PERMEABILITY MAPS OF RESIDENTIAL SETTLEMENTS WITHIN THE COASTAL AREA OF SURABAYA, INDONESIA

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Abstract

This paper is concerned with the spatial structure of traditional coastal settlements in Indonesia. It examines the implications of the open space network for visibility and patterns of airflow, both within and around these settlements. Within the field of space syntax, axial and/or permeability maps have shown a strong and consistent relation between space and movement (circulation). In this study the relation is explored further using a computer-based form of visibility graph analysis, Depthmap. Drawing on techniques of performance simulation developed in the field of computational fluid dynamics, the strong open-space structure of the fishing settlements is considered from another perspective - that of airflow. Computer modelling of wind speed and direction illustrates the combined benefits of accessibility, space-use and air movement. Location and orientation are favourable to the daily life and activity of fisher folk along the coastal fringes of the northeast, owing to the day/night shift in wind direction from land (west) to sea (east). The layout of these traditional forms of settlement cannot be attributed to any single factor. Visibility would seem to be an important generator, but airflow and ventilation may still perhaps prove to be the most important.

Introduction

The discussion in this paper will centre on a group of three fishing settlements that have grown up along the coastal fringe of the city of Surabaya, the administrative capital of the east-Java region (Darjosanjoto, 2002). As shown in Figure 1, Surabaya is confined by the coast on three sides - the north, the east and the south: the settlements of Cumpat, Kejawen, and Sukolilo Tengah lie along the northeast coast (Figures 1A, 1B and 1C) (see Darjosanjoto, 2002). Recent expansion of the city and extension of the road network (including the formation of radial routes and an outer ring road) have progressively strengthened links between the eastern fringe and the inner city. Street widening and upgrading, undertaken by the local authority, have also improved transport connections between neighbouring coastal settlements, allowing increased use of motorcycles, cars and public transport.

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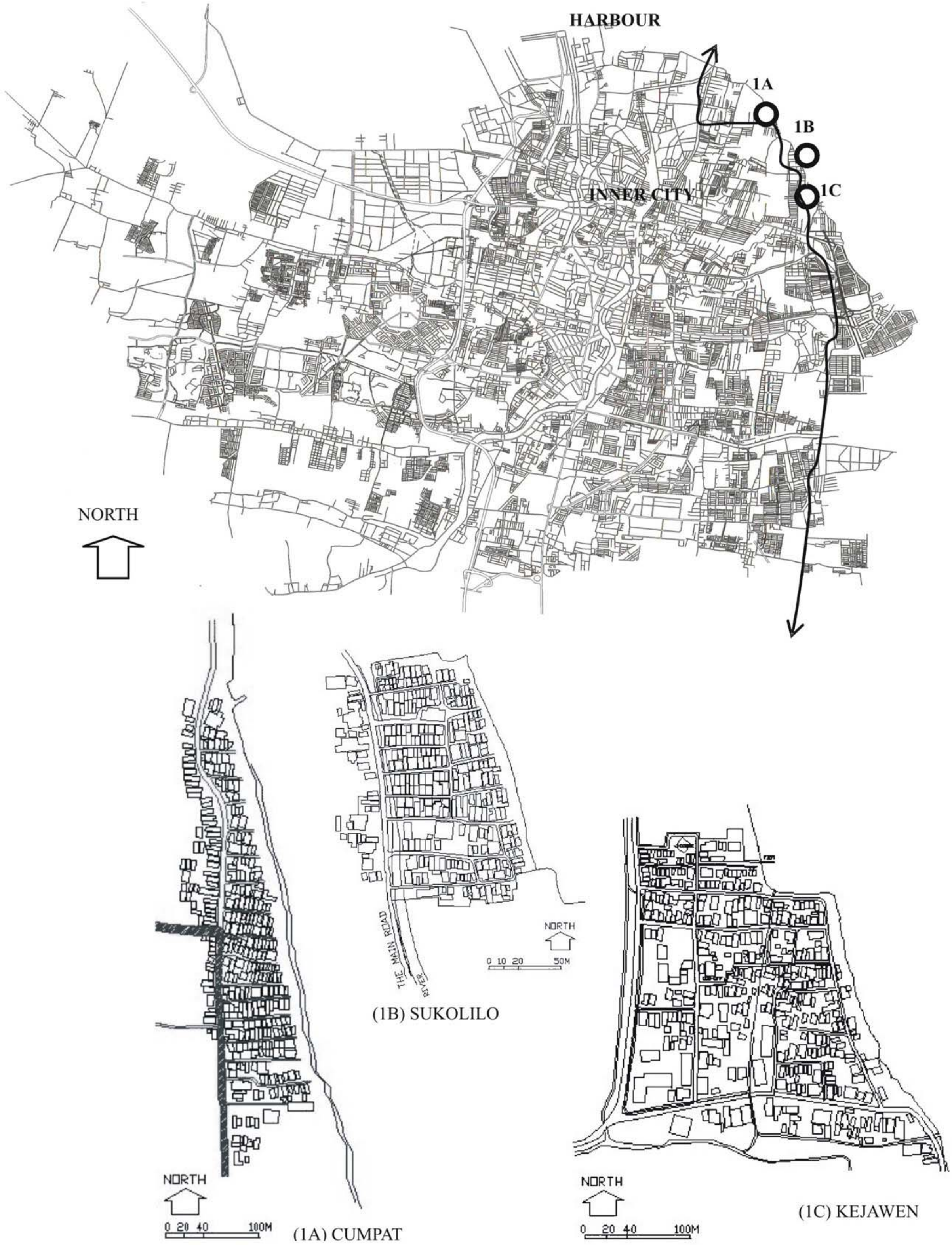

Figure 1:

The map of Surabaya and the three fishing settlements location:
1A-Cumpat, 1B-Kejawen and 1C-Sukolilo

Traditional Coastal Communities and Settlement Form

Coastal settlements occupied by fishing communities tend to be linear in form, closely following the line of the shore. In this context tradition dictates that dwellings are laid out in roughly rectangular blocks. Surrounding the blocks is the continuous open space of the street network. The main streets run in an east-west direction, and provide the frontage for most houses. They are characteristically arranged with their long dimension aligned north-south. Whatever its practical advantages, a north-south orientation is clearly believed by the local community to be beneficial, leading to happiness and protecting the dweller from any afflictions (Darjosanjoto and Brown, 1999). East-west routes, which are everywhere lined by building entrances, ensure a high level of permeability between house and street. They are also the primary link between the centre of the settlement to the shoreline or the main road.

As reported in previous studies (Darjosanjoto, 2002), these east-west lines accommodate many different sorts of activity: they are a place for meeting, chatting, washing clothes, and minding the children, as well as for drying fish - the main source of their livelihood - mending nets and selling goods. They are also the focus of games and hobbies, and are where the men keep their caged birds. At the end of the block corner houses sometimes contain a side access, linked to the private rooms (for washing, praying) at the back of the house. However, dwellings are rarely aligned in such a way as to have their main entrance on north-south routes: these remain predominantly 'un-constituted'. As shown in Figure 2B, the north-south streets, while they may link one dwelling area (or 'block') to another, are normally flanked by continuous walls to each side, unbroken by doors or windows.

Syntactic Representation and Interpretation of the Settlements

An inherent problem in the representation and analysis of the open space structure of a settlement (i.e. the system of space open to public access) is its spatial continuity. While the interior of most buildings is sub-divided into a series of discrete spaces (rooms), the outside has no such divisions: it is a single, unbroken element (Figures 1, 2A and 2B). It is necessary, therefore, to capture the continuous nature of urban space without losing the idiosyncrasies of the system. To achieve a consistent and objective mapping of spatial relations, Hillier and Hanson's space syntax approach is has been used (Hillier and Hanson, 1984 and Hillier, 1996). 'Axial' and 'convex' maps were drawn of every settlement to delineate the spatial pattern. The axial map represents the maximum global linear extension of any part of the system within the settlement. Convexity, the counterpart of axiality, records the two-dimensional extension of space (i.e. its 'fatness'). Every point in the system has both a one-dimensional and a two-dimensional form: it therefore has both a global and a local aspect. The social implications are that "convex space describes where the person is in the system, whereas axial lines give information about where she/he might be going". Axiality would seem, therefore, to be particularly associated with movement, while convexity is more associated with co-presence. In consequence, axiality tends to be related to strangers, while convexity is associated with the inhabitants (Darjosanjoto, 2002:61, cit. Hillier, Hanson and Peponis, 1987).

The system of axial and convex space in the three fishing settlements consists of a series of parallel east-west streets, which link the western edge of the settlement (now the outer ring road) to the shoreline. Two forms of extension characterise these open spaces. The first is where a one-dimensional link is defined by a sequence of adjoining building blocks. This axial extension suggests that the open space serves primarily as a circulation route. The second form is where a series of convex spaces do not share a common building line but describe individual spatial units, which may be bounded by a fence or wall. Taken together, these elements produce a structured, coherent pattern of open space, which takes in the eastern outer ring road (represented by a darker tone, see figure 2C). The interface map indicates the potential for interaction between strangers and inhabitants. The building blocks themselves have the following ground coverage: Cumpat: 43%, Sukolilo Tengah: 53% and Kejawen: 54%.

Axial Integration and Permeability of the Settlements

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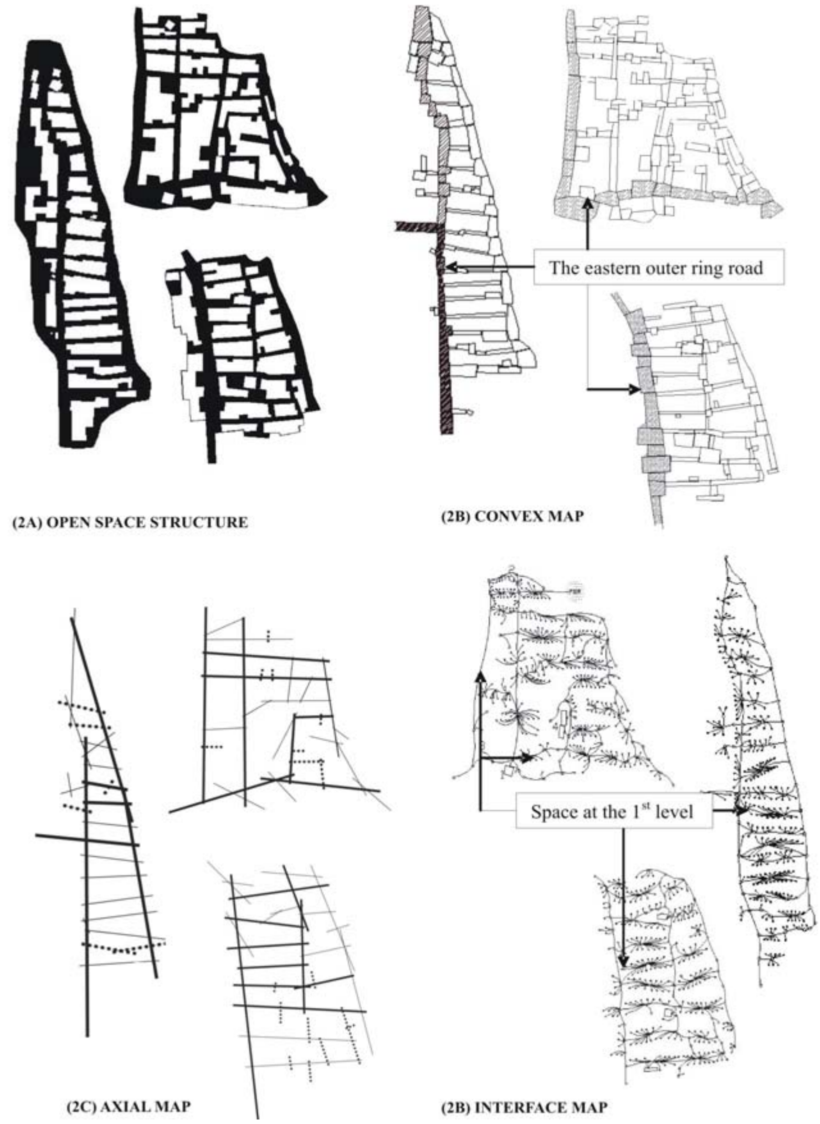
As shown in the axial maps (Figure 2C), Cumpat and Sukolilo Tengah are a type of fishing settlement which is linear in form and very regular in its pattern of axial and convex space. Parallel streets, linked one to another, make Kejawen more compact than the other two fishing settlements (Figures 1A, 1B and 1C). Permeability maps transform the convex map into a graph, which shows the relation between one space and another. Settlement interface maps (Figure 2D) convey, more or less, the permeability of the settlement. This interface map clarifies the fact that the system is shallow from outside the settlement. Some of the east-west open spaces represent convex spaces that are as long as axial spaces, allowing an uninterrupted view from the front of the dwelling to the shore. Thus they are not only the place for day-to-day activities within the settlement, but also the crucial link between the world outside the system and the deepest part of the system - the fishing ground. Following Hillier and Hanson (1984), convex size can be associated in this case with increasing connectivity to segments of space, rather than increasing permeability of buildings.

Figure 2:

Syntactic representation of the settlements case study: open space structure (2A), convex map (2B), axial map (2C) and interface map (2D)



The most integrated line of all lines (which should theoretically carry the most movement) is the main street of the settlement – the north-south route, which defines the western edge of the settlement. It is an important route in the regional context, since Cumpat and Sukolilo both form part of the eastern outer ring road of Surabaya, linking one fishing settlement to another. In Kejawen it is the line running in a northerly direction at the heart of the settlement (represented by a dark line). These lines are clearly used by the inhabitants. They also invite movement by outsiders as well as the locals. Though the settlements are quite open and accessible, the inhabitants do not find it necessary to provide guardhouses to oversee the movement of outsiders, either at the entrance to the 'village' or along the shore. The main north-south street is not only part of the eastern outer ring road (global street), but also the origin of all streets running in an easterly direction (local streets).

Visibility Mapping

A rough picture of the open-space structure of the three settlements can be obtained simply by visual inspection. To make the discussion more systematic and rigorous, we have employed a set of techniques, recently developed, for the representation and analysis of spatial structure, i.e. visibility graph analysis (VGA). In our case the external space surrounding each of the settlements was treated as a single, unbroken element, and the 'depth' of spaces within the settlement calculated accordingly (Figures 1A, 1B, 1C and 2A) The relation between visibility and permeability is critical to an understanding of how settlements work spatially and how they are experienced by their occupants. VGA can help to clarify this relationship.

Turner (2003), the author of depthmap, an automated method of performing visibility graph analysis, has divided the measures into two groups. One group consists of global measures, such as mean depth and point depth entropy; the other deals with local measures such as clustering coefficient and control. We have concentrated on local measures. Clustering coefficient (CC) as formulated by Turner *et al* (2003) had its origin in the analysis of small networks**:** it is useful for exploring the direction of junction points on plan. Control, on the other hand, denotes the relationship between the current neighbourhood and those immediately adjoining it. As Bellal (2003) has shown in his study of traditional house-types in the M'zabite of southern Algeria, the various properties of the visibility graph can provide useful clues with respect to wayfinding and movement within a house or other building. Returning to the system of axial and convex space (figures 2B and 2C), it can be seen that a low mean depth corresponds to a regular and linear layout, and one which facilitates movement in and out of the settlement. In terms of accessibility and visibility, Kejawen requires slightly more effort to get from one place to another. This may be due to the irregularity of shape compared to other two settlements and the greater incidence of junctions and turning points within the spatial structure leading to open-space clusters.

Viewed in terms of their clustering coefficient (Figure 3A), the values for the three settlements were as follows: Cumpat from 0.5544 to 0.9754, Kejawen from 0.3849 to 0.9418 and Sukolilo from 0.4510 to 0.9465. Kejawen clearly has the lowest value and the largest range of values across the sample. This would seem to suggest that more opportunities arise for the pedestrian when walking around the settlement of Kejawen than in Cumpat or Sukolilo. In other words, Kejawen's layout embodies, or promotes, multidirectional fields of view, whereas the elongated plan of Cumpat, tends to minimise the spectrum of views within the spatial configuration.

Control yields a similar spectrum of colours in the three settlements (Figure 3B). Though not extensive, those portions of the settlement coloured nearly black (high values), are significant in that they link the outer ring road, on one side, with the beach and fishing grounds on

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the other. Visual mean depth (Figure 3C) clearly indicated the shallowest open space/street of the settlement: running in northerly direction in Cumpat and Sukolilo, and from east-west and north in Kejawen.

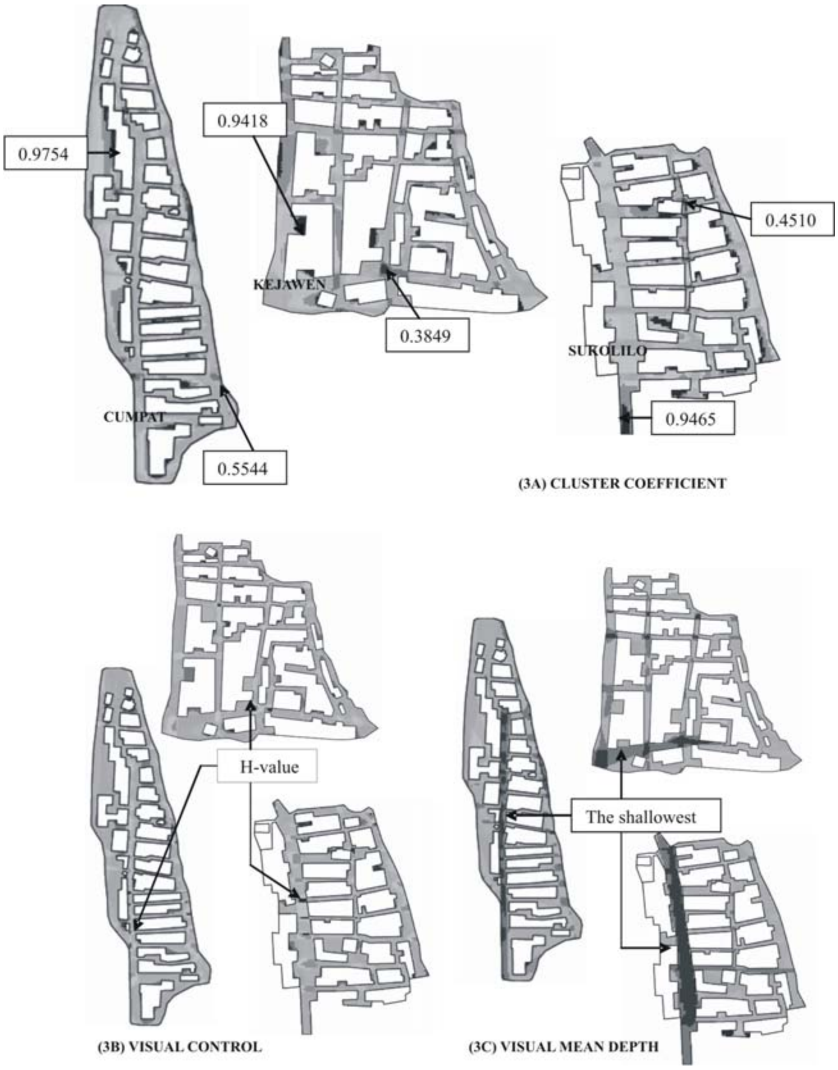

Figure 3:

Visibility Mapping of the three settlements: cluster coefficient (3A), visual control (3B) and visual mean depth

Visual Form of Airflow

According to Moore (1993) the airflow outside a building follows several principles. Other things being equal, wind always moves from high to low pressure areas. In line with this principle we would expect the open space of the fishing settlements to show some relation to the prevailing wind. Under normal circumstances high-pressure areas is created on-shore in the evening; during the daytime they move offshore. Hence the typical pattern of airflow is from land to sea in the evening and *vice versa* during the daytime. To explore this phenomenon the three test settlements have been modelled as a set of building blocks, 4 metres high. A linear sequence of buildings is seen to be the cause of wind-velocity reduction. This means that wind velocity within the settlement will be lower than on entry into the settlement.

A simulation of air movement and permeability illustrates the direction and the velocity including pressure distribution on the surface of the building blocks. Such a model underpins Computational Fluid Dynamic (CFD) analysis, which is embedded in software packages. Data entry in this and related programs includes the overall geometry and dimensions of the settlement building blocks, the type of flow boundary, and the velocity and direction of the wind. For the purpose of permeability and visualisation, isovists have been taken at a nominal height of 1.7 metres above ground level. The average horizontal wind speed in the settlement is considered 5.5 metres/second. Graphical presentation produced by the related software visualization illustrates the pattern of air movement. There are three forms of graphical presentation that can be used to show velocity: streamline represents the simplification of wind movement, contour delineates the velocity of adjoining neighbourhood spaces, and vector shows the magnitude and direction of the wind. A more detailed interpretation of these visualisations will follow.

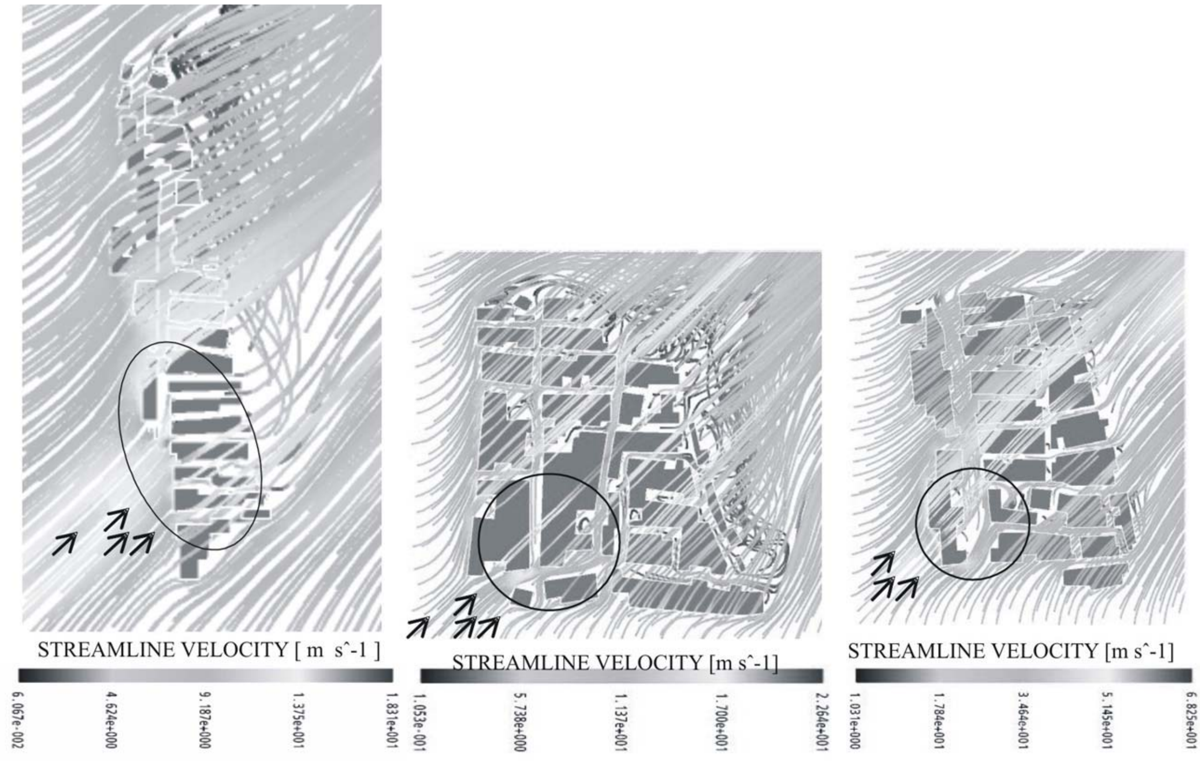

Figure 4:

Visual form of airflow: streamline velocity

The pattern of wind movement during the course of the day is illustrated by means of the streamline velocity (Figure 4). When the wind moves from land to sea in the evening, a spectrum of colours from yellow to red (in the greyscale ranges are shown from nearly black to white), indicating high movement, runs across the middle of the settlement. The contour velocity visualisation (Figure 5A) shows the distribution of different wind velocities. The range of velocities is expressed in a spectrum from green to yellow (in the greyscale ranges are shown in nearly same colour), they are:

Cumpatfrom 2,6 to 14 metres/second,

Sukolilofrom 2,3 to 13,8 metres/second

Kejawen from 2,7 to 13 metres/second.

In all cases occur on the south-west side and at the south entrance of the settlements. The visualisation also highlights the velocity in this area. Higher velocities are to be found surrounding the south entrance of the settlement in the case of Cumpat. In Kejawen, however, these velocities have spread somewhat into the adjoining streets. In Sukolilo, the higher velocities are found at the ends of those streets running in an east-west direction. These are the streets which provide a clear view from the outside of the dwelling to the seashore. Three longitudinal sections through the settlements indicate the gradual change of velocity above the buildings. The closer the location to the shore, the more the velocity will move upward.

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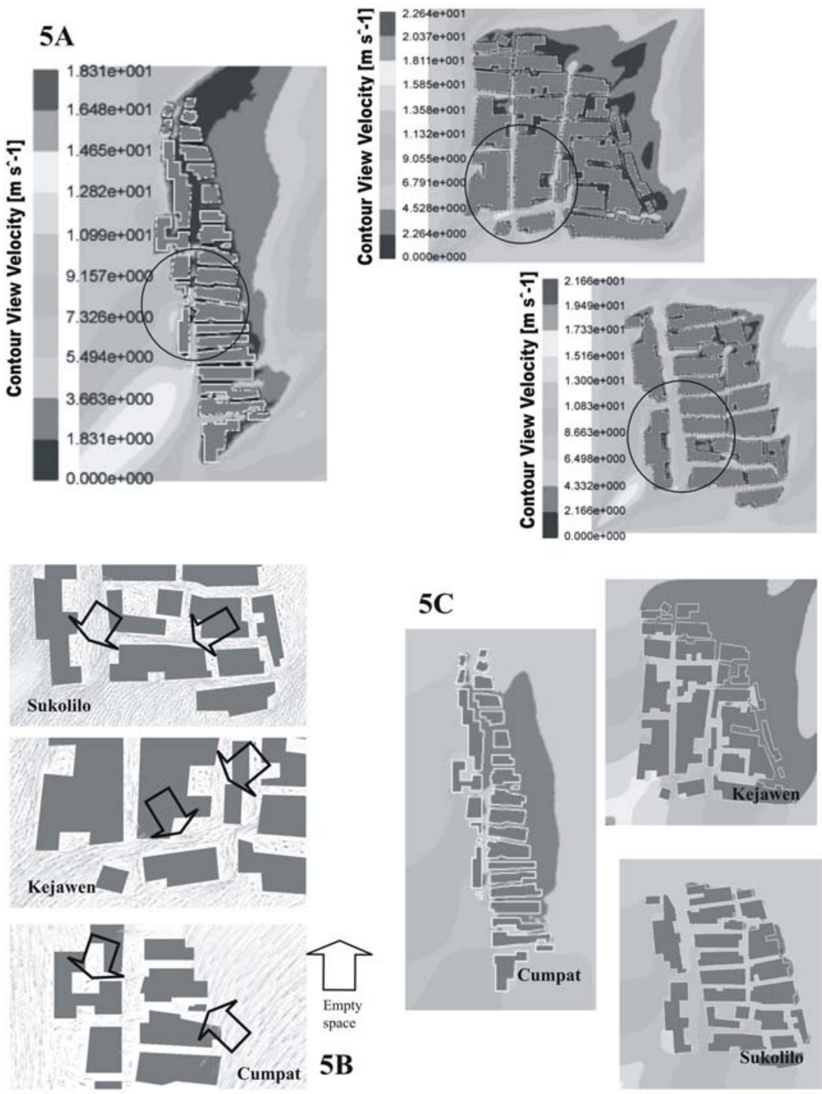
As seen in all cases of visualisation of the vector velocity (Figure 5B), when the movement is from land to sea, after striking the surface of the south-west building blocks, the velocity turns and spreads through the open spaces within the settlement. However, only a few turns to the deep areas of the settlements and gradually extends without breaking onto the surfaces of the peripheral building blocks along the beach. Consequently, the inhabitants in the deep areas within the settlement lack fresh air. The visualisation of Cumpat and Sukolilo velocity density (Figure 5C) indicate that the density occur in the main open spaces of the settlement running in northerly direction and defines the western edge of the settlement. In the case of Kejawen which is bordered by the eastern outer ring road, the density occurs along the open spaces running from east-west and north. In fact, these streets are those with high integrated values in the axial map. The remaining open spaces in the three settlements do not show any great differences of density from one space to another.

Figure 5:

Visual form of airflow: 5A contour view velocity, 5B vector velocity and 5C density



Naturally, these conditions change when the wind blows in the other direction during the daytime. The concentrated high velocity in all of the settlements shifts to the north-east side of the settlement while the wind still crosses the middle of the settlement. The onshore winds from the sea can help guide the fishermen back to land to unload their catch. The parts of the settlement that are affected by the redirection of velocity during the daytime are shown in the visualisation of seashore wind vector velocity. Conditions are quite similar in the evening (see again Figure 4). There is little differentiation among individual open spaces in terms of density.

Computational fluid dynamic (CFD) analysis does much to confirm the findings of visibility graph analysis (VGA). In order to determine which places within a settlement require special handling, the two approaches can be used hand in hand. The correspondence of the visualisation of vector velocity (Figure 5B) with the axial maps (Figure 2C), the permeability or interface maps (Figure 2D) and the visualisation and measures of cluster coefficient and control (Figures 3A and 3B) is one example. More detailed information taking the sample of Kejawen is presented in Table 1 (i.e. Figure 6).

Table 1:

Comparative values of the main open spaces (1-2-3 open spaces): Kejawen sample

Syntactic analysis and measure		Visibility graph analysis (VGA)		Visualisation of computational fluid dynamic (CFD) analysis	
Permeability map	Axial map	Visual integration	Visual control	Vector velocity [m s^-1]	Density contour [kg m^-3]
Spaces at the 1st level	1643 to 2.032 /high integration values of all	2.137 to 2.605/the shallowest of all	Av. 8.309 to 9.671/ high control neighbour-hood spaces	11-16m/sec: high magnitude and direction of all	23 g/m^: high density of all

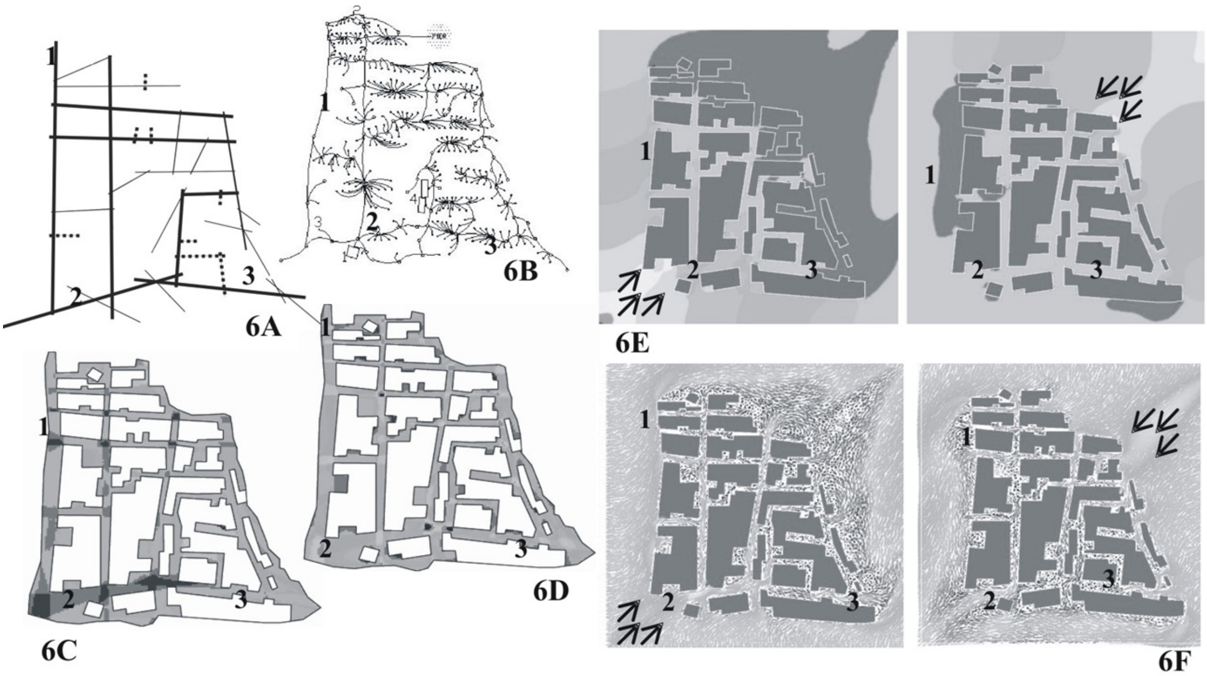


Figure 6:

Comparison visual analysis and measure of Kejawen: 1-2-3 the main open spaces; axial map (6A), permeability/interface map (6B), visual mean depth (6C), visual control (6D), visual density control (6E) and visual vector velocity (6F)

Conclusion

From this limited experiment, visibility graph analysis would seem to have the potential to add significantly to the established syntactic methods of representation and interpretation discussed above. Moreover, patterns of physical movement (circulation) within a settlement can clearly be related to airflow within the open-space layout, an aspect that can be highlighted by application of tools drawn from the field of computational fluid dynamics. In conjunction with social or behavioural patterns, the simulation of pedestrian movement and permeability of the building 'fabric' can, at a schematic level, serve as a source of information for ventilation design in traditional coastal settlements, especially where these are occupied by fishing communities. Following Antaryama (2002), the underlying principle that informed the present study was that the extent of airflow distribution in a settlement is dependent on the spatial configuration of the settlement. The closer the spaces are to the 'root' of the incoming wind, the shallower the configuration will be. The opposite is true when only single access is available to many spaces and the spaces themselves are at some distance away from the root (i.e. the area outside of the settlement).

Fishing settlements, as noted at the outset, are typically linear in form. The very regular system of axial and convex space tends towards elongated plan forms and a high level of permeability. A 'shallow' spatial system will promote access from the outside, and offer scope for considerable airflow. By virtue of their location and orientation along the water's edge, the three settlements discussed here are well-placed to benefit from the inshore and offshore winds that are generated in this area. Whether a street or open space is used specifically as a circulation route or as both a circulation route and a place for performing static activities, the development of these coastal fringes needs to be undertaken with care. The results of this piece of research might be used as guidelines in the development or remodelling of traditional settlements. In the case of public facilities, i.e. open space, market, shops, etc., it is important to recognise that location and function are shaped and reinforced by reference to the larger community. By paying attention to matters of spatial layout and movement, the city government should be better equipped to anticipate and manage potential conflicts of use within the public domain.

With regard to the fishing communities themselves, the available access and arrangement of open space within the settlements helps to induce natural ventilation through the prevailing winds, which blow predominantly in an east-west direction during the daytime, and west-east in the evening. The simulation of movement and permeability has helped to illustrate the critical points in the settlements, i.e. those affected by high velocity and density of airflow. It also demonstrates the likely impact on building blocks. Further experiments combining visibility graph analysis (VGA) and computational fluid dynamics (CFD) should assist designers and administrative authorities make effective use of natural ventilation of houses. This may involve the provision of barriers within and outside the settlement in order to obviate the force of the wind.

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