

BEYOND ANALYTICAL KNOWLEDGE:

The need for a combined theory of generation and explanation

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Abstract

Space syntax is based on the recognition that the generation of possibility is restricted by the laws of generic function, namely, intelligibility, movement and occupation (Hillier 1996). In this respect, it is not a theory of architectural potential but an analytical theory of social performance and realisation. This paper argues that in the domain of design we need a theory of generation and explanation. Starting from the assertion that there are multiple branches of architectural knowledge partaking in design, the paper discusses three artefacts (Venice, Le Corbusier's Venice Hospital and Calvino's Invisible Cities) suggesting that in these artefacts we recognise common morphogenetic characteristics, and the intersection of analytic thought with generative design. The aim of the paper is threefold: firstly, to explore the ways in which these common characteristics in the three works create syntaxes of combinations capable of describing the generative imagination as the outcome of definable processes and relations; secondly, to explain the importance of a theory in dynamic processes of interaction and association aside to static spatial structures. Thirdly, to show where we can situate these ideas in relation to intellectual and design practices of the past and the present, and how to project them in the future.

It is proposed that the diversification of knowledge is the basic condition for the intersection of generative with analytical thought and the dynamic generation of meaning. The paper borrows from aesthetic and literary theory the notion of 'possible worlds' to take into account design as 'worldmaking' (Goodman 1978). It argues that analytic and generative knowledge are central in design, as each allows access to worlds whose centres of reality are not separate, permanent or fixed but interact and shift dynamically with creative activity and time. Aside to theories of explanation we need theories of generation or a combined theory of freedom and necessity in architecture and design.

Keywords: *Imagination, architecture, self-organisation, evolutionary networks, generative design*

Theme: *Spatial Analysis and Architectural Theory*

1. INTRODUCTION: DESIGN AND ANALYSIS – ARCHITECTURAL KNOWLEDGE

This paper is devoted to the intersection between design and analysis. This does not mean that I consider design and analysis individually as less interesting or compelling, but simply I believe that analytic and generative thought can reach their full potential in conjunction with each other. The intersection between design generation and analytical explanation has been explored within space syntax literature in the past from the viewpoint of the relationship between geometry and topology. More specifically, previous research has focused on compositional characteristics identified through geometrical variables and spatial properties of the topological kind (Bafna 1999; 2001, Peponis 1997a; 1997b; Peponis et al 1997; Peponis and Bellal 2005; Sakellaridou 1992a; 1992b; 1994; 1997; 2000, Psarra 1997; 2003; 2009a; 2009b, Psarra and Grajewski 2001). In more theoretical terms these two domains of relationships encapsulate two different kinds of architectural properties: the first one refers to the abstract space which we fill with drawings, diagrams, words and abstract relationships – the non-space of the mind; the second one to the space we cannot capture through language – verbal or visual – the world of direct spatial experience. Central to this line of research is the question of meaning. This has been considered as a matter of geometries used to generate and order design and topological relationships experienced when we move through space. Various studies in the past have looked at how architecture constrains or generates meaning from the domain of the symbolic to the instrumental, including the social activities of movement and interaction.

This paper addresses wider dimensions of architectural knowledge than geometry and topology, conceptual and the perceptual patterns. The intention is to explore meaning as dynamic potential rather than as a fixed or static operation. The paper discuss three artefacts in which we recognise dynamic generation of meaning and the condition of intersections of analytic thought with generative design; it attempts to explain the importance of a theory and a discourse in dynamic processes of interaction and association aside to static spatial structures; finally, it shows where we can situate these ideas in relation to intellectual and design practices and how to project them in the future.

The three artefacts are: a city (Venice), a building (Le Corbusier's Venice Hospital), and a literary text (Italo Calvino's *Invisible Cities*) (Calvino, 1997). Venice is at the core of all these creations, but as the keywords 'possible worlds' in the title suggest, it also denotes a theoretical space of permutations, *the possibility space of the imagination*. I refer to Calvino's definition of the imagination *as a fundamental instrument of knowledge*, 'a repertory of what is potential, what is hypothetical, of what does not exist and has never existed, and perhaps will never exist but might have existed' (2009:91). The imagination, as Calvino puts it, is a kind of 'electronic machine' taking into account all possible combinations in order to choose the one that is appropriate to a particular purpose. In contrast to the traditional idea that the creation of meaning is some mysterious process caused by random inspiration, bringing into architecture a subjective experience of the world, this definition sees the creation of meaning as the output of definable processes and relationships. On the one hand, it links with the early Renaissance idea of *ars combinatoria* - the art of combination. On the other, it is associated with the late 20th and early 21st century developments in the area of information systems and computers (Dade-Robertson 2011).

I have increasingly become aware that between the space of everyday life as addressed it in space syntax and the possibility space of design exploration and imagination there is a gulf that costs increasing efforts to cover. If the intention in analysis is to explain the world 'as it is' (Hillier 1996), a view which I wish to question, the purpose in architecture is to explore a plurality of worlds, a complex system of different kinds of actuality, virtuality and presence. Whether

situated in the actual world - the centre of our system of reality - or in hypothetical perspectives design is a theoretical exercise that structures alternative worlds as syntactic and semantic domains with their own modalities. In doing so, it engages various systems of knowledge. I will suggest that for analysis to come closer to design, we have to address how we define our knowledge; what kinds of knowledge exist that partake in design, and how they relate to spatial analysis.

This paper argues is that there are multiple branches of architectural knowledge: firstly, there is *direct empirical knowledge*. If I happen to live in or to have visited London my knowledge of the city derives from direct experience of the embodied kind. Secondly, there is *encyclopedic knowledge* – I might have not been in London, but I know from the encyclopedia that such a city exists, with such and such properties and qualities (Eco 1994). We trust the encyclopedia for our factual knowledge to an extent that in certain cases we can produce faithful reconstructions of a place from what we hear or read in our mind. The trust we place in it extends to include places, events, states and people of the past that exist only as memory fragments or those that do not exist yet, but will exist in the future - a weather forecast, a new town or building, a project that is in the design stage or in construction.

The third type of knowledge is *theoretical knowledge of the analytical kind*. An example is knowledge generated in space syntax, which captures how complex architectural and urban systems work based on the relationships between parts and wholes. Theoretical knowledge can - and should - refer to how systems have developed based on historical sequence and chronological causality, that is, not simply how complexity is organised in space, but also how it evolves over time. Theoretical knowledge should also refer to how systems and artefacts have been thought of through history taking into account the ways in which architecture is conceptualised (Psarra 2009a).

The fourth type of knowledge refers to the combinatorial world; this is knowledge of possibility, of variants consciously or unconsciously combined, expected or unexpected, realistic or imaginary, evocative or trivial combinations of elements, images and relationships, at multiple ranges, types and scales of magnitude. It contains typologies, morphologies and projects, including places 'visited in thought but not yet discovered or founded (Calvino 2009): Moore's *Utopia*, Campanella's *City of the Sun*, Cedric Price's *Fun Palace*, Le Corbusier's *Venice Hospital*, Phil Steadman's typologies in *morphospace* (Steadman and Mitchell 2010), and Calvino's *Invisible Cities* (1997) among others (Figure 1).

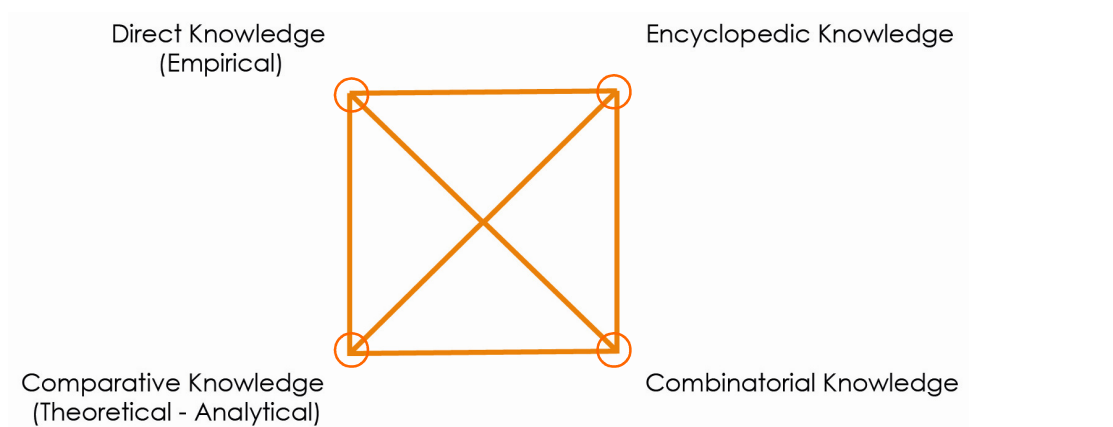


Figure 1: Four types of knowledge

These branches of knowledge intersect with each other informing the multiform, potential and conjectural nature of design. The designer navigates memories direct experiences and facts, repertoires and territories of possible and impossible worlds that may be actualised, thrown away, concatenated, or remain in a virtual state. Alternative possible worlds have the capacity to influence and shift the world of our experience and factual knowledge in which we are located. In contrast to our analytic knowledge of how instrumentality, intelligibility and functional reasoning proceeds, we know precious little in our field in any formal and spatial sense of alternative possible worlds, and of how to design buildings that are functional, imaginative and aesthetically intriguing. A similar assertion was recently made by Sonit Bafna in an attempt to define the 'imaginative function' of architecture (2012). Bafna approaches the imagination through the notion of 'imaginative seeing', which he defines through perception. In this paper I define the imagination as an intersection of diverse forms of knowledge including combinatorial knowledge of possibility and not simply perceptual knowledge. *Through the discussion of the three artefacts I will suggest that the diversification of knowledge is the most basic condition for the intersection of analytical and generative thought and the dynamic generation of meaning.*

2. ARS COMBINATORIA - WHY INVISIBLE CITIES, VENICE AND THE VENICE HOSPITAL?

What is the relevance of Venice, *Invisible Cities* and the Venice Hospital to the combinatorial imagination? We know that Venice has inspired the imagination and mythmaking from early beginningsⁱ (Ferraro 2012). It has also come to express the imaginative charge, the *extraordinary encounter between organic patterns of growth and systematic human intent* in terms of multi-cultural influences, works of art, architecture and spatial organisation. We also know that Le Corbusier and Calvino drew inspiration from Venice like many architects and artists. Calvino was a member of the OULIPO literary group, which used mathematical constraints and syntaxes of combinations. Imagination and literature for him were combinatorial machines based on vocabularies, grammar, syntax and a language of permutations. Reminiscent of the visionary charge of the thirteen-century travelogue *The Travels of Marco Polo* (1871) and More's *Utopia* (2002), *Invisible Cities* is about cities Polo describes to Kublai Khan, the emperor of Mongolia. These are not places the traveller has visited, but cities he invents in his mind. Soon the Khan realises that cities exchange their elements and that speaking of other places Polo always says something about Venice. *Venice, the art of combination, and this fiction are therefore inextricably linked by their capacity to stimulate the imagination.* 'Polo is an architect of invisible cities and models for the Khan and the work's readers how to become architects of their own invisible cities' (Modena 2011). Yet, we don't know how *Invisible Cities* and Venice catalyse the imagination; how they encourage readers to engage their own generation of images and alternative possible worlds.

Based on the recursive repetition of modular elements, Le Corbusier's Hospital is relevant to the combinatorial fiction of Calvino and the organic growth patterns of Venice. The Hospital has exemplified ideas of self-organisation in the 60s as featured in the work of Team 10, and has been a central reference in Alison Smithson's 'mat building' in the 70s, that is, the '*anonymous collective; where the functions come to enrich the fabric, and the individual gains new freedoms of action through a new and shuffled order, based on interconnection, close-knit patterns of association, and possibilities for growth diminution and change*' (1974). More recently, Le Corbusier's project has played a central role in design paradigms as expressed in Stan Allen's essay 'From Object to Field' (1997, 1999, 2009) that emphasise a shift from architecture as object to architecture as evolutionary field based on local scale relations. Influenced by complexity, emergenceⁱⁱ and self-organisation in philosophy, art and systems theory, these new

paradigms argue for formless, non-figural configurations that Corbusier's un-built project came to illustrate. From organic architecture to mat-building and adaptive architecture in the last two decades, the Hospital has come to express an approach to design that is based on possibility and dynamic patterns. These patterns are unmediated by material sensory engagement and geometrical figural composition as a representational practice (Burry 2011).

At the same time a fundamental transformation in how designs are produced within a computational environment brings the notion of emergence in the design process. As the simulation of mental and organic processes by digital technology enters the world of architecture, all three artefacts become relevant to computational design and machine learning. Algorithmic computational geometries create evolutionary designsⁱⁱⁱ and generate forms of advanced complexity and variation. In evolutionary design architectural concepts are expressed as generative rules, and the rules are described in genetic language. Computer models are used to develop prototypical forms, which are then evaluated on the basis of their performance in a simulated environment. As John Fraser wrote in the 50s 'very large numbers of evolutionary steps can be generated in a short space of time and the emergent forms are often unexpected' (Fraser 1995: 9). Since the design product is the result of an algorithm, inputs of the algorithm can be changed and the result is accordingly updated. As opposed to the traditional model of top-down 'composition' presupposing knowledge of the design outcome based on parts-whole relationships, evolutionary design is bottom-up, 'clear in its intentions but "blind" to the eventual outcome of the design process' (ibid.:12).

The shift from top-down geometry to bottom-up rules marks a turn away from the traditional idea of composition to instrumentality such as user activity, collective behaviour, interactive environments, evolutionary networks and the long life performance of a building or a city. The approach to architecture as language that emphasised signification, autonomy and permanence in the 80s has been replaced by an approach that places primary importance on evolution, and resilience. This 'instrumental turn' has its early foundations in Rem Koolhaas' ideas of 'irrigating a site with potential' (Constant 2012, Lucan 2012), and 'architecture-through-process' (Lucan 2012). Taking the three artefacts as examples, this paper explores what happens to meaning when architecture is conceived as formless and self-organising; how we can conceptualise architecture within diverse forms of architectural knowledge, and intersecting systems of reality and possibility.

For Hillier and Hanson meaning can be encoded through the potential of a system, or become embedded and persistently expressed as static representation (1984). Their view of meaning refers to buildings and cities centring on the actual world. This paper extends the consideration of meaning into 'possible worlds' implying the idea of generation, innovation and adaptation. The notion of possible worlds is borrowed from aesthetic and literary theory to take into account design as 'worldmaking' (Goodman 1978, Ryan 1992). The paper argues that a theory on the intersection between design and analysis, generation and explanation depends on engaging the varied relationships between the world of our experience and factual knowledge and worlds visited in imagination. Having presented some architectural ideas and theoretical concepts I will now move to discuss the three artefacts.

3. VENICE - URBAN GROWTH AND SELF-ORGANISATION

Of the early days of Venice in the lagoon very little is known. The earliest map of the city shows a compact 'land-mass' criss-crossed by canals. Churches are the only buildings shown on this map most of which are still standing in the same places today. Removing all information but the

churches and squares from today's map of Venice reveals an archipelago or monuments and open spaces (Figure 2a). However, what appears as a random distribution has a clear logic as the squares and churches are joined by a pervasive network of choice^{iv} (Figure 2b), (Normalised Choice - NACH at a radius 500-3000, Hillier et al, 2012). Choice accounts for through- movement, or the paths that are most frequently used in order to move from every street to all others.

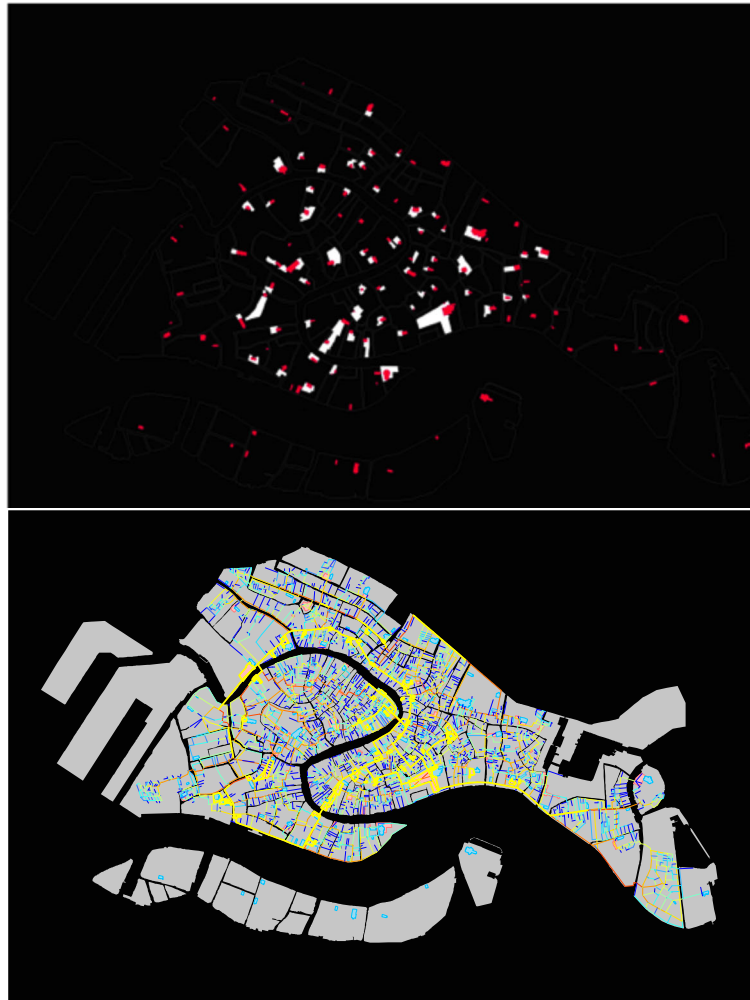


Figure 2: a-b. Top: squares and churches; bottom: NACH (Radius 3000 at 1.3-1.4 with campi at 0-50m distance from foreground structure highlighted).

This property captures a pattern of evolution based on social and economic activity since early times. Howard suggests that the churches and campi were the social nuclei of parish islands that dotted the archipelago. 'Each parish was built up street by street around its own church and campo' (2002:50) Parish squares were semi-autonomous community centres that contained a church and a market, and were serviced through their proximity to water. In his study of civic rituals in Renaissance Venice, Muir explains that the islands had their own 'rich and influential families, patron saint, special feasts, customs and defined border' (1981: 146), including considerable autonomy over local affairs. Thus, the urban structure of Venice consisted of 'semi-autonomous communities, each serving as a microcosm of the city as a whole' (ibid.: 148). The parish islands also facilitated water collection through underground channels, and cisterns located at the centre of each square (Figure 3a-d). The gradual development of the mercantile society generated the need for quick water and land transportation, until through a long process

of land reclamation the islands were joined. The continuous network of 'through' routes indicates that in the process of land reclamation, the bridges that joined the islands were built so as to link the campi with each other, producing a network of multiple interconnecting centralities.

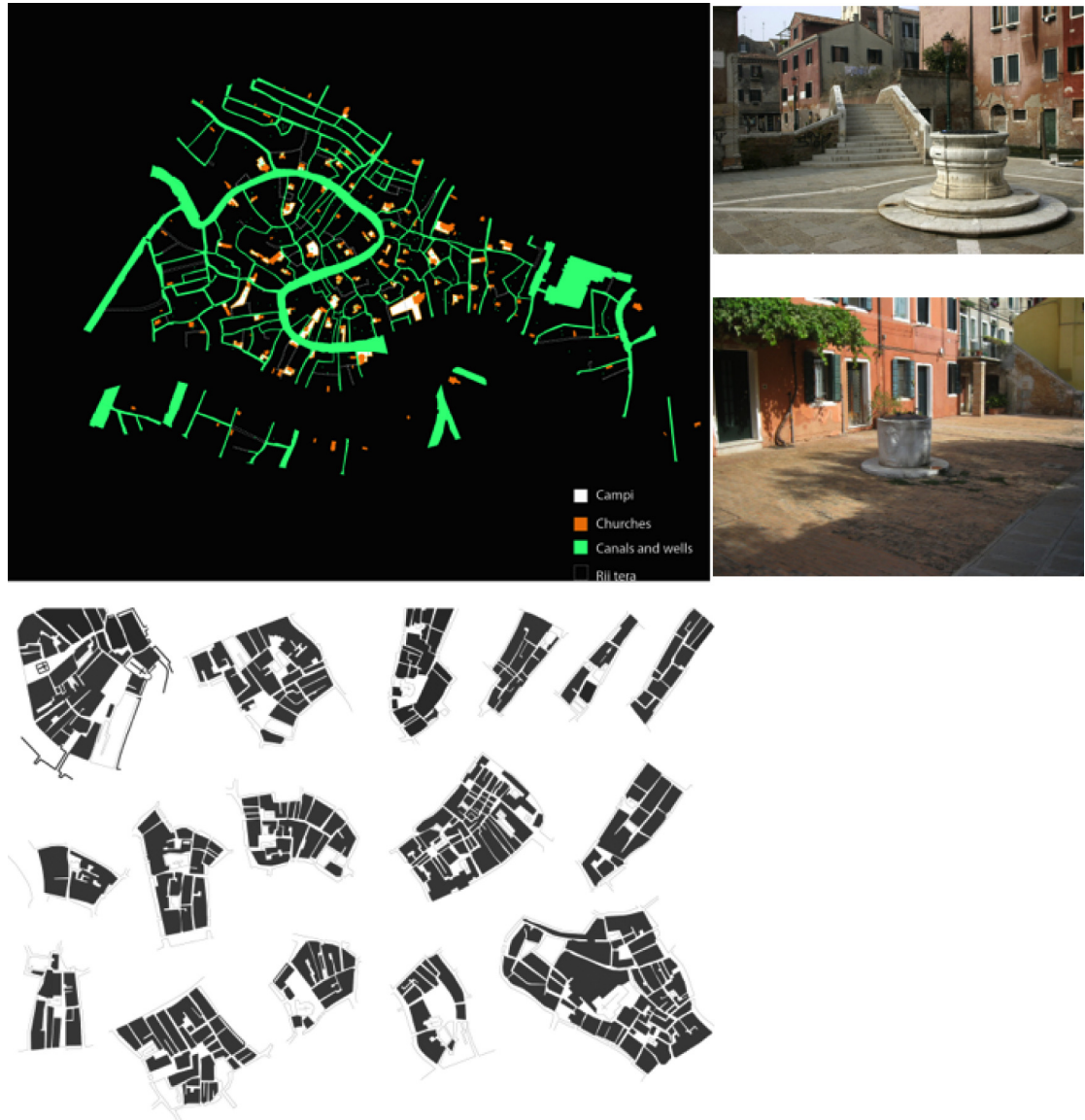


Figure 1a-d: Clockwise: Venice network of canals and cisterns; cisterns in Venice (photos by the author); islands of Venice (adapted from Mancuso, F., 2009, *Venezia è una città*).

It is important though not to forget that seawater runs through the compact body of Venice. To go from one place to another you have the choice between land and boat, as well as a combination of the two (Figure 4a). Water travel and pedestrian routes intersect at specific locations through the *targhetti* and a series of steps in close proximity to bridges and squares (Figure 4). Analysing the canal system confirms that in a city originally made out of island communities large-scale movement would primarily take place through water. However, the squares are still interlinked at both global and local scale of the combined liquid-pedestrian network. This means that the squares of Venice are *nodes in the intersection of the water network and the street system*. This makes sense, as islands were initially separated, and so squares had to be directly serviced by boat. When the islands were joined up, the *campi*

became interconnected by both water and land, facilitating the unloading and distribution of merchandise and people.

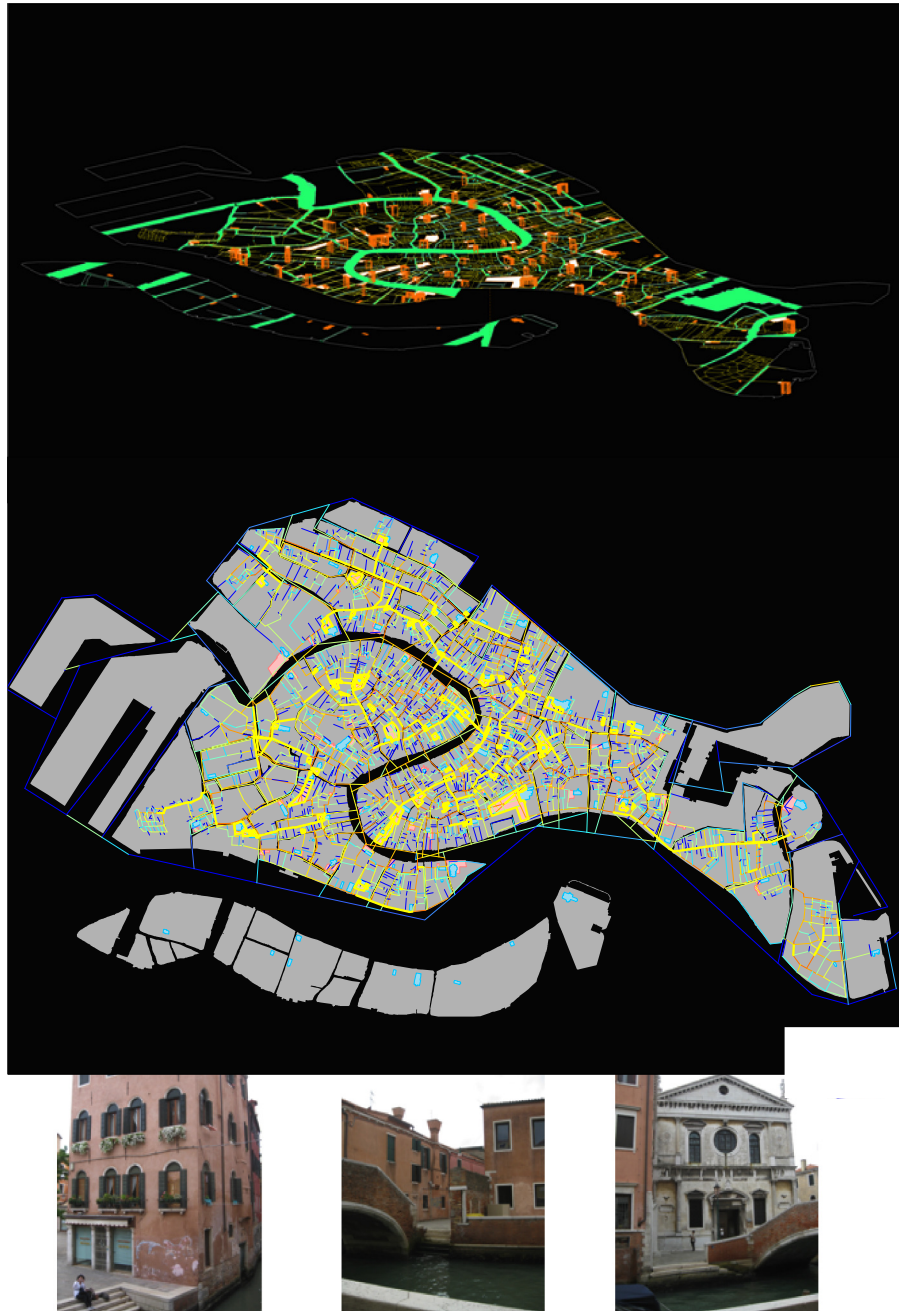


Figure 2a-e: Top: combined pedestrian and water routes; middle: combined pedestrian and water route choice (NACH-radius 500 – foreground structure of NACH at 1.4-1.6, with campi at 0-50 distance from foreground structure highlighted); bottom: points of stepped access are always in proximity to squares and bridges.

The topological proximity of campi to water is further made evident in figure 4g, which shows topological step depth from the canals (directional turns from all segments that constitute the water network). The vast majority of campi (93%) are just one step away from a canal. This figure also captures a pattern of connections between campi and canals, between campi, and between islands themselves. It indicates that the first leg of any journey away from water in

Venice always traverses a campo from side to side or runs parallel to one of its sides. This pattern reveals a 'cross stitching' of campi and islands, implicit of a long-term process based on land reclamation and urban growth. Table 1 shows NACH values for the three networks and the percentage of campi that are directly crossed by the foreground structure of NACH for a radius of 3000, 1500 and 500 (from 0 to 50 m distance from a foreground segment). When the combined pedestrian and canal network is considered, it turns out that 52 -55% of campi are directly crossed by the foreground structure or are within a short distance from it.

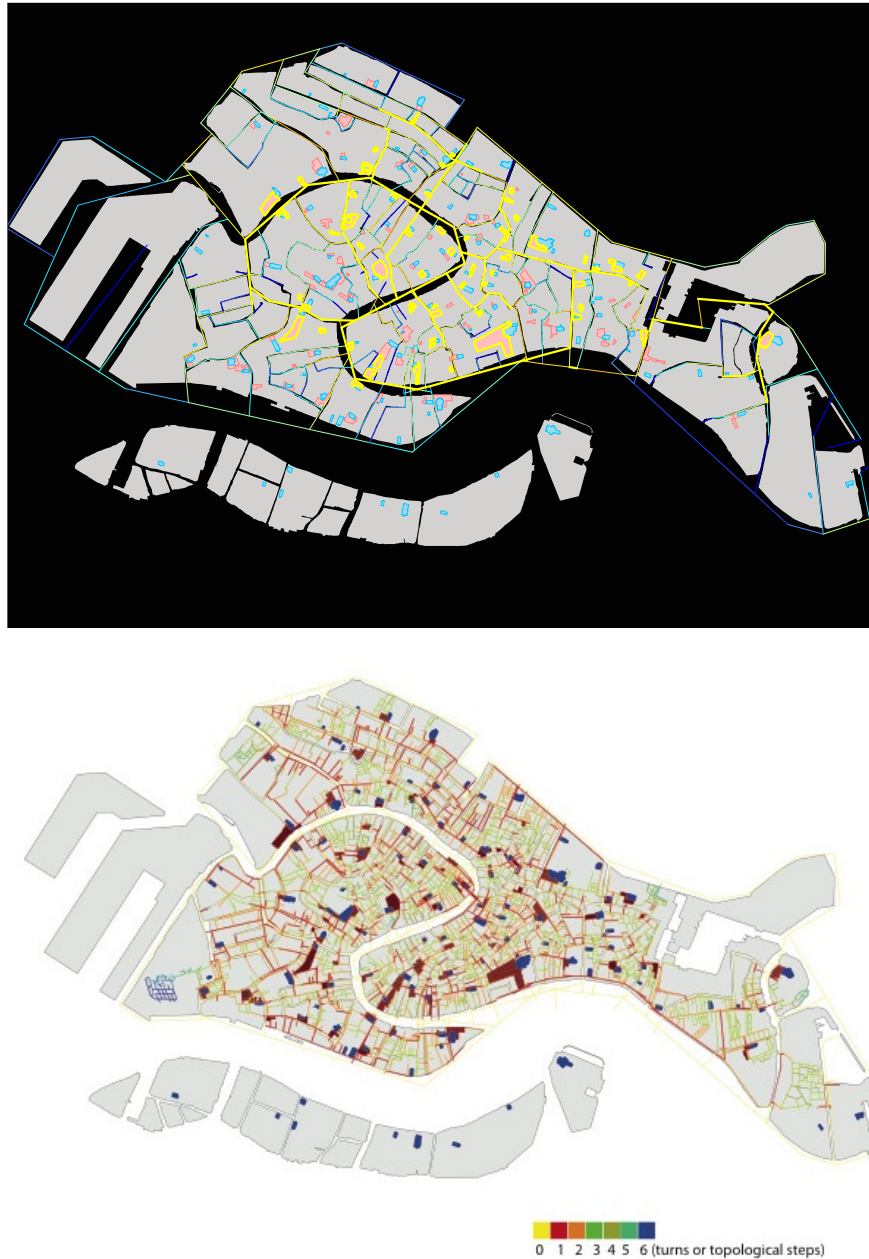


Figure 4f-g: Top: water routes; choice (NACH-radius 1500 – foreground structure of 1.3-1.5 with highlighted campi (at 0-50m distance from 1.3-1.4 NACH foreground structure). Bottom: step depth from the canals with campi that are covered by step one segments highlighted (red).

In terms of NACH values, no significant differences are observed between pedestrian and combined pedestrian and canal routes, but values are higher for the canal system (Table 1). This

suggests that in a city in which movement was structured through water channels large scale navigation is easier through water. While water travel would have been the usual way to cover large scale distance in the city in the past centuries, today most people get around Venice on foot or use the water-bus service. This means that they experience a less permeable and less easily navigable system compared to the ways in which Venice would have been experienced in the past.

Table 1: NACH values at 3000, 1500, 500 radius – in red: highest percentage of campi located at 0-50 distance from foreground structure of NACH in the combined pedestrian and canal network.

NACH	NACH-3000 (radius)				NACH-1500 (radius)				NACH-500 (radius)			
	MAX	MIN	MEAN	% of Campi 0-50 m	MAX	MIN	MEAN	% of campi 0-50 m	MAX	MIN	MEAN	% of campi 0-50 m
Pedestrian network	1.39	0	0.8	38%	1.39	0	0.8	31%	1.51	0	0.84	44%
Canal network	1.6	0	1.14	19%	1.45	0	0.91	44%	1.47	0	0.92	11%
Ped.+can. network	1.49	0	0.86	55%	1.54	0	0.82	52%	1.51	0	0.88	53%

4. THE VENICE HOSPITAL

Moving to the Hospital, Le Corbusier’s technical document describes the building as a result of a morphogenesis based on bottom-up rules, and conceived so as to establish a close-nit relationship between architecture and the city (Le Corbusier 2001). Le Corbusier located the origin of the design in Venice, calling the paths that link care units ‘calle’, and the central space between them ‘campiello’. The basic design unit is the ‘cellule’, or the room of the patient. ‘This element gives rise to the “care unit” [Unité de soins] of twenty-eight patients, which functions autonomously. This unit is organised around a central space of communication and four paths, which are intended for both inhabitation and circulation by patients in convalescence. Four units of care form a “building unit”. Through the progressive juxtaposition of building units, this framework yields a horizontal hospital’ (ibid., 42). This system should have the flexibility to accommodate growth, future medical innovations as well as an effective and economical cure built around the preventative and rehabilitation capabilities of the hospital (Figure 5a-b).

The proposition that grid-like configurations based on small units are flexible was a shared view among architects of the Team 10 in the 60s (Allard 2001). These views are clearly reflected in the technical document, which uses the modularity of the design as the means to validate the functional efficiency of the Hospital and its evolutionary, anti-institutional logic. At the same time, the report exploits the metaphoric relationship between organic urban growth, modularity and the ‘Modular Man’ to establish poetic affinities between the city and the

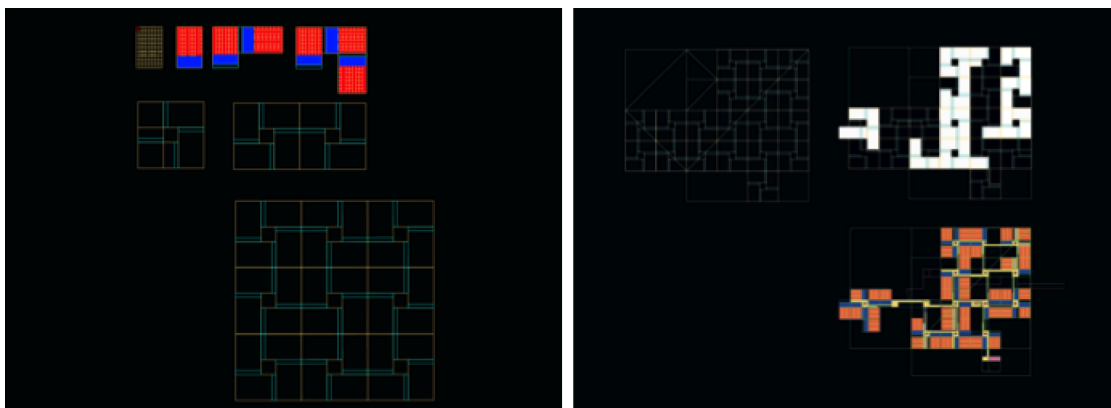


Figure 5a-b: Left: Venice Hospital-morphogenesis; right (clockwise): golden section, solids-voids, 3rd floor plan

Hospital and universalise the project. These raise the question: does the association between the building and Venice extend beyond the metaphors of organic growth and the typologies of 'calle' and 'campiello'?

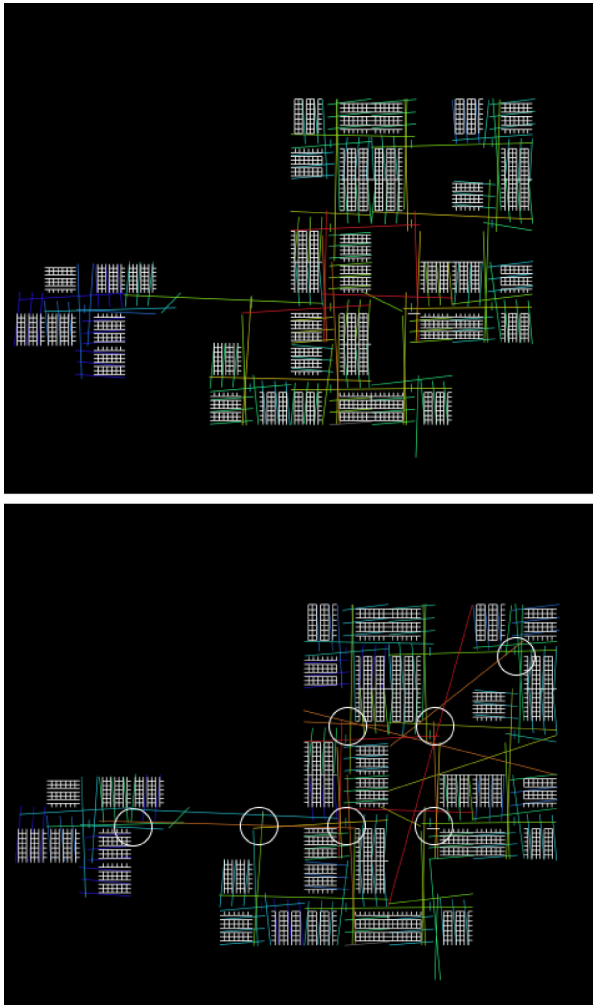


Figure 6a-b: Top: axial integration – permeability; bottom: axial integration – visibility. The circles indicate the square areas where the lines of visibility intersect with those of permeability.

The axial integration analysis shows that like the streets and squares of Venice the pathways and square-shaped areas in the building are interconnected (Figure 6a). *The morphological analogy between the Hospital and the city therefore, is not based on fragment-types, but on a conceptual and configurational complexity based on a combinatorial system of elements and spatial interconnections.* But there is an additional property showing that the Hospital is strongly influenced by the city. The architects have used a series of courtyards traversed by pathways and bridges. The analysis of visibility on the top floor indicates that integration develops along a set of orthogonal lines that cover the pathways, and long lines that stretch diagonally over the voids from side to side (Figure 6b). The square-shaped areas are the points where the lines of visibility intersect with those of movement. Similarly to Venice's squares acting as nodes in the water and land systems, the square-shaped areas in the Hospital interface two separate and intersecting structures: visibility and movement.

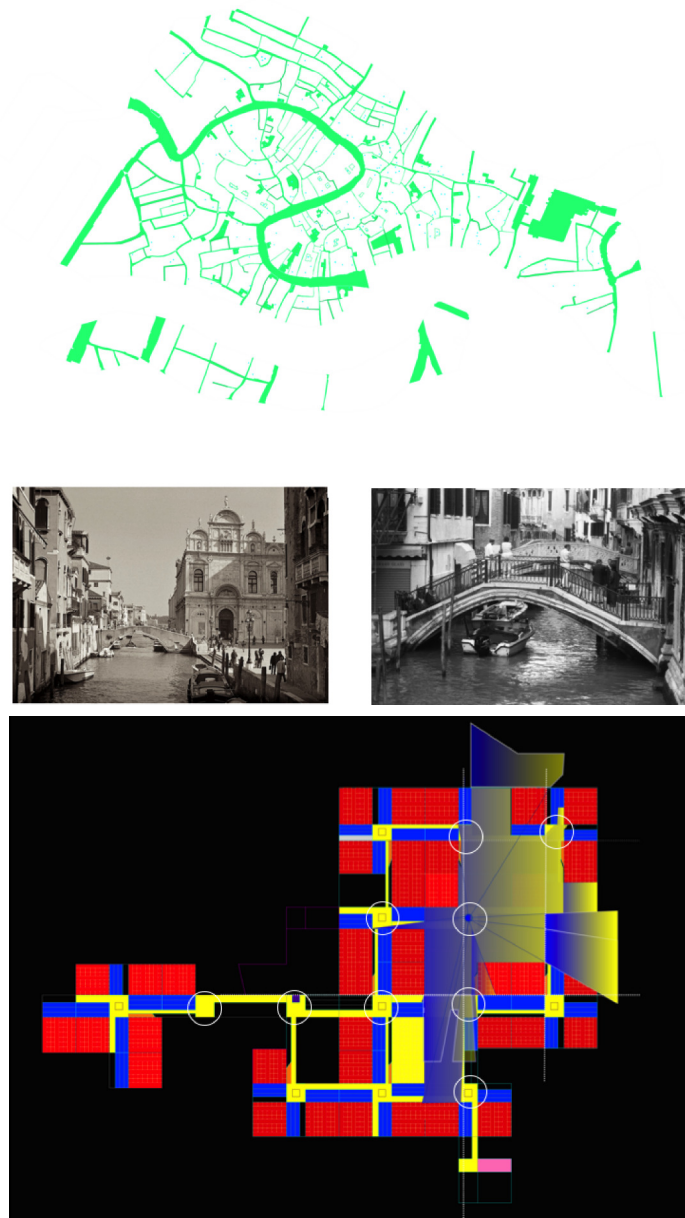


Figure 7a-d: Top: canals and squares (immediately accessible by water) - the latter are 75% of the total number of squares in Venice; middle: Campo *San Giovanni e Paolo*, photo by the author ; succession of bridges over a canal, photo by the author; bottom: actual and reflected visual fields (on glass surfaces). The circles indicate the square areas which are dematerialised by being close to voids.

These properties are possible through the material treatment of the building. *The project dematerializes in plan and in its vertical layering the patios, and perforates its perimeter at different levels, a property found in the city.* If we ‘flood’ the canals and squares with the same colour, we see that the *campi* are not completely enclosed by surfaces, but open on one side (Figure 7a). A close look shows that 57% of the *campi* are adjacent to the canals (Figure 7b). If we add the *campi* next to *rii terra* (covered canals) this figure rises to 61%. This is a characteristic that is evident from early days as seen in the map of Barbari. Similarly, ten out of the fifteen square spaces (67%) in the Hospital are ‘dematerialized’, that is, bound by glass and open to patios and gardens on two at least sides’ (Figure 7d). This property exposes a system of

walkways extending over the voids in a manner that is suggestive of the succession of bridges that link islands in Venice (Figure 7c). What Le Corbusier captured through the *campello*, the *calle*, the patios, the catwalks, the hanging gardens, were not individual type-fragments isolated from the urban fabric, but integral parts of Venice, and its combinatorial imagination consisting of a combinatorial syntax of campi, churches, bridges, cisterns, steps and networks of interconnected routes half liquid half solid. Like Calvino's Venice, which will be discussed next, Venice contains at its core potential other Venices inexplicably wrapped one within the other.

5. 'THIS PATH WAS ONLY ONE OF THE MANY THAT OPENED'^{vi} – ITALO CALVINO'S *INVISIBLE CITIES*

Invisible Cities consists of 55 short city-texts and 18 dialogues between Kublai Khan and Marco Polo. As the emperor faces the potential destruction of his empire, he seeks in Polo's accounts 'the tracery of a pattern ... [that] could escape the termites' gnawing' (1997: 5). Polo feeds the emperor's quest for knowledge with pantomimes, games and dialogues that frame the narrative at the beginning and end of each chapter. The short texts describe cities as fantastic constructions. There is a city suspended between two steep mountains, a city made of a forest of pipes, a microscopic city concentrically expanding over time. Some cities are heavy and monumental; others are skeletal and dismountable; a few have a secret plan manifested in the starry night. The range and sensory qualities of places Polo describes compel Kublai to understand the invisible order of Polo's imagination. The dialogues move from Polo and Kublai learning each other's language, to establishing a conversation, thinking in silence, playing chess and examining the Khan's atlas. The novel is intended to provoke thought rather than develop a plot towards closure. However, as the final dialogue focuses on the question of utopia versus 'inferno', it advances a proposition: Polo's final utopia is a city that is 'discontinuous in space and time' (ibid.: 147) consisting of interruptions and openings. His last advice to the Khan is to learn to recognize 'who and what in the midst of the inferno is not inferno' and make them last, 'give them space' (ibid.: 148). If utopia has traditionally been about idealised geometries expressions of totality hierarchically applied, Calvino promotes a utopia that is bottom-up, recombinant and adaptive.

The 55 city-texts are distributed under eleven thematic rubrics^{vii} and organised in nine chapters. Each chapter contains five cities (with the exception of the first and last chapter, which consist of ten cities each), arranged so as to construct recursively descending sequences of numbers (5 4 3 2 1). In spite of this mathematical orchestration, to the average reader the fiction is a collection of loosely interrelated narratives that can be read in sequence or at random (Breiner 1988). Another characteristic, as Kublai suspects, is that cities seem to exchange their elements resembling each other. Confronted by the emperor, Polo admits that Venice lies behind all his descriptions. The cities of *Esmeralda* and *Phyllis* that follow ramify in 'tortuous optional routes' (Calvino 1997: 79) on dry land or water. Calvino alludes to the web of alleys and canals of Venice to express the ways in which the lack of unity in the fiction might create disorientation.

Losing oneself in a city or a book contrasts Kublai's search for a model from which all other cities derive. In the opening dialogue, Kublai is able to discern in Polo's descriptions a scaffolding of relations. In another dialogue he observes that 'a splendid hard diamond takes shape' (ibid.: 51-52) and that the empire is made of the geometry of a crystal. As the emperor plays chess with the merchant, he attempts to understand cities following the rules of the game^{viii}. *Invisible Cities* juxtaposes images of coherence with images of entropy and decay, ruins, mazes filled by earth, dirt, refuse, and formless suburbs. Whether in narrative mode or in dialogical fashion, Polo systematically frustrates and excites the Khan - and Calvino the reader - to think of the

book as a labyrinth and speculate an invisible order identical to the diaphanous ‘tracery of a pattern’. The city-ales and the dialogues thus construct an echoing system that amplifies the challenge facing the Khan to reconstruct the labyrinth and dissolve its power. The emperor’s search for intelligibility mirrors the question in readers’ minds: what makes a book larger than the sum of the city-texts, a novel out of these pieces, a story out of these fragments? (Breiner 1988).

Studying *Invisible Cities* critics often assemble a narrative structure based on a diamond shape (Peponis 1997, Milaninini 1990, Briganti 1982, McLaughlin 1998) (Figure 8a). For McLaughlin, the diamond shape expresses the relationship ‘between the neatness of numerical structures and the messiness of the real world’ as the main theme of Calvino’s work (1998: 103). John Peponis has offered a more nuanced interpretation arguing that the shape expresses a symmetrical narrative structure that links the thematic rubrics centring on the sixth category: ‘Cities and Eyes’ (1997). The diamond shape and its symmetries thus help to unravel poetic relationships that are not made explicit in the text, or are lost in the sequential motion of language.

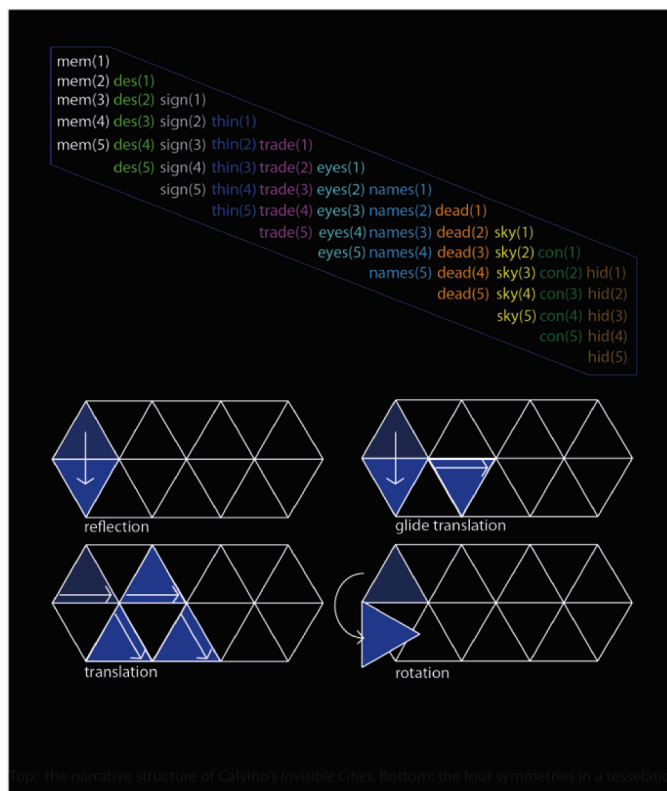


Figure 8a-e: Top: the narrative structure of *Invisible Cities*; bottom: the four symmetries in a tessellation.

Calvino was an Oulipian, fond of exactitude and mathematical patterns, and must have had a good grasp of the symmetries involved in his narrative structure. This structure has a close relation to a tessellation, created by repeating a triangle so as to cover a plane without gaps or overlaps. Group theory defines symmetry as an operation that leaves a configuration invariant. There are four types of symmetry in this tessellation: reflection, translation, glide-reflection and rotation (Figure 8b-e). This means that overall bilateral symmetry articulates hierarchical relationships distinguishing ‘Cities and Eyes’ from the rest of the cities, but local-scale symmetries make all points in the diagram identical implying, as Kublai suspects, that cities are interchangeable with each other. Looking at the fiction we see that it is often impossible to

decide on the basis of a city's description what rubric it appears under, and many concepts would be equally at home under some other city or rubric (Breiner 1988). In *Isidora* for instance, desires become memories, blurring the thematic rubrics of 'Cities and Memory' with 'Cities and Desire'. In *Euphemia* memories are traded every solstice and every equinox exchanging the theme of memory with that of trading. These observations suggest that meaning in *Invisible Cities* is multi-scalar and multiform, fluid at the small scale of individual tales, and more stable and fixed at the scale of the overall narrative structure.

Each of these tales evokes conceptual relationships that express variations of the four symmetries in the tessellation. *Reflection* is systematically encountered throughout the fiction, as most cities have a mirror, an opposite or a double, such as *Valdrada* which consists of twin cities, one erect above a lake, and the other one reflected on water, or *Moriana* which has a face and an obverse that cannot be separated or look at each other. *Translation* characterises those cities that repeat and shift on a vast terrain, such as *Eutropia*; glide reflection occurs in cities, which have a copy that influences the original. In *Eusapia* for example the inhabitants build an identical double of the city underground (reflection). The city of the dead makes innovations evolving over time (expressing a horizontal shift on the plane, or translation). The *Eusapia* of the living in turn copies the novelties of its underground copy (denoting a second order glide translation). Finally, *rotation* is expressed through cyclical patterns as in *Sophronia*, which consists of a permanent and temporary half. The former comprises a rollercoaster. The latter is made of stone and periodically shifts on trailers returning to the original place after a certain time. *Invisible Cities* is permeated with images that on the whole express two things: first, the four local-scale symmetries and their permutations conveying the ideas of *organic growth, transformation, evolution and adaptation*; second, the idea of a combinatorial syntax between the physical city erect on the ground and the city in the mind as representation through language, signification, discourse, perception, nature, knowledge of the past, projections into the future, memory and desire; or a mathematics of combinations between signifiers and signifieds.

Given a number of different elements n , where n stands for the number of symmetries, the number of arrangements that can be made of them in any order is expressed by their factorial $n!$, which is calculated as $1*2*3*4*.....*n$. In the case of the four symmetries we have 24 combinations. If we want combinations of fewer symmetries, for example couples of symmetries such as reflection and rotation, the formula is $n!/(n-t)!$. Such calculus-algorithms are employed in the solution of problems, but they can also serve as discovery procedures, that is, procedures for inventing a variety of possible scenarios (Eco 1997). Umberto Eco explains that they work as expression systems, which can reveal possible content systems.

Ars Combinatoria is the art of uncovering combinatorial rules and restrictions that govern the placement of information objects and realising these patterns of relationships through systems in which these combinations can be expressed and in which all allowable permutations are meaningful (ibid.). In fact all information systems can be reduced to combinatorial patterns in this way. It is restrictions in the combinatorial possibilities of letters from which we can derive meaningful words, and it is the combinatorial rules inherent in the grammar and syntax of language, which allow us to construct meaningful sentences (Dade-Robertson 2011). Pioneers of *ars combinatoria*, such as the 13th century Majorcan philosopher Ramon Lull, sought to understand the power of combinations and permutations to express and develop universal languages. He came up with a mechanism of three concentric circles of decreasing size inserted into each other. By turning the wheels Lull could build statements consisting of 84 possible combinations (ibid., Yates 2001, Eco 1997).

Invisible Cities is the most characteristic expression of what Calvino meant by the combinatorial imagination: 'a multi-faceted structure in which each brief-text value or concept is close to the others in a series that does not imply a logical sequence or hierarchy, but a network in which one can follow multiple routes and draw multiple, ramified conclusions' (2009: 71). This refers not only to the many ways in which it is possible to circulate through the fiction, but also to the relationship between the networks of signifiers and signifieds. In *Hypatia* the traveller realises: 'I had to free myself from the images which in the past had announced to me the things I sought' (1997: 40-41). The power of *Invisible Cities* to stimulate the imagination lies in the capacity to convey a multiplicity of virtually embedded combinations leading to the generation of possibility, to meanings that are factual as well as potential and dynamic. Like Lull, Calvino has created a combinatorial device in which symmetries and thematic rubrics rotate on a wheel system, *a type of computer*, where meaning is encoded through the potential of the system rather than persistently expressed as a static representation. This strategy exposes readers to a wealth of unexpected associations, and generates alternative worlds through a process of combinations, training their imagination.

6. POSSIBLE WORLDS: THE NEED FOR A THEORY OF GENERATION AND EXPLANATION

This paper set out to describe the creative imagination as the output of definable processes and relationships, and locate analytical knowledge within a broader spectrum of discourse necessary for a combined theory of generation and explanation in architecture. To this purpose it examined Venice, the Venice Hospital and Calvino's *Invisible Cities* as paradigmatic examples of the intersection between the self-organising properties of cities as learned practices and traditions, the collective and individual concern with generative knowledge and innovation.

A city like Venice appeals to the imagination for multiple reasons, and this analysis does not claim it covers them all. However, the creative affinities between the three artefacts can explain the potential of Venice and the other two artefacts to stimulate imaginative engagement in relation to the properties discussed in this paper. Venice, the Venice Hospital and *Invisible Cities* share the characteristics of a modular logic based on discrete elements and recombinant network-like generative laws. These characteristics facilitate recognition of combinatorial universes, and their embeddedness into networks of relationships.

In her study of narrative theory and possible worlds, Marie-Laure Ryan explains that 'the complexity of a plot depends on an underlying system of purely virtual embedded narratives' ... 'contained in dreams, fictions, fantasies and belief systems conceived or told by characters and any kind of representation concerning past and future states and events'.... Among these embedded narratives some reflect the events of the factual domain, while other delineate unactualised possibilities (1992: 156). The aesthetic appeal of a plot is a function of the richness and variety of the network of virtual sequences, the narratives produced by speculative activity and promising plot-lines. A plot is therefore, not simply the textual world depicted in the narrative, but a larger and more complex universe containing possible worlds that can be actualised or remain virtual in the readers' minds.

Like every multi-permeable urban system, Venice's spatial network affords many ways to connect points in space and time – being about a graph of movement choices. What makes Venice unique though are firstly, the networks of pedestrian and liquid routes, which intersect and separate from each other, and secondly, the combinatorial syntax of elements. Any path from A to B has interruptions, suspensions, sudden turns, and ups and downs, resulting in

sequence networks produced by embodied activity and virtual networks produced by speculative activity in the mind. Since the shortest and most frequently crossed routes intersect on the urban squares, the city exposes from these locations a combinatorial logic of urban elements - square, church, cistern, canal, bridge, stepped access - and of actual and hypothetical walks on land or water. From Venice's squares imagination sets forth creating multiple Venices of pathways taken in actuality and in the mind, intersecting the explanatory function of intelligibility, with the exploratory function of excursion, and the larger imaginative function of prediction, projection, hypothesis, interpretation, correct and incorrect inferences, unactualised plans, previous experiences, memories, encyclopedic knowledge and desires^x. All of these universes inform our knowledge calling into question the distinction between the actual and the possible and casting them all as forking paths on the actual map, therefore increasing the size and diversity of territories travelled in imagination.

To the imaginative potential of ramifying itineraries, the infinite variety in which the route segments can be combined in sequences, floating, elevated or on ground level, we should add of course the phenomenal and perceptual aspects of gravity, transparency, reflections, and water together with their metaphorical power. In metaphorical terms, Venice is the 'lightest' of cities, floating on water. In literal terms, structural demands for reducing loads have led to filigree facades and buildings of pierced thickness. Water penetrates the ground floor of these buildings, which can be accessed by boat as well as on foot. One might say that what strikes the architectural imagination in the most architectural city of cities is the balance of forces that enable weight and lightness to float on water. These forces do not have a mere visual effect, but enfold the body as it follows an up-and-down course of bridges, canals, steps, and hanging landings. Whether floating in a canal, walking on a bridge, or dry land, or entering the loggia of a building, the city heightens our perception of weightless gravity, through intersecting routes that dematerialise its mass, half-liquid, half-solid.

The potential of a city, a building or a novel to stimulate the imagination depends to a great extent on what is experienced, that is, its geometrical/topological properties, perceptual qualities and poetic logic. It is argued here that it also depends on a great extent on the alternative roads it invites us to access in our imagination, in dynamically generated and virtually embedded meanings. This diversification of knowledge and possible combinatorial universes constitute the most basic condition of dynamic generation of meaning and intersection of analytic with generative knowledge. If generative knowledge concerns the generation of possible worlds and variants, analytic knowledge restricts or limits the number of possible worlds we can conceive of. As soon as we maintain that certain universes are not possible in respect of what is given in our past experience, or that they do not correspond to what encyclopedic knowledge holds to be the laws of reason, we are, at this point, involving external criteria not only to discriminate the results of the *ars combinatoria*, but also to introduce restrictions within the art itself in order to control and limit the possibilities of the system.

Space syntax is based on the recognition that the generation of possibility is restricted by the laws of generic function, namely, intelligibility, movement and occupation (Hillier 1996). In this respect it is not a theory of architectural potential but an analytical theory of social performance and realisation^x. However, the intersection of analytic and generative knowledge in design is what produces unactualised possibilities and evaluates them based on the laws of reason. Even when the outcome of work explicitly foregrounds one type of knowing rather than the other, as when the designer engages with generation, or the analyst with explanation, reflective activity always annexes both kinds of knowledge. Designers enable possibility to become actuality by overcoming limitations imposed by laws of necessity or reason. Theorists

and analysts enumerate possibility and explain how we arrive to actuality by the laws of reason. The *reflective designer* and the *creative theorist* on the other hand, identify both possibility and the laws that need to be breached for design to produce new knowledge, finding thus the gap between necessity (laws of reason) and freedom (possibility). Analytic and generative knowledge are central in design and theory, as each allows access to worlds whose centres of reality are not separate, permanent and fixed but interact and shift dynamically with creative activity and time. Aside to theories of explanation we need theories of generation or a combined theory of freedom and necessity in architecture and design.

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ⁱ Feraro explains that 'folklore and civic pride blended over the centuries to produce the mythical foundations of a Roman and Christian past values that sustained the power and imagination of Venetian rulers, writers, and visual artists' (Feraro 2012, p. 2).

ⁱⁱ According to Peter Corning, "Emergence is a term in evolutionary theory describing what self-organising processes produce. It has been used by physicists to explain Bénard (convection) cells, by psychologists to explain consciousness, by economists and investment advisors to explain stock market behavior, and by organization theorists to explain informal 'networks' in large companies. Indeed, a number of recent books view the evolutionary process itself as a self-organizing, emergent phenomenon" (Corning 2002, p. 2).

ⁱⁱⁱ There is a variety of terms describing evolutionary design, such as computational design, automated design, autopoiesis, genetic coding, replication and selection, (in an analogy with natural evolution), morphogenetic design, generative algorithms, parametric modelling, etc. (Fraser 1995).

^{iv} Depthmap v10.

^v Additional 'dematerialisation' is caused by the use of reflecting materials as shown through isovists on glass surfaces (Figure 7d). *The Hospital was conceived as an aquatic realm in which the light would bounce on water, slabs, walls, the ever-extending sequences of pilotis, and water would penetrate the chapel and the patios, dissolving materiality and its limits* (Allard 2001).

^{vi} Calvino, (1997), *Invisible Cities*, p. 8.

^{vii} 'Cities and Memory', 'Cities and Desire', 'Cities and Signs', 'Trading Cities', 'Cities and Eyes', 'Cities and Names', 'Cities and the Dead', 'Cities and the Sky', 'Continuous Cities' 'Hidden Cities'.

^{viii} As Calvino explains, Kublai Khan personifies the tendency for rationalization, geometry and algebra reducing the knowledge of his empire into combinatorial arrangements of castles, bishops, knights, queens and pawns on the chessboard.

- ^{ix} In their study of the British Museum, Penn et al refer to Ryan's notion of a 'tellable story' to suggest that viewers 'make active choices about where to move next which are at least in part informed by their imagination of the possibilities embodied in any particular choice' (2007).
- ^x Hillier explains that 'combinatoric possibility is the framework within which architectural actuality exists, and the proper form of a theory is one that describes how possibility becomes actuality'. So although we need to 'eliminate combinatorics as a theory of architecture, we must re-admit it as meta-theory' (1996, p. 258).