousands at Vinci to 50000 at Arezzo and Siena), quite different historic genesis and vicissitudes, quite different political and administrative role and importance (some once capitals as state-towns, some mere military outposts), quite different geographic locations (some in the Appennine inland, some along the coastline), quite different morphological patterns. Only an unquestionable common denominator: their position on high and steep rises. Just slope, meanly over 5%.

In such settlements, the steepness will be obviously expected to play a role of deterrence towards the location of activities, in that it makes harder the paths, discourages their actual pedestrian use and hence
increases the spatial impedance between the origins and the destinations of movement. In other words, central spaces (defined as the most crowded with activities and then movement) will therefore be expected to be along the flat paths, more easy and inviting, so as to reduce the actual spatial impedance, while the steep ones, so hard to go through, should likely be far more segregated and deserted. Such assertions, although obvious by simple intuition, could be easily confirmed by means of an interactional approach, if we only would appraise the spatial impedance between locations in terms of mean movement time, or in terms of trouble, nuisance and effort, what anyhow increase as the slope of the path from the origin to the destination gets bigger. As a consequence, the urban spaces which lie on steep paths will result provided with lower values of economic-spatial potential, that's to say they will be characterized by a poor level of generalized accessibility, while we could easily recognize as the most accessible places just the flat ones, plain and easy to go through, well inviting for movement and hence optimal locations for the setting of activities.

The experimentation over our cases was aimed at verifying such an intuitive expectation, by means of the analysis of the correspondence on their grids of the levels of urban centrality (assumed in terms of attractiveness towards activities, resulting from the observed density of the existing ones) with the actual slope of the paths, as it results from its direct survey. And the results were quite surprising, so as to turn round the above sketched expectations: in all cases the distribution of the density of activities does not correspond to the flatness level; even more, flatness and attractiveness do appear negatively correlated, so as to show activities preferring to be located along the steepest paths, against the expected logic. Even more, in most cases, the main urban street (that is the most crowded with shops, and offices, and people strolling, and urban life) just coincides with the steepest street (or at least one of the steepest streets), where at a guess shops, and offices, and strolling people and urban life should not be.

At Arezzo, at Massa Marittima, at Siena, people (both young and elderly ones) cheerfully climb over a 10 % steep main street, and there go for shopping, patronize the most prominent activities, go to the church, meet and relate each other, neglecting and leaving deserted most of the level streets. We could also add that those steep and crowded paths in all cases go and converge into the main wide open space of the grid, the "piazza grande" of the settlement, the public place that was recognized the suitable urban seat for meeting, gathering, interaction (Cutini, 2003). In other words, far from discouraging movement (and hence the location of activities), the slope of the paths appears so as to attract it, and therefore to stimulate activities to locate in order to flourish, taking benefit from such a precious irrigation. Can such a singular phenomenon be considered as casual or incidental, despite its regular confirmation in all the selected urban cases? Or, on the contrary, should we assign the slope some attractiveness towards the pedestrian movement or towards the presence of urban activities, despite any behavioural logic? Or, and that's our thesis, could we consider the inquired aspects (the presence of activities and the slope of the paths) both significantly correlated with the configuration of the urban grid, so to allow us to regard their mutual correspondence as a logic consequence, rather than a singular fortuitous incident (thesis 1) or an improbable deterministic effect (thesis 2)?

In order to verify this thesis, we've then analysed the configuration of the selected urban grids, so to obtain the distribution of the configurational indices and, in particular, the distribution of integration,
which was proved to be a reliable indicator of the level of urban pure accessibility. The purpose was to investigate the correspondence between configuration and centrality, and the correspondence between configuration and slope. In the affirmative, we should infer that, just as in the previously studied cases, urban centrality can be assumed as a function of the grid configuration; but we should also try to account for the correlation of configuration with the slope: somehow, the distribution of the configurational indices in the lines of the grid should in fact depend on the slope of the correspondent paths. As the only macroscopic limit of this test, it’s worth pointing out that the correspondence of the streets of the settlement with the lines of the axial map of its grid is actually inevitably rough, since in most cases a single line does corresponds to several streets, or a single streets is actually covered by several lines. But that's all.

The result of the configurational analysis provides a strong confirmation to the prospected thesis. In all the selected cases, configuration and centrality (again appraised in terms of attractiveness towards activities, and then reproduced by the actual presence of the located activities) appear narrowly correlated. Grouping the lines in 12 sets, in order to clean the distribution of integration from any incidental effect, the resulting correlation was attested by $R^2$ values always well over 0.75; in some cases (Massa Marittima, Siena, Volterra) the determination coefficient resulted over 0.90, referred to an exponential relation between the variables. More in detail, as a matter of fact the centre of the settlement, defined according to the density of the located activities, does coincide with the integration core, and in most cases the main street, the “corso” (as it is named in Italian towns, so as to define the stroll path, the most crowded with people and shops) is just the prime integrator. And that just can’t be a mere incidental coincidence. Configuration (as it results expressed by the distribution of the integration value in the lines of the grid) is therefore strongly correlated with activities, so as to prove their location (and hence the attractiveness of the correspondent urban spaces) as a direct function of integration; as it can be argued, the exponential form of the relation can be easily referred to the multiplier effect the located activities are likely to play, attracting movement and then additional activities (Hillier et al., 1993).
The second (but fundamental) part of the research was the analysis of the correspondence between configuration and slope, which was carried out on the same urban cases, studying by regression analysis the correlation of the integration value of the streets (that is, roughly speaking, the correspondent lines) versus their mean slope. Again, such analysis was carried out with reference to groups of streets, in order to neglect, or at least to strongly limit, the effects of local, incidental and fortuitous elements. And, again, in most cases (7 on 8) the presence of a correspondence was certified by the result of a significant correlation coefficient, when referred to a linear regression. On such basis, we went on searching a further prove of this correlation verifying the correspondence of integration versus slope in the grid of other 10 settlements, smaller in size and hence far easier to study and analyze. Here are those further case studies, all located in southern Tuscany: Arcidosso, Castiglione della Pescaia, Cetona, Gavorrano, Giglio Castello, Lucignano, Manciano, Montemerano, Montepescali, Scarlino. Those settlements actually correspond to the fortified core of ancient Tuscan towns, which in the recent decades (since the mid XX century) have been widely developing outside the town walls, so as to determine the radical shifting of the activities in the suburbs and the complete functional emptying of the historic centre (Detti, Di Pietro, Fanelli, 1968). Of course, in those settlements we cannot study the distribution of centrality (lacking any activity we can’t determine the likely attractiveness of the correspondent spaces), even if in some cases we can make some guesses, basing on the position of some ancient prominent functions (the main church, for instance, or the ancient seat of political and administrative power) whose building are still easily findable on the grid. All the same, assuming centrality as a direct function of configuration (on the base of the researches so far), we did feel allowed to investigate around the correlation of configuration and slope. And in all the additionally
selected cases the results appear fully confirming our thesis: as a matter of fact, integration and slope go together, linked in most case by a linear relation, attested by significant coefficients.

What can we deduce by such singular result? In general, we can’t but notice that in orographically irregular settlements slope and integration are significantly related, so that the distribution of slope can, at some extent, reproduce also the distribution of the levels of integration. And such correspondence remains within a material sphere, involving only geometric features and configurational patterns. Still, such correspondence let us draw out another, quite singular, inference: slope and centrality, by means of their mutual relation with the grid configuration, are significantly correlated, so that in many cases we can identify the most central urban areas just in the steepest paths. And that inference appears dramatically conflicting against the intuitive expectations on the relation between slope and attractiveness towards activities. In other words, configuration, as linked according to different relation with slope and attractiveness, seem to play a role of go-between with them: as linearly correlated with slope, it appears to attract activities towards the steepest paths, while common sense would suggest the opposite.

All the same, the correspondence of configuration with slope can’t be merely accepted as a matter of fact; since it appears to invert the most obvious expectations, it’s worth discussing it and accounting for it, so as to let us fully understand such an outstanding relation.

Few urban cases, selected in the others as particularly small and simple so to work as paradigmatic samples, can be here presented and discussed in order to account for this singular phenomenon. On such regard, in order to take into account the original urban pattern, we’ve used in this further experimentation the urban consistency preceding the (little, to tell the truth) transformations which have been carried out in the last decades; with such aim, we have used the precious drawings of the Lorraine cadastral register, which capillarily covers (drawn to a scale 1:1250) the whole territory of Tuscany at the date of 1825.

First, let’s have a look at the smallest urban case, the ancient village of Castiglione della Pescaia, which around the XII century was erected by the Republic of Pisa as a fortified military outpost on the Tyrrhenian Sea. The settlement, still encircled within its ancient town walls, lays on a high and steep hill over the coast line, with a difference in height of more than 50 metres, what determines a mean slope of the inner paths which varies from 0 % up to 15 %. The regression analysis of the correspondence between slope and integration shows a very strong correlation, attested by $R^2 = 0.92$. The steepest street (characterized by a mean slope value of 16 %) is the path that connect the entrance gate of the town walls (down the hill, on its eastern side) to the turreted castle (on the top of the hill, on its western one) is even by far the main integrator; on the contrary, most of the other streets, which are studded with the largest part of the housing estates, appear almost flat, running as concentric crescents around the top of the hill, southbound to northbound parallel to its contour lines. It’s worth noticing that most of those houses, arranged parallel to he slope of the hill, present on their side downhill one more level than on the side uphill. Other steep paths (and among them some even provided with stairs) cross those level streets, and offering the possibility of climbing the hill gain a relevant integration value. Drawing out some conclusions, it’s possible to say that the village appears “naturally” arranged according to the contour lines of the hill, and that the paths which connect its lowest side to the top are disposed according the maximum slope direction of the hill, so as to
result, orthogonally crossing all the other streets of the settlement, the most integrated lines of the urban grid. We cannot but specify that in XX century most of the economic activities of the settlement have shifted outside the ancient encircled town to locate in the suburbs; all the same, it’s easy to notice that all along the steepest path (i.e. the main integrator) still we can recognize the presence of the doors of pre-existing shops and stores, what is likely to indicate that street as the most crowded with activities all over the village before its recent suburban development.

Figure 3:
A planimetric representation of Castiglione della Pescaia at 1825 (from the Lorraine cadastral register)

Figure 4:
The urban grid of Castiglione della Pescaia in 1825 (with overlaid its contour lines) and the lines correspondent to the street meanly steeper than 12%
As a further, small example, here we present also the ancient urban centre of Manciano, which was constructed in the XIV century as a feudal settlement around a castle, which lies on the top of a high rise in the inland of southern Tuscany. Also this settlement is characterized by an irregular orography, with steep paths which get over 70 meters in heights. Also this settlement is actually still regularly inhabited, but, just like in Castiglione della Pescaia, all the economic activities have moved from the ancient core towards the new development areas of the XX century, so as to leave the original settlement as an entirely residential urban area. Again, the study of the correlation between slope and integration has provided outstanding results, with a determination coefficient $R^2 = 0.90$. and also in the case of Manciano it is possible to recognize the distribution of the larger part of housing buildings along a sequence of flat streets that revolve around the castle following the contour lines of the hill, and a minor part of streets that connect the lower areas (and especially the gates of the town walls) to the higher levels (and in particular the areas surrounding the castle, on the top of the hill). It’s easy to find out that the level streets are provided with low values of integration, while the integration core of the grid interest the radial (and steeper) ones. Also in this urban case, the ancient dense presence of shops and stores along the main integrator (that’s to say along the steepest path of the settlement) can be easily retraced in the lots of doors and gates and windows that, now closed, appear lined up that street; on the contrary, the level paths which run parallel to the contour lines of the hill are outlined by merely residential estates, whose windows overlook the flat country downhill.
Figure 6:
A planimetric representation of Manciano at 1825 (from the Lorraine cadastral register)

Figure 7:
The urban grid of Manciano in 1825 (with overlaid its contour lines) and the lines correspondent to the street meanly steeper than 12 %

Figure 8:
Distribution of integration in the lines of the axial map of Manciano
Arcidosso is the third case we here present as an example. It’s located at a bigger altitude (over 600 metres above the sea level), but it still shares their ancient origins (around the X century) and quite similar orographic features: a high and steep rise circled by ancient town walls, a lower side, with the gates of the town, a castle on the top of the hill; here the town walls were far ago demolished and removed, so that they do no longer appear in the urban layout. Again, a strong correlation result characterizing the correspondence of slope with integration ($R^2= 0.90$) and again the prime integrator is the line which roughly corresponds to the steepest streets (with a mean slope over 12 %); and thanks to the lasting presence of shops and offices, it’s easy to recognize that street as the main street of the settlement, the most crowded one, the “corso”. Besides, also the most prominent historic functions of the settlement lie along that line, so as to confirm it as the central path of the whole settlement.

Figure 9:
A planimetric representation of Arcidosso at 1825 (from the Lorraine cadastral register)
And we could go on, stepping from a settlement to another. Summing up the results of the experimentations sketched above, several common elements seem to arise, so to point out a peculiar role the grid appear to play. Its role, as it results from a configurational approach, was squarely hit defining it as “a mechanism for generating contact” (Hillier, 1996b); now such role is confirmed and ever detailed, defining the urban grid as the real intermediary between the place (with its physic and geometric features, and orography above all) and the functions that are at being arranged over it.
Conclusions

The following inferences can briefly summarize the fundamental common elements which can be drawn out of the researches so far.

- All the observed settlements are characterized by an uneven orographic pattern, as they are arranged on the slopes of high rises.
- The settlement were (and still at present are) encircled within ancient townwalls, located at the foot of the hill.
- The gates of each town are disposed in the lower areas of the settlement, while the top of the rise is generally occupied by a castle or a fortress.
- Most of the residential estates are arranged on the level, along little (or even not at all) inclined streets that revolve around the top of the hill, almost parallel to the isohypses of the ground.
- Few paths connect the lower areas (and the gates, above all) to the higher ones, intersecting the level streets according to perpendicular angles.
- As a result of configurational analysis, the level streets appear mostly segregated, while the integration core of the urban grid does coincide with the steeper ones that climb up the hill.
- In the bigger cases, where economic activities still do remain within the ancient core of the settlement, it is possible to verify the actual correlation of slope with integration and the correspondence of both them with centrality (defining it in terms of attractiveness towards activities). In all the other cases, where the inner core appears now completely residential, only the correspondence of slope with integration can be actually tested: what was regularly and positively verified.

But if the considerations above can be asserted as a matter of fact when referred to the selected urban settlements, what kind of conclusions can be drawn out, more in general? In such case, we ought to point out and eliminate all the incidental and specific elements that are likely to concur in favouring the observed correlation, such as the position of the town gates in the lower areas or the presence of the castle on the top of the hill. Yet, even if the elimination of those elements could weaken the strength of the correlation, all the same some general assertions can be easily drawn, so as to be suitable for the application to any kind of urban settlement.

First (and most obvious): morphology and configuration are undoubtedly linked, in that the way the blocks of buildings are singularly shaped and mutually disposed within a whole settlement, as well as the way the paths are arranged in order to connect all them, does certainly influence the distribution of the configurational indices. And in such arrangement the orography of the site represents a fundamental variable, so as to determine the recurrence of typical solutions in the urban genesis and development, what implies the recurrent appearance of some typical configurational pattern. And the configurational pattern, in its turn, determines typical and recurrent effects in the land use and in particular in the distribution of urban centrality.

Second (and less obvious): orography does matter, and not according to the traditional and intuitive appreciation, which regards the spatial impedance as a function of slope, positively correlated with its values: orography does matter in that it influences the organization of urban space, and then the configuration of its grid. In some cases (those here summarized), such influence can ever determine the attractiveness of the steepest paths and the segregation of the flattest
ones. In such sense, the orographic features of a settlement can be said internalized within the variables which represent the configurational state of the system.

Third (and least obvious): not only does integration, hence, reproduce the internal geography of an urban settlement with regard to the distribution of activities and land use, that's to say the way that settlement is used It can also describe (roughly but constantly and reliably) the way an urban settlement fits the specific orographic condition of its site, that's to say the way that use is actually made possible in the local geographic context.

References


