"Data on the appearance of the environment must be gathered in order to prepare designs and take action. Professional uncertainty as to what is relevant at the city scale, and how it may be best organized for analysis and manipulation, bas made it difficult to include visual considerations in city designs. The nature of the data, and the language in which it is recorded, always have a profound impact on the nature of proposals.

> Kevin Lynch, 1968 "City Design and City Appearance" in *City Sense and City Design*, p. 475

PART II:

THE PATH TO CITY KNOWLEDGE

4 TRAILBLAZING

- 5 The "VENICE INNER CANALS" PROJECT
- 6 **PROTECTING VENICE** from the TIDES

TRAILBLAZING



THE VENICE PROJECT CENTER

creating a bridge



bootstrapping

I had only graduated three years earlier with a Bachelor Degree in Electrical Engineering¹⁴¹ when I hatched the idea of creating the *Venice Project Center* in 1987. Following a stint as a "coop" student, I was appreciated enough by my company – BTU/Bruce Engineering of N. Billerica, MA – to be retained on a three-year H-1 visa (I was – and still am – a citizen of Italy). Taking advantage of my fringe-benefits, I applied to the Masters program in Computer Science at WPI and enrolled in two CS grad courses per semester, attending evening classes paid for by my company. By the time my visa expired, I had almost enough credits to graduate, so I slipped into a Research Assistant job at WPI with the Intelligent Machines Laboratory¹⁴². I had just started my Masters thesis when I received the news that my dad had stomach cancer and had already been operated on before I even knew of the illness.

T here was no point in hurrying back, but I decided that I needed to move back to Venice as soon as possible to be near my family in this time of crisis. Accordingly, I began to make arrangements to complete my Masters thesis in Italy and simultaneously invented the Venice Project Center (VPC) as the "bridge" that would keep me connected to WPI while living in Italy.

What amazes me about the creation of the VPC is not how I possibly conceived that the WPI administration would let me – a mere graduate student – start a center where dozens (eventually hundreds) of WPI students would spend a term conducting a serious interdisciplinary project to complete a major degree requirement¹⁴³. Nothing works better that the naïve drive of an inspired 27-year-old for such audacious gamble. On the contrary, what truly amazes me is that a mature, distinguished professor of English and Associate Provost of WPI was actually convinced by the passionate grad student to embark in a transoceanic adventure of such magnitude. Granted, the plan seemed innocuous when I proposed to simply conduct a preliminary "bootstrap" project to determine the feasibility of creating the center in the first place.

The fateful "feasibility study" took place from mid-October to Christmas of 1988. The center proved "feasible" indeed as witnessed by the over 500 students who have spent a term there since then. The rest – as they say – is history.

¹⁴¹ My senior project had to do with "machine vision", which later got me into Robotics and Artificial Intelligence.

¹⁴² Where we worked with autonomous vehicles controlled by an "activation framework" of intelligent agents communicating with each other and acting locally using heuristics and stored knowledge. These were prototypical "emergent systems" except the name had not been coined yet.

¹⁴³ WPI operates about 20 centers around the world, from Melbourne to Copenhagen, from San José de Costarica to Bangkok, where every year over 400 students complete some part of their college curriculum for a Bachelors Degree in Science, Technology or Engineering.

the early years	Meanwhile, I had miraculously ¹⁴⁴ got a job at the University of
	Venice, to run the fledgling Laboratory for Humanistic Informatics. After the pioneers in the winter of 1988, I had a couple of WPI teams in Venice, in the summer of 1989, but the first big year was 1990. Students same in the
	Winter, Spring and Summer terms, a total of 11 teams and almost 40
	students. That year, a project on lagoon archeology received the Best- Project-of-the-Year Award (known at WPI as the "president's IQP Award").
	It was the first of many such awards, but served as early recognition of the quality of the center, where I conceived and advised all projects, together
	with a faculty colleague as co-advisor.
286 laptops	strongly on the use of personal computers. When we first started, we were
	operating with top-of-the-line 286 laptops, with two floppy drives (and no hard drive as I recall). Technology was progressing fast and we quickly
hard drives!	moved up to 386's with 10, then 20 Megabyte hard drives. Wow! We felt like we were at the forefront of high-tech (and in fact we were), although the
	machines we used had fewer resources than even the simplest Personal Digital Assistant (PDA) of today.
GIS	c eographic Information Systems (GIS) were barely making their debut
	O in the late eighties, yet somehow we jumped into the GIS bandwagon from day one. This was a serendipitous twist of fate that augured well for
	the future of the VPC. I remember vividly taking a long drive to Troy, New
	York, some time in 1987, to go visit a company called Mapinfo, which at the time consisted of two people in a small office in a warehouse-style building.
mapinfo for DOS	We bought one of the first licenses of Mapinfo that year and were very happy with it, even though it was operating under DOS and there were no
unavailable maps	maps to use with the software in Venice ¹⁴⁵ . In order to make use of this powerful tool, we spent a great deal of
	time, for the first couple of years of VPC operation, digitizing Venice maps
making our own	early GIS maps and orthophotos that were not – unfortunately – available to
	the public in electronic form. We threw away our homemade maps a few
	years later when the first electronic maps of Venice became available to us through our contacts with the City of Venice and the Consorzio Venezia
	Nuova.
DATABASES	\mathbf{C} imilarly, we also pioneered the use of real databases, as opposed to the
Dbase III	D spreadsheets that were very much <i>en vogue</i> at the time (remember Lotus
	Tate's Dbase III and III+ which appeared around the time of my return to
Dbase IV	Venice. Around 1990, Dbase IV would make its appearance on our 386
	¹⁴⁴ It's a long story that involves calling Venice historian Frederick Lane out-of-the-blue, after realizing
	Venice A Maritime Republic. Another naïve, spontaneous action that led to unbelievable consequences.
	As it turned out, the Italian projection system was not supported either, but we were so unaware of

 ^{AS II} turned out, the Italian projection system was not supported the finer nuances of GIS that we didn't even notice this drawback...
¹⁴⁶ Published by Marsilio Editore in 1990. r,

machines. Despite the numerous limitations of these early relational databases, we began to put away the results of our first studies in electronic formats that proved to be rather long-lasting in retrospect. More importantly, we acquired a "habit" of structuring our data in ways that made it amenable to analytical computation and to cartographic representation through GIS.

PRELUDE TO CITY KNOWLEDGE

the database "habit"

the grand scheme

City Knowledge by any other name

THE REST OF PART II

the Venice Inner Canals project

Protecting Venice from the Tides

I recall quite clearly having dinner with the parents of one of my first six students in the early winter of 1988. The father of the student surprised me a bit by asking me: "What grand scheme do you have in mind for these student projects"? He thought he could detect some sort of an ulterior motive in the fanatical manner in which we treated data even during that very first project in Venice. I was taken aback by the question since I had never publicly admitted to anyone that I indeed had a grand scheme in mind.

I guess I was not very good at keeping a secret since that man read right through me and saw that I intended to gradually build up a storehouse of knowledge about my hometown. Although we all appreciated the ambitious nature of an endeavor that aimed at gathering information about the "totality" of Venice's reality, none of us had any idea about how difficult that would be, as we sat around that dinner table in 1988. Well, it took almost twenty years and a lot of effort to produce this dissertation, but the scheme I hatched in 1988 now has a name. It's called City Knowledge. And this document is an attempt to define it as I describe just how it evolved from 1988 until today.

The rest of Part II is composed of two chapters. The chapter on the *Venice Inner Canals Project* contains a sample of the numerous aspects of the canals that we studied for over a decade, most of them in the framework of a United Nations Educational, Scientific and Cultural Organization (UNESCO) project – the *Venice Inner Canals* project – sponsored by the Italian Ministry of University and Research in Science and Technology (MURST). The chapter does not cover all of the aspects of canals we studied in the 1990's¹⁴⁷, but introduces only the those that exemplify some of the lessons that were most valuable in the formulation of my City Knowledge approach, which is detailed in Part V of this dissertation.

The last chapter in this Part¹⁴⁸ exemplifies many of the tenets of City Knowledge. It shows how it is possible to tap into "plan-ready" information produced by a variety of past projects in order to postulate a method for the quantification of the damage that high tides can inflict on the material fabric of the city of Venice. Without the incremental accumulation of urban information that I adopted since 1988, the difficult task of ascertaining the cost of *acqua alta* would be neigh impossible. More importantly, without some of the acquired knowledge to guide such an effort, we may in fact arrive at erroneous conclusions and miscalculate the consequences of human

¹⁴⁷ For complete details see <u>http://www.unesco.ve.it/</u>. See also note 151 and Carrera, 1996, 1999b, 1999c, 1999d.

¹⁴⁸ Adapted from a paper currently being published (Carrera, 2004).

and natural acts that affect the behavior of the waters of the Lagoon and of the inner canals, which in turn affect the stones of Venice.

All of the rich examples in the rest of this Part II will help to gradually build a case for City Knowledge, which will be further enriched in Part III, dissected in Part IV, and finally summed up in Part V.

THE "VENICE INNER CANALS" PROJECT

a fateful suggestion

the first scientific study of the canals



VENICE OFFICE UNESCO

MURST





he canals of Venice have been a defining feature of the city since Charlemagne's son Pippin forced the Doge to relocate to the islands of the Rialto in AD 815. When a Venetian scientist¹⁴⁹ suggested that we study the hydrodynamics of the Venetian waterways in 1989, I thought that it would be an interesting project for my students which may provide some interesting information to contrast against past studies on the same subject. A comparative study of the hydrodynamics of the inner canals could, for example, provide support for the hypothesis that the creation of the artificial Canale dei Petroli in the central lagoon had dramatically altered the flow of water in the city. Such a study could also demonstrate how some canals became more stagnant after some adjoining canals had been filled-in and turned into rii terà. When the first team of students began studying the Venice inner canals in the Dorsoduro section of town in the winter of 1990,150 we were looking forward to these before-andafter comparisons. Generally, canals exhibit a bi-directional current, flowing in one direction when the tide is coming in from the sea, and in the opposite direction once the tide retreats back out to sea. Instead, our study showed that the four canals we monitored always flowed in the same direction, regardless of whether the overall tide was rising or falling, which was a rather unexpected result. The most surprising discovery, however, was the fact that these thousand-year-old canals had never been scientifically studied before. In their millenary history, nobody had ever bothered to do what these four twenty-year-olds from America had done in just a few weeks. This was an amazing discovery that led to a decade of in-depth studies of the entire canal system, making the Venice Project Center the foremost repository of knowledge about the inner canals in the history of Venice. What had started as a comparative study of water currents, soon turned into a thorough multiyear baseline survey of many different aspects of the target canals.

Our solo beginnings caught the attention of a local official of the United Nations Educational Scientific and Cultural Organization (UNESCO) who enlisted me to write a major funding proposal to the Italian Ministry of University and Research in Science and Technology (MURST). The resulting project, based on our initial studies, was officially named the *Venice Inner Canals* project and it attracted over one million dollars in funding. From 1992 to 2002, the Venice Project Center played a major role in carrying out the planned research, which can be perused on the web at www.unesco.ve.it.¹⁵¹

In 1997, the City of Venice, spurred in part by the UNESCO-MURST project, created a public-private company, named Insula S.p.A. to

 ¹⁴⁹ The man's name is Gianpietro Zucchetta, a Venetian chemist who at the time was working with the National Council of Research in Venice, and who had just published a book entitled *I Rii di Venezia*.
¹⁵⁰ Ciacciarelli *et al.*, 1990.

¹⁵¹ The synthetic reports in English and the web site design were part of the final contract that the author had with UNESCO. The web site may have been relocated since this writing, but my personal web site should redirect an interest reader to the new site (see <u>www.wpi.edu/~carrera</u>).

the Venice Inner Canals project





carry out urban maintenance activities, primarily on the inner canals. In 1998, Insula and UNESCO entered into a cooperation agreement whereby all of the data collected by the UNESCO teams (including the WPI Venice Project Center teams) were transferred to the fledgling company to get the initial maintenance activities off the ground as rapidly as possible. The cooperation gave Insula the jumpstart it needed to quickly begin canal dredging and repairs and also resulted in the publication of a joint UNESCO-Insula book entitled *Venezia la Città dei Rii* (Venice the city of canals)¹⁵² which I co-edited.

In this chapter, I retell the story of the Venice Inner Canals project as a way of introducing many of the essential elements of City Knowledge that were first identified in the course of these studies and later became permanent features of our *modus operandi* in other areas of research. In particular, this chapter will describe our early efforts at a systematic standardization of the spatial reference frameworks along "reasonable" atomic elements (the so-called "canal segments"). Even though most of our studies were "plan demanded" in the early years, the "scaffolding" that we created quickly became the source of "plan ready" knowledge that later was re-used for a variety of different purposes.

Our work received lots of recognition from the media. In addition to the aforementioned book, we were also featured in numerous magazines, such as National Geographic¹⁵³, the Smithsonian¹⁵⁴, Wired¹⁵⁵ and New Scientist¹⁵⁶. I was also personally featured as the main character of a National Geographic documentary entitled *Venice: City under Siege¹⁵⁷*.

Most importantly, though, our success can really be measured by the impact that our projects have had and continue to have on the city of Venice, where many of our suggestions have been implemented and where much of our data are used daily to make the city function, from the canal dredging that Insula is performing, to the management of boat docks by the city's public services department, from traffic modeling to sewage disposal. City Knowledge is in fact working in Venice, albeit in embryonic form and through isolated cases that still lack overall coordination and integration. Yet, the examples shown in this chapter will demonstrate that the dice has been cast and I think it's only a matter of time before the first full-fledged City Knowledge system is developed in its entirety.

- ¹⁵³ National Geographic magazine, August 1999.
- ¹⁵⁴ Smithsonian magazine, September 2002.
- ¹⁵⁵ Wired magazine, August 2003.
- ¹⁵⁶ New Scientist, September 2003.
- ¹⁵⁷ National Geographic Video, "City Under Siege", series: Out There, aired worldwide 2002-2004.

¹⁵² Caniato et al., 1999.



The last few paragraphs of each section, entitled *Lessons Learnt* (or some variation thereof), recap and distill the "lessons" that the section is meant to convey. One of the overall lessons of this particular chapter is that there are <u>immediate</u> benefits to the systematic standardization of a city knowledge framework. These instant advantages ought to be enough to justify the standardization effort by themselves. Breaking up the canal network into small bite size chunks allowed us to reorganize these atoms into any combination we needed when more advanced issues were tackled later in the research effort. Here the moral is that if you just look at the "trees" you may lose track of the big picture, but seeing the urban environment as groups of objects or elements affords great freedom to recombine the atoms into any configuration, as long as there is an overarching scaffold to support the organization of these pieces. Once the framework is in place, the benefits extend far beyond the immediate.

THE CANAL NETWORK



lack of canal studies



lack of standard referencing



he Venetian canal network performs a double duty for the City of Venice. It is at the same time both a transportation and a sewage disposal network. Boats ply the network to transport all manner of goods and people, as trucks and buses do in "normal" cities. Everything that moves on wheels on the mainland moves on water in Venice. Taxis are boats, as are buses, ambulances, police cruisers and fire engines. The uniqueness of Venice is that the transportation grid never crosses the pedestrian routes at grade. LeCorbusier (among others) considered this an ideal system for urban mobility. Similarly, up until the late 1800's, most people looked at the Venetian canals as the ideal sewage removal conduits. Before the advent of modern sewer systems,¹⁵⁸ large cities were infested by untreated sewage. Human and animal¹⁵⁹ excrements piled up along streets and in back lots until rains mercifully washed off the noxious refuse. Not so in Venice, thanks to its canals. Unfortunately though, to this day (2004) a majority of the residential sewage still ends up in the canals, to be flushed out to sea by the daily tides. What was once a marvel in the eyes of XIX century visitors, has become an eyesore to contemporary travelers and a source of embarrassment and occasional discomfort to today's Venetians.

Given the importance of these dual roles, one would think that, over the centuries, Venetian authorities would have committed significant resources to the study of these bodies of water. Surprisingly, such was not the case. For example, the hydrodynamic behavior of the canals, which is of considerable importance in the dispersal of the sewage outflows and can also affect boat traffic¹⁶⁰, was never really quantified until WPI students carried out their first measurements in the 1990's. The earliest record of a qualitative investigation dated back to 1900¹⁶¹ and the only limited quantitative campaign was carried out in 1966¹⁶². In all, even counting studies of dubious scientific value and studies that were only vaguely referenced in the literature, as of 1990, only about nine publications existed about the topic of the hydrodynamics of the inner canals and none of these were truly scientific, systematic or representative of typical behavior.

Even when previous data existed, it was nearly impossible to compare them to what we were measuring, since the location of the past measurements was identified just by a canal name, without any specification of where, along its length, the measurement was taken. This issue was nontrivial since traditional canal names often referred to waterways that didn't change name through several intersections, just like many roads in American cities don't change name every time a side street intersects with them. Since water currents are affected by the flows of intersecting canals, not knowing exactly where the measurement was taken vis à vis these intersections meant

¹⁵⁸ Ancient Rome had the "cloacae", so sewers are not really a modern invention.

¹⁵⁹ Let's not forget that horses and mules were the primary means of cargo transportation, which compounded the problem. Cf. for example, Rodolphe el-Khoury, "Polish and Deodorize: Paving the City in Eighteen Century France".

¹⁶⁰ Especially when oars were the only means of propulsion.

¹⁶¹ Paluello,1900.

¹⁶² Dorigo, L., 1966.



that there was no reliable way to make an apple-to-apple comparison with later measurements.

The problem was that, whereas we knew <u>exactly</u> where we took <u>our</u> measurements, the reference systems of past studies did not allow for the pinpointing of their measurement locations with the same level of accuracy, rendering such comparisons impossible. In order to change this state of affairs and to make possible future comparisons with <u>our</u> data, we devised a system for the unequivocal identification of each tract of canal, through a process of segmentation.

The next section explains how such a system was developed.

REPRESENTING THE NETWORK



canal segment



islands



I norder to define the indivisible, fundamental components of the canal network that would make hydrodynamic comparisons feasible, the discriminant was the presence of an intersection. The "atom" was defined as a tract of canal between two intersections and was labeled a "canal segment". This simple concept was complicated a tad by the fact that in Venice there exist several filled-in canals (called *rii terà*) that were turned into pedestrian streets. In many cases, these *rii terà* maintain a subterranean conduit that is overlaid with pavement, thus preserving the hydrodynamic function of the former canals. Therefore, for our segmentation, we had to also consider as intersections the points where *rii terà* joined regular canals. In fact, since nobody had ever mapped out the canal network on a Geographical Information System (GIS), we were faced with the task of determining the shapes of the canal segments as we identified their boundary intersections.

Of course, we could have created "stick canals" or "stick segments" by simply representing the water network as one-dimensional centerlines, as is still frequently done in many GIS applications when dealing with roads¹⁶³. Back in 1990, working on Mapinfo® for DOS, lines were certainly more appealing than full two-dimensional shapes or regions to represent the canal segments. However, the linear representation was deemed inadequate early on for a variety of reasons. For example, it didn't allow to tap into the geospatial dimensioning features of GIS, such as the ability to automatically determine surface areas which are needed to calculate water and sediment volumes. Also, the arc representation of canals prevented the measurement of widths, which are crucial for canal navigation. Conversely, shapes do not directly provide canal length information, which lines would provide instantly. What aided our decision was the consideration that, once regions are defined, it would be somewhat easier to derive the respective centerlines than to transform lines into shapes in the opposite direction. But, before we even began the creation of two-dimensional canal regions, we needed to first define the most fundamental units of space that gave shape to the canals, i.e. the islands. Once we had defined the perimeters of all the islands, everything between these islands would belong to the canals layer¹⁶⁴.

In 1990, when we had started this project, G.I.S. maps were still treated as rare commodities and access to the few existing layers was essentially barred to anyone but a few insiders. Thus, we began to make our own maps by tracing on a digitizing tablet the printed outlines of islands that were published in a marvelous publication that had just been issued at that time, called the *Atlante di Venezia*¹⁶⁵. A few years later, once we obtained electronic maps from the City, we repeated the process and produced a final "official" version of the layers for islands, rii terà, intersections, canals and canal segments, all of which have been adopted in day-to-day use by all

¹⁶³ For example, the Census Bureau's *Tiger Files* are just simple line arcs.

¹⁶⁴ Using a similar approach with regular city blocks may be a good way to define road shapes in

[&]quot;regular" cities, since blocks are probably fairly stable features in urban settings.

¹⁶⁵ Atlante di Venezia. 1990.



Lesson 1: atomize

departments of the City of Venice and also by Insula S.p.A. and other governmental and non-governmental organizations¹⁶⁶.

The other fundamental layer needed before segmentation could be applied to the whole network was an *intersections* layer, representing the connections between two canal segments and also between a canal segment and a *rio terà*. Thus the second layer that we developed was a *rii terà* layer. This layer was extracted primarily from existing publications on the topic of rii terà¹⁶⁷. These former canals were classified as vaulted or filled, based on the available information, but both types were equally used to determine valid intersections for the intersection layer.

Once all of the 125 islands and the 50 rii terà had been defined, it was possible to identify and map out all of the intersections that bracketed all of the segments in the city. Intersections could come in two flavors: one type of intersection occupies physical space and has a definite surface area; another type is a symbolic line that represents a potential location for an intersection, but does not physically occupy space. The latter are generally connections between real canals and filled-in *rii terà*, but can also represent junctions between small canals and very large ones like the Grand Canal. "Real" intersections, which occupy physical space, occur at intersections between segments and include tracts of water that do not belong to any of the intersecting segments, which were terminated flush with the end of the two islands that formed the sides of the segment.

After all 307 intersections were identified and represented, we could define all of the 367 segments in the network. By definition, each segment could only connect to exactly two intersections. Concatenations of two or more segments could then be used to reconstruct as completely as possible the traditional canals that are still the "unit" that is understood and referred to in common parlance by today's Venetians. Even these traditional canals have been nonetheless "formalized" and must begin and end on an intersection, since they are "molecules" composed of the "atoms" of canal segments. In all, we defined 182 neo-traditional canals with official names, and distinct beginnings and ends.

The main lesson we learnt from trying to deal with an unstructured framework of traditional canal names was to divide the territory into the smallest units (or atoms) that made sense at that time. The guiding principles in determining when to stop the breakdown were technical and logical. First of all, we would only be able to keep track of elements that were adequately representable and measurable using current technology. Moreover, we would only divide reality into units that "made sense" in terms of what our purposes were for the practical utilization of our territorial datasets¹⁶⁸. The units of analysis that we foresaw using for urban maintenance, management or planning dictated the units of measurement that we set up.

 $^{^{166}\,}$ Personally, I feel that the naming and coding of canals and canal segments is one of the most rewarding and lasting consequences of my work.

¹⁶⁷ Zucchetta, Gianpietro. 1992. Un'altra Venezia.

¹⁶⁸ See Evan's (1997) discussion of river reaches for more on this subject.

I guess the generalizable lesson is that one ought to make the units of measurement as small as technologically feasible and as big as practically appropriate in terms of transaction cost vs. analytical benefit.

STANDARD REFERENCE SYSTEM



canal names and aliases





island codes and names





In order to make all references to these atomic segments uniquely distinguishable, each segment was assigned an alphanumeric code as the primary identifier. Each of the 182 newly created canals was assigned a four-letter code representing the most significant letters of the prevailing name of the traditional canal whose course most closely approximates the course of the new concatenated one. For example, the canal commonly known as *Rio de San Salvador* was assigned the code SALV. Once canal codes were assigned, based on the prevailing traditional name, the latter became the "official" name of the canal and was permanently associated with that canal.

Many Venetian canals however are known by more than one name, so an arbitrary decision had to be made about which name to assign to the canal as the official appellation. To allow multiple names to be connected to a canal, we created an "alias" list in a database table, so that each canal code could be associated to a variable number of names.

Any segment that is part of this newly defined canal would subsequently be assigned a unique identifier according to the syntax XXXXnn, where XXXX is the code of the longer, neo-traditional canal that encompasses that segment, and "nn" is a two-digit consecutive numeric index that sequentially numbers the segments from north to south, starting at 1. So, for instance, if a traditional canal is called *Rio dei Scoacamini*, the code for the neo-traditional canal that most closely approximates the course of that ancient waterway would be assigned a canal code of SCOA, and the two segments that make up the new canal would be labeled, from north to south, SCOA1 and SCOA2. If a new canal was made up of only one segment, then such segment would not have a numeric suffix, thus the canal code and segment code would be identical, as in the case of the aforementioned SALV.

Islands had already been numbered, though not completely, by the City of Venice, so we adopted the existing enumeration, and numerically labeled the remaining islands. In addition, being a fervent admirer of alpha codes, because of their inherently higher information content, I also insisted on a four-letter code for each island. The four letters would represent the most significant letters of the most prominent landmark on that island, be it a church, a palace or even a famous street or square. Thus, each island would have a dual link to outside data, through the pre-existing numeric code and through the new alpha code. For example, the island where Saint Mark's square is located is doubly labeled with the mnemonic character label MARC, as well as with the more compact, but less identifiable number 92.

In spite of my personal bias toward the more explicit character labels, intersections were simply numbered sequentially from northernmost to southernmost, according to the Y coordinate (latitude) of the centroid. The increment was set at 5 units instead of 1 to allow for potential insertions of additional intersections in future years. Thus, the northernmost intersection was numbered 5, the next one to the south 10, then 15, until the 309th intersection that became number 1,545¹⁶⁹. This north-to-south

¹⁶⁹ Since the original numbering, two intersections have been deleted, bringing the total from 309 to 307 and creating two 10-unit gaps in the sequence at number 400 (395-405) and 1,515 (1510-1520). Despite



legacy identifiers

embedded permanent parameters





Fabio Carrera

ordering implied that the two intersections that bracketed a specific segment would frequently have widely differing intersection numbers, but the northernmost node would always have a lower number than the southernmost one¹⁷⁰.

Rii terà were not assigned text codes, but were simply numbered sequentially. After their important initial role in the determination of the intersections to use for the segmentation of the network, filled-in canals were not associated with specific datasets until a later date, when I wrote a small article on *rii terà* for the book on the canals that I co-authored in the year 2000¹⁷¹. On that occasion, the date of the conversion of a canal to a pedestrian street and the government¹⁷² that commissioned the work were recorded and a preliminary analysis was conducted to determine what public administration was most culpable for these *ante litteram* "urban renewal" activities.

Aside from the standard codes that uniquely identify each element, the fundamental layers discussed so far – namely the islands, rii terà, intersections, segments and canals – each had additional pieces of information that were permanently embedded into the structure of the layer. First of all, individual objects in most layers are frequently associated with a number of additional reference codes and IDs that are part of the heritage that these objects carry with them. Pre-existing IDs should always be included when possible¹⁷³, to allow for some retroactive linking to legacy databases that may have been in use up to the present.

My personal approach is to limit the amount of data embedded in the layer itself and instead keep all related data in separate external databases. Nevertheless, a modicum of information is permanently affixed to each element in each layer, in addition to all of the necessary identifying codes and labels discussed above. The permanent parameters that may be typically embedded within each element of a layer are:

- immutable physical features of the geographical object, such as its surface area or its perimeter¹⁷⁴, and/or
- topological aspects, such as codes of objects that are connected to the element in question, and/or
- categorical classifications, such as typologies (e.g. whether a rio terà is vaulted or not), and/or



the deletions, the north-to-south sequencing remains intact and proves the resilience of the method adopted.

¹⁷⁰ This built-in feature proved really useful at a later date, when Insula S.p.A. requested that we include, inside the segment layer, the codes of the north and south nodes attached to each segment.

¹⁷¹ Caniato, Carrera, Giannotti and Pypaert, 2000, Venezia la Città dei Rii. Cierre ed., pp. 216-221.

¹⁷² Namely the French empire, the Italian Kingdom, the Austrian empire or the Venetian republic itself. Some projects were combined Venice+Austria efforts, since they were started before the fall of the republic and completed by the Austrians.

¹⁷³ One must always be very cautious with existing IDs to ensure that the old and new objects are exactly the same or sufficiently comparable for the purposes for which they are used.

¹⁷⁴ Even though any GIS system could easily extract these features from the geometry, it is usually convenient to have these parameters ready without additional effort, especially if they are to be used frequently.

reusability

• information about the object's creation history (such as what government filled-in the canal, to stay with the above example) or other metadata, where appropriate.

The information attached to each object in a layer should be homogeneous and, to be truly useful, it should be as complete as possible across all objects in the layer.

The unique coding of each element of each of the fundamental layers had to be done manually, but once this was done, any piece of data subsequently collected on any aspect or phenomenon related to any of these objects could be automatically linked to its location in space, thanks to these spatial units of reference. This spatial framework made it possible for all of the data collected in later years by dozens of WPI teams to be forever referenceable and hence re-usable *ad infinitum*, as will be shown in detail in later chapters. Once defined and labeled, a typical segment (like the aforementioned SCOA1), could very easily be linked at any later time to additional information such as: physical dimensions, boat traffic counts, hydrodynamic current velocities, the extent of canal wall damage, the quality of the water, estimates of sewage discharge and many other pieces of city knowledge. This is exactly what we did in the rest of the 1990's.

The next several sections describe in some detail many of the varied pieces of knowledge that we collected following the creation of the reference system, showing how we were able to instantly link several datasets to the corresponding segments via the aforementioned standard codes.

Lesson 2: codify Alongside the atomization of the spatial objects that compose the city, it is important to assign unique codes to each of these atoms, in order to make further references possible. Once each object has a clear nametag, many disparate sets of attributes can be connected to it by a variety of different organizations or individuals to suit different needs. This simple concept, which has been around for years in the Relational DataBase Management System (RDBMS) community, is not often applied wholesale to all mappable objects that make up the municipal territory.

Later on, in Part IV, I suggest ways in which these identifiers can be assigned uniquely and reliably by specific public agencies who have jurisdiction over the "birth" and "death" of these physical objects in reality.

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PHYSICAL CHARACTERISTICS

The first pieces of city knowledge that were attached to the newly defined and identified canal segments were related to physical aspects of the segments, specifically length, width, surface area, depth and volumes of both water and sediment in each segment. All of the dimensional parameters except for the depth (and consequently the volumes) were obtained directly from the GIS maps. The measurement of canal depth (also known as bathymetry) took several years from 1990 until 1994, since students were only in Venice for a few months every year.

surface area

The easiest dimension to calculate for each canal segment was its surface area, since this measure was automatically implicit in the segment's geographical shape. GIS systems will instantly provide the surface area of an object once it has been spatially defined.



length



Now that segments had a clear beginning and end at an intersection, it was possible, for the first time ever, to truly determine the length of canal segments and of neo-traditional canals in a definitive way. It may seem patently obvious, but one cannot measure the length of a stretch of transportation network – be it a road segment or a canal segment – if there is no clear definition of the extremities of the stretch being measured. Knowing the length of a transportation arc is useful for a myriad of mundane maintenance and management tasks. Contracts and payments are often based, for example, on lengths of road plowed, or miles paved, or – in Venice – on the meters of canal dredged. It is amazing that Venetian authorities had operated for so long without an official listing of canal lengths. Once again, we were the first to produce a fundamental piece of

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city knowledge – one that will conceivably remain unaltered for ever and will be used for years to come.

Determining the length of a canal segment entailed first and foremost the definition of *centerlines*. These were constructed manually for all canal segments, by drawing lines along the segment's midpoint from one extremity of the segment to the other, keeping the centerline equidistant from both sides at all times. Intersections received a similar treatment. The centerline of a neo-traditional canal was simply formed by the concatenation of the centerlines of all of its component segments together with the centerlines of all the intervening intersections. Once the centerlines were drawn, segment and canal lengths were computed instantly through standard GIS functions¹⁷⁵.



width



The width of a canal is an elusive measure, due to the irregular shape of the Venetian waterways. Even though typical city roads are more regularly shaped, any single measure for the width of a transportation link is often misleading. One can use an average or resort to other statistics, such as the width at the widest and narrowest points, but it will be rarely possible to define a single width as easily as one defines a single length or single surface area. Measuring the narrowest and widest points is also non-trivial since this determination implies the laborious ranking of several

¹⁷⁵ Since canal lengths were expressed in meters, we settled for one decimal digit, representing 10ths of meters as the highest precision that made sense, though meter-precision is probably even more realistic.



measurements. With highly irregular segment shapes, it is even difficult to determine exactly what point on the opposite side to measure to.

Fortunately, the average width of a segment can be computed by simply dividing the surface area by the segment length. Thus, we were able to determine this dimension for <u>all</u> canal segments in Venice.

modeling canal geometry

narrowest point

Average widths were very useful for the creation of the geometry of the hydrodynamic model discussed in later sections. In modeling applications, the complex network is reduced to an abstract chain of parallelepipeds characterized by the length, average width and average depth of the segments that they represent. For practical purposes, the longer and the more irregular the network arc, the less useful a single measure like the average width will be. For instance, a cargo boat driver looking at the thematic map of the average canal widths (above) could detect some potentially troublesome canals that one should probably avoid traversing with a wide boat (the red canals in the above map), but there is no guarantee that there are no additional choke-points in the other canals that would still impede navigation. The narrowest width of each segment is extremely useful for practical purposes, and the author's company (*Forma Urbis*) has just completed all such measurements for the development of a boat traffic model for the City¹⁷⁶.

¹⁷⁶ See p. 82.



depth or bathymetry

normalizing to the absolute zero



dynamic segmentation



Measuring the depth of the canal segments was a non-trivial endeavor. First of all, depth is a three-dimensional quantity that is hard to

> represent succinctly. Ideally, depth could be determined with some sort of a sonar or radar device that would produce a topographical map of the bottom of a canal. Unfortunately, since canals are only about 1-2 meter deep on average – depending on the tide – the error that many commercial electronic sounding devices produce is often greater that the entity being measured, thus making such an automatic approach not feasible. Instead, we resorted to manual soundings of the canal bottom using a weighted tape measure that was reeled down from the surface to

the bottom of the canal at intervals of one meter across the canal's width, starting with a measurement along the northernmost wall and ending with a measurement along the southernmost wall¹⁷⁷.

To take into account tide fluctuations, we had to normalize all our soundings to the so-called "mareographic zero" of 1897 – a standard reference level for all tide-related measurements in Venice. To do this, we had to monitor tide levels in parallel with our bathymetries, in order to measure the difference of each of our depth soundings from the standard zero. These parallel tide measurements were conducted near the location of the bathymetric sounding by a team member who measured the height of the water from a sidewalk of know altimetry (or elevation).

Cross-sectional soundings were repeated at intervals of 25 meters along the length of the segment. In some ways, this could be interpreted as a "sub-atomic" segmentation of the atomic segments. Each section was uniquely identified by the code of the segment in which it occurred plus the distance of the section, in meters, from the northernmost end of the segment along the centerline. This type of sub-segmentation is similar to the so-called "dynamic segmentation" used in "linear referencing systems" to, for instance, pinpoint accident locations on road segments¹⁷⁸. The Venetian bathymetric cross-sections prove that whatever unit of space is chosen as the "fundamental atomic particle", there will invariably be cases in which subatomic divisions will be necessary, therefore all we can really do is to settle for a "reasonable" happy medium and adopt the breakdown that seems most appropriate as the unit of analysis for the majority of users.

Whereas we could determine the definitive lengths, surface areas and average widths for <u>all</u> segments, we only obtained reliable depth measurements for 130 of the 367 segments¹⁷⁹.

¹⁷⁷ This north-to-south order was not always maintained, but an arrowhead on the section lines in the corresponding GIS layer indicates the exact direction of measurement for each section.

¹⁷⁸ Some GIS products, like ArcGIS, support dynamic segmentation on-the-fly. See also Fletcher *et al.*, 1998.

¹⁷⁹ The Insula company has since contracted additional bathymetric campaigns to determine the depths of the remaining canals.



average depth

modeling canal depths

sediment volume

Fabio Carrera

In the end, the bathymetric dataset was represented by 7,768 individual measurements along 850 section lines. We chose not to represent each individual measurement graphically as a dot in its exact location along the section¹⁸⁰, though this approach may have been useful to determine navigation paths, as explained below. The tedious complexity of such a task made us opt instead for a sort of recursive dynamic sub-segmentation, achieved by including the section's identifiers (i.e. the segment code and the distance of the section from the northern end of the segment) with each bathymetric sounding in the database. In the linked database, each depth measurement was labeled by the code of the segment where the measurement was taken (e.g. SALV), plus the distance of the sounding from the northern end (e.g. 25) and the distance of the sounding from the northern wall of the segment (e.g. 4).

Similar to widths, depths are also difficult to express uniquely for each segment. Moreover, unlike widths, average depths cannot be easily computed from other GIS-derived dimensions, but require instead extensive field campaigns. As mentioned, almost 8,000 measurements¹⁸¹ had to be conducted - all at night to avoid interference from boat traffic - to quantify canal depths. On average, 55 soundings were performed in each canal segment. The average of all the depth measurements in one segment was used as the overall average depth of the entire segment¹⁸².

Average depths, like average widths, proved useful for modeling purposes, but not too practical for everyday life. However, there is another useful utilization of the average depth - in conjunction with the surface area - namely for the calculation of sediment volumes, which are used, among other things, for estimating dredging costs. Being the first to systematically determine these dimensions, we were also the first to be able to produce reliable estimates of the volumes of sediment that needed to be removed from each canal segment. Such volume calculations obviously depend on a definition of where the bottom of a segment lies.

¹⁸⁰ Each sounding location could in theory be determined algorithmically and mapped with a small GIS application utilizing the information already available.

¹⁸¹ In reality, well over 10,000 measurements were conducted, but only 7,768 were validated and transferred to Insula in the framework of the UNESCO-Insula accord. In all, the bathymetric campaigns took over 12,000 hours of work to complete.

¹⁸² In fact, in order to make the average depth as realistic as possible, the average was computed omitting measurements along the canal walls on both sides of each section.



canal bottom

water volume



Being semi-natural watercourses, canal segments do not have an easily identifiable bottom. For practical purposes, the city of Venice has arbitrarily defined the so-called *fondo di progetto* (project bottom) of each segment as the desired depth that the segment should be maintained at to allow smooth navigation of emergency boats even during low tides. Such a bottom is generally set between 1.8 and 2 meters below mean sea level¹⁸³. Once the target bottom depth is defined, sediment thickness is simply derived by subtraction.

Complementary to the notion of sediment volume is that of water volume. In a perfectly dredged canal, all of the volume, dictated by the surface area and the desired depth, would be occupied by water. As sediment begins to accumulate, the total capacity of the canal segment is shared by a combination of water and sediment. Water volume is indirectly useful in modeling applications, both for hydrodynamics and for transport of suspended matter in water, as will be discussed later.

Depending on the draft of one's boat and on the tide conditions, one would probably tend to avoid canals with low average depths (red in map above) no matter what. But, once again, there would be no guarantee of

¹⁸³ I have publicly argued whether this depth is to be taken from the standard mareographic zero of 1897 or from today's mean sea level, which is 23 cm higher than the standard. I even calculated the difference in cost, due to the additional sediment one would remove if measurements were based on the absolute zero of 1897, which adds up to several million dollars. My view is that nature (or global warming) has done us a favor in this case by rising the mean sea level thus sparing us from dredging about a quarter of a meter of sediment throughout the entire network. We should take advantage of this bonus and not squander resources on unnecessary excavations.

being able to navigate the segments with medium average depths (yellow above) or paradoxically even the ones with the highest average depths (green). One shallow point in an otherwise deeper channel would be sufficient to completely impede passage, even though that canal segment may be very deep on average as a whole.

Looking at just the data, one may be tempted to identify the shallowest data point as the bottleneck. This would be fallacious, since the absolute shallowest points are almost always along one of the canal walls. Knowing that such points are the shallowest would be useless for all intents and purposes. No boat could possibly travel along the canal walls anyway. In fact, a boater would always attempt to tread a route through the deepest part of the canal, so that, at any moment, the boat would be passing over the deeper point of a particular cross-section, staying well clear of the shallowest. Therefore, what would be truly useful, is to know where these deeper points are across any section. We did precisely that, with a two-step manipulation of the fundamental soundings dataset. First of all, we identified the deepest points of each section, and then we selected the shallowest of these to truly determine the navigability bottlenecks. In our research, we defined what we called a navigability axis as the line connecting the deepest points of each of the bathymetric sections. Thus, even though we could not vouch for the depth of any water between sections, we could determine the point along this navigation axis where the water was shallowest, hence providing a more useful indicator of navigability to local boaters. This "shallowest of the deepest" concept is one demonstration about the difference between data and information.

As a further example of the usefulness of dynamic segmentation, one could imagine an intelligent application that could determine, for a boat with a given draft traveling during a given tide phase, the impassable sections in all canal segments. Depending on the exact destination of the boat's travel, one could even imagine that a system could allow travel part of the way down a segment with a known shallow obstruction, as long as the boat did not have to go through such a point, but was going to dock before reaching the impasse. Although we didn't use such level of sophistication, the ambulance dispatching application discussed earlier¹⁸⁴ could potentially benefit from such dynamic segmentation of the canal network.

Unlike the other physical dimensions, the determination of a canal depth is ephemeral in nature. With the passage of time, additional sediment will accumulate and canals will get shallower, rendering our measurements obsolete. Also, as Insula proceeds with its dredging program, canal segments will be deepened all the way to their *fondo di progetto* and sedimentation will start over from a *tabula rasa*. The action of human beings and nature combine to make these measurements short-lived, but not necessarily futile. In fact, our data collection jump started the operations of Insula when it was a fledgling company in 1997. Since then, several canals have been dredged and Insula has maintained the information up-to-date by resetting the bathymetries to the *fondo di progetto* for those segments. More complex is the



navigation aids

shallowest bottleneck.

partial navigability

data longevity

data maintenance

¹⁸⁴ Page 34.

sedimentation model	issue of maintenance of the information for segments subjected to natural sedimentation. One way to monitor the silting process is to conduct periodic measurement campaigns similar to the ones we pioneered. However, this would be a rather expensive proposition. An alternative that we have proposed to Insula, through UNESCO, is the creation of a sedimentation model to simulate the natural processes and estimate sediment levels over time, to plan preventive maintenance on a regular basis. This model is discussed in more detail later. Our data, even though it is obsolete by now, is still useful as a baseline to compare with subsequent measurements. The "growth" of sediment over repeated measurements, using our initial efforts as a baseline, will help determine sedimentation rates and thus inform the development of the sedimentation model.
lessons from our physical studies	Having set up the geographical framework made up of coded spatial objects, this aspect of our canal studies, despite its simplicity, taught us a few additional lessons.
[do not oversimplify reality]	Lesson one was that many of the physical characteristics of real- world objects are easily managed by GIS as long as the representation of the real objects is "literal", i.e. unfiltered and un-simplified. If we represent a
[represent objects as they are]	canal segment as a "region", i.e. a polygon whose shape reflects as accurately as possible the shape of the actual segment, then we can rely on the GIS representation to tell us the basic physical dimensions (like area and perimeter) automatically and for free. Simplifying the canal network into a series of centerline segments may bring some efficiency savings in some arenas (like calculating the segment length and enabling transportation modeling of links), but it also produces a net loss of usefulness in many other areas. The fact is that these two representations are not mutually exclusive. What worked for us was to use the geometric representation that
[create geometry to suit needs]	best suited our analytical needs. In general, this lesson suggests to create GIS objects that reflect the true shape of the objects in real life, which means to use "regions" (or polygons, a k a "shapes") whenever an object with a real surface area is
[multiple geometries can be appropriate]	being represented. More specifically, it seems appropriate to represent road- like elements (like our canal segments) using both a region/shape geometry as well as linear objects (centerlines).
[capture permanent physical dimensions]	measured and archived once and for all, as soon as we have settled on an appropriate atomization of the objects. GIS provides us with basic measurements for free, but we first have to define the exact extent of each object using the atomization that best suits our needs ¹⁸⁵ . The choice of how much detail to include and where to draw the line while divvying up reality is not so simple ¹⁸⁶ . In fact, just when we thought we had identified the "indivisible" atoms of the canal network – namely the segments – we
[prepare for sub-segmentation]	immediately ran into "sub-atomic particles" when we had to deal with depth measurements at cross-sections. The bottom line is that we will use ¹⁸⁵ Cf. Evans, 1997.

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¹⁸⁶ See lesson 1 on page 50.

whatever segmentation makes sense at the time. Some of these partition decisions may have staying power and prove useful for an overwhelming majority of uses and some may not. But we should not refrain from making these choices lest no progress will ever be made in representing our urban features¹⁸⁷.

The natural process of sedimentation immediately emphasized the shortcomings of a 2-D GIS platform. Depth is an inherently 3-D measure, so we couldn't quite visualize it in our Mapinfo system¹⁸⁸. This process is also dynamic, so our measurements are ephemeral and bound to become quickly obsolete. Yet, the sedimentation process is gradual and somewhat predictable, so our third lesson was that it makes sense to develop a sedimentation model to predict the silting up that will happen over time. The cost of such a model, if successful, would certainly be cheaper, in the long run, than repeating the bathymetric measurements periodically for ever and ever.

[2-D vs. 3-D]

[update ephemeral dimensions]

[modeling predictable processes]

[modeling vs. re-measuring]

¹⁸⁷ Fletcher *et al.*, 1998.

¹⁸⁸ For an example of how we dealt with this shortcoming, see the 3-D graphing functionality we added to our *SmartInsula* application (page 102 ff.).



acqua alta (flooding)







hydrodynamic behavior

T idal currents in the canals are responsible for flushing the urban sewage out to sea, redistributing sediment along the canal bottoms in the process. Hydrodynamic currents are created predictably by the cycles of the moon and less so by meteorological phenomena such as barometric pressure and winds. Stagnant canals will not benefit from the cleansing action of tides and will thus become malodorous pools that negatively affect the lives of residents and visitors alike. Stimulating good hydrodynamic activity in all canals has always been a goal of government administrations in Venice for centuries. The worst of the stagnant canals were the first to be converted to *rii terà*¹⁸⁹.

Tides in Venice are infamous primarily because of the phenomenon of Acqua Alta (high water), which has grabbed most of the headlines since the record-breaking event of November 4, 1966, when 1.94 meters of water submerged the entire city and all of the islands of the lagoon ¹⁹⁰. Since then, numerous national and international initiatives have been undertaken to safeguard Venice from floods. Most notorious is the long-lasting controversy about the construction of flood gates at the three lagoon openings (a.k.a. bocche di porto) of S.Nicolò (Lido), Malamocco and Chioggia. The biblically-titled *MOSE* project, developed by a consortium of large construction companies called the Consorzio Venezia Nuova (CVN) has been quite appropriately in the works for a biblically long time (since about 1984), with an infinite litany of approvals and rejections by a wide variety of agencies, both Italian and international, that have monopolized the attention ADRIATIC SEA of public opinion away from some of the more pressing issues affecting Venetian citizens, some of which are described herein. In fact, tides are not a "bad" thing at all, as long as they keep below the threshold of 1-1.2 meters above standard sea level (1897). Unless and until Venice is endowed with a modern sewage system, tides will continue to play a crucial role in the hygienic health of the city.

> The ups and downs of tide levels, together with the complex topologies of the lagoon channels and of the internal canals, create height differentials in the water levels in different parts of the city and of the lagoon such that downhill gradients are created that dictate the direction and velocity of flow of water from the higher points to the lower points. In most cases these differentials are ever-so-slight and therefore produce very minimal flows, but especially in conditions of full or new moons, during socalled *spring tides (sizigie* in Italian), the influx of tidal waves from the Adriatic sea into the lagoon produces significant flows in many parts of the canal network, with peak currents of more than 2 Km/hr in places.

> From 1990 until 1999, several teams of WPI students collaborated on the systematic recording of the hydrodynamic behavior of all of the segments that make up the Venetian water network¹⁹¹. The various campaigns generally entailed the simultaneous measurement of as many segments as the number of members of the research team allowed. Three to

¹⁹¹ We even engaged the local schools in two days of simultaneous current measurements involving over 1,000 children from all middle schools in Venice and in the lagoon.

¹⁸⁹ Cf. page 50.

¹⁹⁰ Florence was subjected to an even worse flooding by the Arno river on the same day.



six sets of segments were measured by the team in each campaign both during *spring tides* (full or new moons) as well as during *neap tides* (half moons) for about two months at a time. Each day of campaign entailed 5 measurements at the predicted High tide time (H1), the Low tide time (LOW) and the subsequent high tide (H2), plus the two highest-velocity moments half-way between high and low (DSC) and then half-way between low and the next high tide (ASC). At the end of the study, the hydrodynamic behavior of practically all the inner canals was determined and mapped, both for incoming (bottom) and for outgoing tides (next page)¹⁹². The arrows in these pictures indicate the prevailing direction of flow during that type of tide. Red arrows indicate a general flow toward the north and west, whereas the green ones indicate a general tendency to flow south and east.



Mapping the currents in this manner had to wait until some advanced features became available in Mapinfo[®] that allowed to create thematic maps using bidirectional arrows. The arrows are based on plain line segments, drawn with a south-to-north direction along the centerlines. Black arrowless segments are used to represent the absence of flow, i.e. stagnant canals.

¹⁹² The maps shown in this section come from Carrera, 1999b.



cyclical regularity



hydrodynamic model





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In the previous section, most of the physical characteristics of canal segments, with the exception of canal depths, were immutable and permanent. An effort to characterize parameters such as surface, length and average width would produce a definitive body of knowledge that would be good forever and would only need to be collected once. The hydrodynamics of a body of water like the lagoon of Venice are constantly changing from day to day, due to the moon cycle and to weather patterns. Nevertheless, despite its cyclical nature, hydrodynamic behavior is also rather repetitive and displays a high degree of regularity from year to year. Unless major topological changes are made to the underlying physical environment through which tides travel, one would expect to get fairly constant peak current velocities and unwavering current directions on the same segment under the same lunar conditions, after the "noise" due to weather has been factored out.

Such steady behavior makes investment into the development of a hydrodynamic model more appealing, since such a model would also only have to be developed once (and possibly adjusted or tweaked once in a while). In fact, our pioneering work on hydrodynamics led to the development of the first hydrodynamic models of the circulation in the inner canals of Venice.

Starting in 1995, two different hydrodynamic models of the inner canals were created in the framework of the UNESCO-MURST Venice Inner Canals project. Both of these models made use of the fine-grained datasets collected by us in our hydrodynamic campaigns. Curiously, even though we focused primarily on the typical hydrodynamic behavior during

coupling GIS and models

spring tides, which we arrived at by discarding unusual readings with high standard deviations, the hydrodynamic modelers instead used whatever data were available for specific measurement days in their entirety. This was an example of the reusable nature of our fine-grained, spatially referenced datasets, even though the modelers used separate systems (and FORTRAN!) to run their simulations on our data.

The issue of coupling GIS with models remains important and worthy of a separate discussion. The UNESCO models were developed at UC Berkeley¹⁹³, the International Institute for Applied Systems Analysis (IIASA)¹⁹⁴, Georgia Tech¹⁹⁵ and the National Council of Research in Venice¹⁹⁶.

The hydrodynamic model of the inner canals was interconnected with existing models of the Lagoon to allow simulations to start with the forcing functions of the tides at the Lido inlet. In the final model, the inner canals were represented by one-dimensional segments and these in turn were connected with a 2-dimensional finite element model of the surrounding lagoon channels, as shown below¹⁹⁷.



- ¹⁹³ De Marchi, 1993.
- ¹⁹⁴ De Marchi, 1996.
- ¹⁹⁵ De Marchi, 1997.
- ¹⁹⁶ Umgiesser and Zampato, 1999.

Hydrodynamic models could be used to forecast the effects of local interventions (like the dredging of a canal) on surrounding areas; to determine the most effective dredging sequence; to simulate the reopening of filled-in canals; to analyze the possible utilization of pumps to stimulate circulation in stagnant areas and also to act as a foundation of more complex models of sediment transport and deposition¹⁹⁸. This sophisticated sedimentation model, that will be discussed in later chapters, will need, among other things, to take into account the re-suspension of sediment due to boat traffic, which is the topic of the next section. lessons from our hydrodynamic studies Hydrodynamic behavior is predominantly guided by the gravitational pull of the moon and the sun, coupled with the topology of the paths that the water has to travel along. The physical dimensions of the segments that make up the canal network and their topological connections are thus essential to understanding hydrodynamics. The cycles of the moon and the sun are equally important. Hydrodynamic behavior displays a cyclical regularity and as such it is a candidate for modeling. Knowing the [cyclical regularity and modeling] physical dimensions of the network, together with measurements of tide levels and current velocities allowed the calibration and validation of the model. As we saw here, fine-grained hydrodynamic measurements are eminently re-usable. With some statistical manipulation, they allowed us to [re-usability of fine-grained data] characterize the "permanent" behavior during the highest tides (spring tides), giving us the predictable current direction and velocity in each segment at the time of fastest flows with both incoming and outgoing tides. The same data - this time taken in its raw, untreated form - was later re-used as input to the model calibration and validation. After mapping our "statistical", maximum current scenarios we could have thrown the data away, as people often do after achieving the aim at hand. Thankfully we didn't, so modeling simulating and forecasting was that much easier to carry out and that much cheaper too, since there was no need to re-measure the currents and levels all over again. [use finest grain] The lesson therefore is twofold: (1) collect data at the finest grain possible (within reason) and (2) do not throw it away. [keep data in raw form] A more sophisticated lesson here was that the canal segments that were used in the model were already "right" for hydrodynamics since we had already thought ahead to the possibility of hydrodynamic modeling when we

[think ahead!]

[enrich maps and data teleologically] [re-use model itself] your data accordingly. A final lesson that further compounds the benefits of a City Knowledge approach is that the hydrodynamic model, which brought

conducted our segmentation. Hence, as you may recall, we had decided to use intersections with filled-in canals (some of which retained hydrodynamic

modeling exercise¹⁹⁹. So the third lesson here is: think ahead! And structure

flows under them) as nodes of our canal network. Had we not acted teleologically, we may have had to create a "new" segmentation just for this

¹⁹⁷ Can you detect the outline of the city of Venice in the figure?

¹⁹⁸ More on the sedimentation model starting at page 92.

 $^{^{199}\,}$ As we have had to do for our traffic model (see page 82 and ff.) to characterize pseudo-nodes corresponding to docks and bridges.

	together plan-ready data about the physical canal network, and the fine-
	grained hydrodynamic measurements to determine the "permanent"
	behavior of the canal currents, is itself, as a whole, a component of an even
[hierarchical re-utilizations]	bigger model – the sediment transport model – of which it forms the
	backbone. So, here we have a multiplicity of re-utilizations at different
	hierarchical levels of complexity, which further demonstrates the power of
	City Knowledge.

BOAT TRAFFIC

motorboats



moto ondoso



R ow boats and sail boats have traveled the canals of Venice ever since the fall of the Roman Empire, but motorboats have only been around since after WWII. In the few decades since their widespread diffusion in the 60's, motorboats have become one of the major problems the City is facing today. Boat traffic in Venice not only generates the problem of congestion that most mainland cities are gridlocked by, but it is actually a much more insidious phenomenon than its land cousin. Unlike automobiles, boats have actually the ability to physically destroy the foundations of buildings along their path. The passage of cars on a street cannot dismantle a city block piece by piece like water turbulence and wakes do when boats ply the inner canals²⁰⁰.

Despite the massive exodus of Venetians away from their city of birth, boat traffic continues to increase in order to cater to the needs of a growing tourist industry. According to our own calculations, traffic has almost doubled in the last 25 years²⁰¹, as population declined by 50% in the same period. People who live along the canals are literally seeing their dwellings crumble under the constant pounding of boat waves. In desperation, many property owners have begun a public protest against the

daily assault on their homes. "Stop Moto Ondoso" (loosely translatable as "stop making waves") is a common phrase that even tourists are beginning to recognize after seeing it posted on sheets hanging from windows all over the city. The moto



ondoso problem is particularly intense along the primary arteries. In fact, despite the apparent intricacy of the web of canals, the entire water network can be schematically simplified to just a few primary routes where most of the boat traffic concentrates. Although there are 367 segments and 182 inner canals in the city, for a total of 47.5 kilometers of waterways, the main thoroughfares can be counted on the fingers of two hands.

²⁰⁰ The problem is so big that the mayor has been nominated *Commissario al Moto Onsoso*

^{(&}quot;Commissioner of Boat Wakes") by the national government in 2002 to deal with this issue once and for all. As commissioner, the mayor has absolute powers over regulations related to boat traffic, above and beyond any existing law.

²⁰¹ Fiorin and Carrera, 1999, pp. 143-159.





One could schematically represent the important traffic arteries in and around Venice starting from two concentric rings²⁰² (red rings in figure on left). The outer ring includes the *Canale delle Fondamente Nuove*, *Colombola, Tronchetto, Giudecca, Bacino di S.Marco*, and the *Canale delle Navi*. The inner ring is made up of the central part of the Grand Canal and the entirety of the *Rio Nuovo*.

The next level of arteries include the *Rio de Noal, Canale di Cannaregio*, the northernmost and southernmost tails of the Grand Canal and the *Scomenzera*. These are all canals that connect the inner and outer ring (purple). The canals that are part of the ring and the ones that connect the rings are among the most traveled in Venice, especially by taxi boats and large cargo vessels. Public transportation boats from the ACTV (*Azienda del Consorzio Trasporti Venezia*) travel all of these canals, except the *Rio de Noal*.

Beyond the two rings and the ring connectors, there are two more types of arteries that play an important role in the flow of traffic in Venice, the so-called *secondary arteries* (blue in the side diagram) and the *bypass* canals (yellow). The secondary arteries include the *Rio de S.Sebastian, Carmini, Briati,* and *Tre Ponti.* connecting the *Canale della Giudecca* to the *Rio Novo*. The blue canals also include the two parallel canals in Dorsoduro that allow travel between the *Canale della Giudecca* and the *Canal Grande* (*Rio de San Trovaso* and *de San Vio*), and the two parallel canals that connect outer and inner ring across the borough of San Marco (*Rio de S. Moisè* and *Rio de la Canonica, S.Zulian, de la Fava* and *Rio del Fontego dei Tedeschi*). The list of secondary arteries is completed by two canals that connect inner and outer ring to the north and East, namely the *Rio dei Santi Apostoli* and the *Rio de Santa Marina* (which actually connects the inner ring to one of the bypass canals described below).





The final major elements of the water traffic network in Venice are canals that *bypass* parts of the network and create shortcuts (yellow) between two parts of the inner and outer rings. For instance, the *Rio de San Polo* and the connecting *Rio Marin* e *Rio de San Zandegolà* together create a "Y-shaped" bypass that cuts right through the heart of the inner ring inside the boroughs of S.Polo and Santa Croce. Similarly, the *Rio de Santa Giustina* and the *Rio dei Greci* and *Sant'Antonin* form an inverted Y that connects two parts of the outer ring in the Castello region, as does the *Rio de l'Arsenale* a little farther East.

²⁰² Ibid., p. 144-145.



turning movement counts (TMC)

automatic traffic recorders (ATR)

WPI-UNESCO traffic studies





turning movements

The canals listed in the above discussion could be identified as "important" transportation links by anyone who has experienced Venetian boat traffic first hand, but the relative levels of traffic in each of those arteries, despite the obvious importance of such knowledge, were not systematically quantified until WPI students began to record traffic flows in 1992. In truth, the City of Venice had conducted three studies before WPI

systematically quantified until WPI students began to record traffic flows in 1992. In truth, the City of Venice had conducted three studies before WPI students began their research in the framework of the UNESCO *Venice Inner Canals* study. The 1978 City study was never published, but was referenced in the following 1986 City Traffic Report²⁰³. Both the 1986 and 1987²⁰⁴ City studies attempted to give a snapshot of the traffic levels at key points in the canal network through the monitoring of "maneuvers" that resembled what automotive traffic engineers call "turning movements". Unlike professional Turning Movement Counts (TMCs), though, the studies conducted by the City of Venice in 1986 and 1987 did not exhaustively monitor <u>all</u> of the "maneuvers" that a boat could make at any given location. In fact, at some counting locations, the counts resembled more the "volume counts" that mainland traffic engineers conduct along traffic routes using "automatic traffic recorders" (ATR)²⁰⁵, i.e. total number of transits in each of the two opposing directions along a single network segment.

Starting in 1991, our canal studies (not yet under the auspices of UNESCO) began to analyze traffic experimentally²⁰⁶. Our early forays led to a full blown traffic study, in the framework of the UNESCO-MURST project *Venice Inner Canals*. Between 1992 and 1994, six two-month campaigns were conducted in Winter, Spring and Summer, recording almost 60,000 transits in almost 400 hours of counting as part of an effort to which 21 WPI students dedicated a total of about 15,000 thesis-hours. These efforts were summarized in a final report to UNESCO in 1996.²⁰⁷

Our traffic campaigns monitored traffic from a total of 29 stations (intersections) in the city of Venice, concentrating exclusively on the inner canals and only marginally touching the main thoroughfares of the City, like the Grand Canal, and the canals of the *Giudecca*, the *Fondamente Nuove* and the *Scomenzera*. Each traffic counting station was uniquely labeled with an ID that reflected the borough (*sestiere*) where the station was located (e.g. San Marco stations were prefixed by the letters "SM") followed by a numerical suffix (e.g. SM-4). Counting stations were selected in such a way as to maximize the number of canal segments that could be observed and they were placed along the main thoroughfares that were described earlier in this chapter.

At each location, a number of "maneuvers" were monitored, that captured all of the possible turning movements available to a boat at that intersection²⁰⁸. For any number n of segments that connect at an

²⁰⁸ Excluding U-turns.

²⁰³ Comune di Venezia, 1986.

²⁰⁴ Comune di Venezia, 1987.

²⁰⁵ These are the rubber strips laid across roadways that we have all noticed at some point as we ran over them with our cars.

 ²⁰⁶ Carvajal *et al.*, 1991.

 ²⁰⁷ Carrera, 1996. An English summary is available at <u>www.unesco.ve.it</u>.



maneuvers



from turns to volumes



from traffic data to traffic information



intersection, the number of available moves turns out to be $\binom{n}{2}$ which is

read as "n choose two" and translates to a mathematical formula of $\frac{n!}{(n-2)!}$

which in turn simplifies down to n(n-1). This simply means that a threeway intersection will allow a total of $3 \times 2 = 6$ turning movements, a fourway will permit $4 \times 3 = 12$ moves, a 5-way 20 moves and so on.

To capture all of the traffic at each station, we labeled each of the approaches to the intersection with consecutive letters of the alphabet, starting from the northernmost approach and moving clockwise around the intersection. In this way, any particular boat would be recorded as making maneuver AB or BA or AC, and so on. Contrary to what is commonly done in mainland traffic counts, we decided to actually record every single boat that went by, identifying its type, load (number of people or amount of cargo, in 1/8 increments) and even its license plate²⁰⁹. Each passage was time-stamped in 15 minute intervals. The number of records in the database is exactly equal to the number of transits recorded. Each record in the database is uniquely connected to a specific turning movement (labeled according to the "from" and "to" approach letters) at a specific station (labeled with a station ID). Although we came up with this method on our own, it isn't very different from what traffic engineers commonly use around the world to record turning movements. The main difference is that, for automotive traffic, movements are usually recorded as Left, Right or Straight.

Using appropriate ancillary tables, each lettered approach at each station was related to the codes of specific segments touched by a boat making that particular turn. Total traffic volume in any specific segment was simply equivalent to the total count of boats that showed the corresponding letter of the alphabet in either the <u>from</u> or the <u>to</u> maneuver fields. So, for example, if one wanted to know the total number of boats that traveled up or down the segment coded as FERA1, a query would be set up to count all of the boats that either came from or went to the segment labeled B, namely AB+DB+CB+BA+BD+BC.

The structure of the boat traffic data we collected was rather simple. As mentioned, each boat that was observed passing by a counting location was recorded as a single record in our field forms and in our databases. Each record was characterized by a station code, a date and time stamp, the turning movement (maneuver) the boat performed, the type of water craft observed, its license plate, name and permit number, and the load it was carrying. Such a simple raw dataset allows numerous and complex manipulations that can produce higher-order information, by reconfiguring the data along any of the characterizing dimensions. For example, one could want to explore the temporal distribution of taxi boats in the course of a day, to find out when the peak times of taxi traffic occur. Or one could be

²⁰⁹ License plates were not present on each boat at the time of our studies, though a 2003 ordinance has finally made them mandatory for every vessel. They were only recorded starting with our study for the Provincial government and COSES in 1997 (Carrera, 1997). The data we recorded in the framework of the UNESCO project did not include license plates.



interested in the number and/or percentage of boats of each type that travel a certain canal over the entire day. Or else it may be of interest for someone to know the average number of motor boats per hour that make a certain turn at an intersection on weekends. All of these are plausible requests that would satisfy specific informational needs. Each inquiry can be resolved by crafting an SQL query (or a sequence of queries) that will address the issue. Custom-tailored answers to these pointed questions are always possible, as long as a technical expert is at hand who can deftly interact with the database.

Similarly, a GIS expert could manipulate the information to produce geospatial renditions of the information, creating thematic maps to accentuate one particular pattern of behavior or another. In GIS, however, the temporal component would be much harder to depict, although some techniques do exist to portray time in GIS, at least in part²¹⁰. Nevertheless, if one had to produce a final report on a traffic







monitoring campaign, as I had to do on several occasions²¹¹, then the issue becomes one of depicting a complex phenomenon in a digestible manner. Instead of focusing on specific areas, a general report would have to provide the "big picture". Graphs of various types come in handy to display some of the trends and behaviors observed, but these inevitably entail pretty massive spatial aggregation. Bar graphs, pie charts and line graphs are useful when looking at the entirety of traffic in the whole city either as a total or as averages or percentages. If dozens of canal segments were monitored, it would be impossible to show all of the segment codes on the X-axis of a graph while presenting the traffic levels in each segment on the Y-axis.

GIS tools allow the depiction of spatially-specific information in its entirety, as long as the area to be displayed is not too vast in comparison to the individual elements being depicted. The city of Venice is right about as big an area as is feasible to thematically map, when the units of analysis are the narrow canal segments. When it comes to thematic mapping, traffic data lends itself to three primary visualizations: by maneuver, by counting station and by segment. These three units of spatial analysis are not just appropriate in Venice, but also in mainland cities, as I have personally experienced in the cities of Worcester, Cambridge, and Quincy in Massachusetts²¹².

- ²¹¹ See Carrera, 1996, 1997, 1999a.
- ²¹² See part III.

²¹⁰ See bottom of p. 80.


traffic by maneuver

The type of spatial visualization that most closely approximates the fine grain at which traffic data are collected in the field is the representation by maneuver. In this depiction, each turning movement would be represented by an arrow and the color or size of each arrow would be representative of the number of boats making that turn. The quantities could represent the total number of turns in a day of counting, or an average per hour, or any other time scale. This finer-grained visualization allows a more in-depth analysis of driver behavior and can give clues to the preferred pathways across the city.

The problem with a presentation by maneuver is that it is difficult to view many stations in a single map, since the arrows tend to blur into each other as the view is zoomed out more and more. Nevertheless, careful placement of the arrows will allow a decent number of stations to be viewed simultaneously. With some effort, the entire city of Venice was visualized in a single map (shown below are total daily transits by maneuver).







The representation of traffic counts by station (or counting location) is the simplest of all. It entails aggregating all traffic counted at each counting location, regardless of the turning movements. These data may be visualized as an overall total for a whole day of counting, which would be applicable only when the counting was conducted uniformly for the same amount of time, on the same day, at each of the stations. Alternatively, the data could be averaged per hour of counting, thus removing many of the possible idiosyncrasies, though uniformity of field methodology would still be necessary. These totals or averages could be easily depicted by graduated symbols, whose size is proportional to the value being depicted (the total or average/hr).

Additionally, the type of boats that were counted at each station over the whole time period of choice could be displayed by replacing each dot with a pie chart showcasing the percentage of each boat type that contributed to the total. The size of each pie would still convey the overall volume of traffic at that station, whereas the size of each slice would give a proportion per boat type.





The usefulness to traffic engineers of a representation of overall traffic volumes at an intersection, however, is rather minor. A more valuable visualization that is also based on each intersection (or counting location) is what traffic engineers call "critical sums", which represents the sum total of all crossover movements, which interrupt straight through traffic. Critical sums are not too difficult to obtain starting from turning movement counts, but they would be impossible to obtain from typical automatic traffic recorders.

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ATR vs. TMC volumes
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The third and final means of display is that by segment. In this representation, the volume of traffic in each segment can either be calculated from turning movements or can be obtained by automatic traffic recorders. The volumes based on TMCs are more nuanced than the simpler ATR volumes, but the latter can be much cheaper toobtain for much longer periods of time. Despite their resource-intensive nature, the breakdown of TMCs into segment volumes holds the potential to allow the extrapolation of ATR counts to adjoining segments, through a statistical knowledge of the preferential turns made by cars at the intervening nodes.



In this type of visualization, each segment is colored thematically depending on the total (or average) hourly traffic it sustained during a temporal interval of choice (usually hour or day). This type of presentation facilitates the identification of the main arteries that carry most of the traffic segment traffic and moto ondoso

direction of travel



extracting and encoding direction







in the city. Segment volumes can be used to determine the carrying capacity of a certain pathway, as well as to forecast the number of boats displaced when a segment is closed for upkeep. Displaced boats will tend to be diverted to adjoining canals, thus compounding themselves upon the traffic volumes already existing in those nearby segments.

Segment-specific issues like wear and tear, congestion and noise will be directly related to traffic volumes regardless of whether the city streets are made of water or asphalt. In Venice, total volumes of traffic in each segment are also useful to know because they relate to the total amount of *moto ondoso* that is produced by motorboats traveling along the segment. Direction of motion is immaterial in all of these contexts, whereas it may be very significant in other types of analyses.

An example of where direction of travel is important, is in the analysis of the effectiveness of directional regulations. Venetian canals, like roads in mainland cities, are regulated by one-ways. Some directions of travel are prohibited in some canals, although going the wrong way on a one-way canal is not usually as dangerous as the equivalent action on the mainland. In fact, wrong-way travel is rather frequent in Venice. To capture the extent of this phenomenon, we wanted to separate the traffic volumes in one segment into two separate volumes in the two directions of travel.

In a database, separating the traffic flows into two separate directions is fairly trivial, though there are some standardization issues that need to be addressed. For instance, how should the two directions be labeled? Our choice was to separate traffic into North and South directions based on whether a boat was moving towards the northernmost or southernmost node at the two ends of a segment. The northernmost node would be the one with the higher Y-coordinate (or latitude). Even in the more challenging situations, when a segment is oriented East-to-West, one of the two nodes would always be ever-so-slightly farther to the North than the other²¹³.

Keeping the traffic information separated into the two directions of travel along each segment became useful later, when we wanted to explore the effects of the creation of a new one-way canal using the MANTA traffic model²¹⁴. This level of disaggregation will also provide a more sophisticated appraisal of the local, direction-specific effects of canal closures on boat movements.

One of the practical issues that we had to deal with, when separating segment traffic into two directions, was the issue of how to depict the two flows (geo)graphically. One possibility is to create two overlapping layers of polygons, one representing the Northern segments and one the Southern ones, so that thematic coloring of the regions could be possible, based on the volumes recorded in each of the directions. The problem with this approach is that only one direction could be shown at a time. Another possibility is to attach two arrows to each segment, a N arrow and a S arrow

²¹⁴ See page 82.

²¹³ In fact, the intersections (nodes) in Venice were coded with numeric labels proceeding from North to South (again based on the Y coordinate of the centroid) so that implicitly the Northernmost is always the node labeled with the smaller numeric ID.

so that the traffic volumes for each direction could be thematically depicted by coloring (or varying the thickness of) these arrows appropriately. The drawback here, as explained above for the representation of maneuvers, would be once again the difficulty in visualizing large areas of the city on a single map, since the arrows would tend to tangle up above a certain zoom level.

Traffic data lends itself to a myriad of analyses. Information could be necessary for very focused decisions about regulating traffic in a specific canal, or for the development of very broad planning guidelines for the entire city. A long time period may be of the essence in one determination, whereas a very narrow spatial extent may be highly significant in another. The typologies of boats add another dimension to the combinatorial explosion of the innumerable cross-tabulations that are possible and desirable. To bring down the complexity of dealing with the 18 boat types, many of the analyses in my reports are limited to just the 9 boat classes (with 6 classes being the truly important ones), or to the 6 use categories, all the way down to the 4 main boat classifications of Cargo, Recreation, People and Other.

temporal analysis

analyzing traffic data

analysis by vehicle type

classes and categories

Another way of looking at the data is on a temporal scale. Peak hours may vary from day to day and from boat type to boat type. Overall traffic volumes at each hour will identify times of congestion, whereas a type-bytype analysis of the hourly fluctuations may stimulate reflections on the underlying causes for the different peak times, which in turn may suggest actions to limit the overlapping of peaks, by creating temporal restrictions for some canals at specific times of the day for specific types of boats. For instance, gondolas could be barred from some inner canals until 11am to give cargo boats space to complete their deliveries.





seasonal variations

Due to the influence of tourism, traffic in Venice exhibits some distinct seasonal trends, with an increase in overall volumes in the summer months. The nice weather also encourages private boat owners to use their vessels for recreation, further compounding the problem, especially out in the Venice lagoon, as evidenced by our studies conducted in the entire lagoon on behalf of the Venice Provincial Government²¹⁵.



traffic decision support systems

The intricacies of the analyses of traffic data are reflected in the commensurate complexity I encountered when I designed a preliminary prototype of a Decision Support System (DSS) for Venetian traffic engineers. The DSS needed to first of all provide instant information about boat traffic on any of the Venetian canals, predicated of course on the availability of such data. Even this simple spec turns out to be much more complicated than one would expect at first glance. Exactly what data does the user want to extract from a specific segment? The total traffic? The average hourly? For a weekday or weekend? For just one type of boat or for all (or some)? It is easy to see how quickly things can get really messy, even when dealing with a single segment and one single counting campaign (the latest one of course). Imagine the difficulty of allowing the user to select a set of segments or permitting the analysis of longitudinal trends over several datasets!

²¹⁵ Carrera, 1997, 1998.

multimedia interface

The prototype I proposed would allow the user to visualize data by segment, maneuver or station, plus it allowed one to focus on any category, class or type of boat. The interface conforms to a "look and feel" that I have used in other information systems. It allows the user to simultaneously see data, photographs (of the station location), maps (at varying zoom levels) and even graphs (with a variety of choices of representation). Although it was never fully implemented, this DSS would have allowed multiple segments to be aggregated together, and would have allowed the user to look longitudinally at past campaigns on the same segments.



City Knowledge



origin and destination





moto ondoso index

The traffic DSS is a stepping stone towards a more complex traffic model. Late in 2003, I was asked to contribute to the development of just such a traffic model for Venice²¹⁶. This traffic model differs substantially from *terraferma* models in that Origin-and-Destination (O&D) information is only marginally useful in Venice, where nobody commutes to work on his/her own boat. In Venice, rush hours are due exclusively to commercial traffic, like cargo or garbage, as well as people transport, like taxis, gondolas and public transportation (ACTV). O&D studies would have to be replaced or integrated with very localized "detour studies" to determine the local O&D within a sub-network, and thus forecast the most likely diversion a boat of a certain type would take when a canal is closed or precluded *ex legis* to navigation.

Despite its idiosyncrasies, the Venice traffic model needs to answer the same questions that "normal" land traffic models typically address. It should allow city officials to forecast the effects of canal closures and to simulate the consequences of changes to regulations, like the institution of new one-ways, or the temporal restriction of access to some canals for some boats at some time of the day, or the effect of alterations to the routes of such regular services as garbage pick up and other realistic scenarios in which the city can purposely attempt to modify water transportation for the better. The development of the model has benefited tremendously from existing, plan-ready city knowledge.

Since the real problem with traffic in Venice is not so much the congestion that occurs in the canals during rush hours, but rather the deleterious effect of boat wakes on the foundations of buildings that flank



the canals, in the summer of 2002, we developed a metric dubbed the moto ondoso index that would parameterize the wake-production potential of each boat type²¹⁷. In this framework, boats that produce lower wakes than other boats, while traveling at the same speed, would be assigned a lower "moto ondoso coefficient". The moto ondoso index would then be the product of these coefficients (related to boat type and velocity) and the traffic volume for each specific boat type in each of the canals. At any arbitrary maximum speed limit, the overall index for any segment would be the sum of all of the indices of each of the boat types that had been recorded in that segment during the traffic monitoring campaigns. Once again, our

²¹⁶ The *Modello per l'ANalisi del Traffico Acqueo* (MANTA) was completed in the winter of 2004 and presented to the public in the summer of 2004.
 ²¹⁷ Chiu *et al.* 2002.

turbulent energy discharges



updating traffic data





turning movement counters



plan-ready city knowledge made the development and quantification of this higher-order concept fairly expeditious.

While the *moto ondoso index* was being developed, we immediately realized that the observable waves created by boats are only the more visible

symptom of the problem. Another major factor in the destruction of canal walls would certainly be the turbulence created by propellers undergoing sudden acceleration or – even more significantly – deceleration, during breaking or docking maneuvers. To measure the effect of turbulent energy discharges in the canal network, I supervised a WPI, on-campus project for the creation of an instrument²¹⁸ that enabled us to create a map of turbulent discharges in the canals. The instrument was tested in the summer of 2003 and the plan is to duplicate it and mount it onto a dozen boats of various typologies for an extended period of data collection.

Traffic data are ephemeral by its very nature. Today's data are of little use to us next year, except to evaluate change and to analyze trends. Unlike the more permanent features of the physical make-up of the city, traffic is a dynamic human activity that requires periodic updating. To make the collection of traffic data easier, mainland traffic engineers make use of devices called Automatic Traffic Recorders (ATRs) that normally consist of pneumatic hoses connected to electromechanical boxes, usually chained to a post or guardrail along a road. Recent developments in this arena have seen the adoption of buried inductive spires that sense the passage of cars due to electromagnetic disturbances. Radar devices are also used in some applications, despite their high cost. Although the most recent ATRs are capable of distinguishing several types of vehicles, from trucks to small sport cars, they can only be used to collect volume information along single segments of a road network. Moreover, despite their otherwise impressive capabilities, inductive pickup devices cannot reliably count motorcycles, scooters or bicycles. These devices are also more intrusive in their installation, making them more suitable to being installed as permanent implants, frequently associated with traffic light controls.

Turning movements need to be collected with different devices, like Turning Movement Counters (TMCs), that are generally still manually operated, by pushing a button for each vehicle making a specific turn. These simple devices usually have upwards of 4 or 5 buttons for each possible turn, one for each of 4 or 5 types of vehicles. These devices can be used to count any type of vehicle, and they are often used also to count pedestrians (or *peds* as they are called in the lingo of traffic engineers).

²¹⁸ Chiu et al., 2004. See page 117 for a picture of the instrument.

RFID boat monitoring device

For obvious reasons, standard ATRs cannot be used in Venice. Radar devices, on the other hand, have great potential applicability in Venice's narrow canals, as proven by an experimental instrument that we developed at



WPI, which was capable of measuring boat wakes and could recognize an approaching boat using a Radio Frequency (RF) tag, similar to those that are used to automate the payment at tollbooths (in Massachusetts it's called FastlaneTM)²¹⁹. The problem with this device was that it assumed that every boat would be "tagged" with a Radio Frequency ID (RFID). The benefit of this device, despite its intrusive nature, would be the exact identification of each individual boat, which would allow the ability to tap into very precise information about the boat, through the ID code. Unfortunately, the fear that the ID would be linked to enforcement and ticketing of traffic infractions made this device politically unpopular.









²¹⁹ Blomberg et al., 1999.

GPS boat monitoring device Although the RFID solution was ultimately rejected on "political" grounds, the alternative that was subsequently pursued by the city of Venice was a GPS system installed in all licensed boats (taxis as a start, then licensed cargo boats at a later date). The oddity is that the objections that made the RFID undesirable were not really done away with in a GPS system. Each unit is still tagged and identified and its whereabouts are known with even more precision. The danger of these devices being used for purposes beyond mere knowledge and statistics, i.e. the possibility of the GPS being used to detect speed limit violations and the like is exactly the same as with the RFID system, yet this system was installed on the entire fleet of Venetian taxis in late 2003.

The limitation of the GPS device, as it is being used in Venice, is that it will only provide a partial picture of the traffic in the city since only "licensed" boats will be forced to carry the devices. All other boats will not be detectable through these gadgets. To allow a more generalized automatic ability to monitor all types of boats, we have been developing a secondgeneration instrument at WPI, based on ultrasound technology, that will allow the automatic monitoring of boat traffic, without imposing the installation of an RF tag or a GPS upon every boat owner²²⁰. The next version of the instrument will count boats, determine their velocity, measure their wakes and noise levels, and quantify the pressures exerted on the canal walls by each wave.



²²⁰ Johnson et al., 2003 and Gomperts et al., 2004.

automating traffic volume collection

Our ultrasound devices are being designed to eventually be placed at key locations in the canal network where they will collect traffic volumes autonomously. Each boat will be archived as a record that will be tagged with a time-and-date stamp, plus with an indication of the boat type (detected through the acoustic signature of the engine noise) and with the speed and direction of travel, plus the height of the wake produced and the pressure the wake exerted on the canal wall (measured through a series of pressure transducers). These devices will collect data continuously for months and years, and will exceed what Automatic Traffic Recorders (ATRs) do for vehicular traffic.

Unlike ATRs, Turning Movement Counters (TMCs) are potentially usable in Venice, though we never actually used them, preferring to employ paper field forms which allowed us to collect a much richer qualitative dataset than the merely quantitative data produced by the electronic TMCs. In general, any automated device will allow longer time periods to be monitored with little or no human intervention, but these benefits will be offset by the fact that the data produced will be much less rich in nuance and detail. TMC's do not automate the collection anyhow, since human beings are still needed to push the buttons. Basically TMCs constitute a shortcut in the data entry process, since they remove the need to transcribe paper forms and input the data into a computer database.

Despite the existence of technological solutions to monitor traffic, good old fashioned manual counts will always retain an important role in the periodic updating of the more nuanced and possibly more useful traffic data. Origin and Destination, for one, would be never possible using technological devices unless every car is somehow tagged and identified automatically. It is difficult to foresee the day when sophisticated traffic analyses such as tripchaining would be possible without a substantial investment of human resources to collect and organize the necessary underlying information.

Since periodic traffic counts are inevitable, cities can be creative in how to make these cyclical updates as effortless and inexpensive as possible. In Cambridge, MA, we experimented with modifications to existing city regulations that force developers of large sites to produce traffic studies in order to gain approval for these sizeable construction projects²²¹. Since these are already accepted requirements, all we had to do is figure out how to parlay these professional reports into a system that would "grow" and accept all studies into a single framework, which would thus continually provide the best available traffic information for all areas of the city for which data were available.

automating turning movement counts

manual traffic data collection

²²¹ See Gage *et al.*, 2003.

the infrastructure of traffic knowledge



structure of traffic GIS



structure of traffic databases

In fact the creation of an informational scaffolding into which to structure traffic data is a *condition sine qua non* for the creation of any serious traffic information system²²². Three basic spatial objects need to be defined, positioned and labeled on a GIS platform. These same labels will then be reflected in the associated relational databases that will contain the bulk of the actual traffic data. The three spatial entities that need to be firmed up are the aforementioned: stations (or intersections), maneuvers and segments. The latter is assumed to be already in existence if a proper road (or canal) network has already been structured for other purposes. Intersections are beginning to be standardized nationally, through an effort of the Census Bureau to include them into their *Tiger* maps²²³. Maneuvers are thus the only traffic-specific GIS layers that need to be mapped appropriately. Maneuvers are usually labeled with a unique identifier that combines the intersection code as well as the maneuver code, to simplify the linking to the associated database of traffic counts.

In addition, a layer of bidirectional traffic arrows would also be useful to attach directional information to each road segment, to allow even more nuanced types of traffic analyses and simulations, like those that would accompany the creation of new one-way streets.

In all, though there can be considerable room for personalized referencing standards from one town to the next, the items that require a definitive representation on a traffic GIS and a clear and unique labeling are:

- the Intersections (or *nodes*)
- the Maneuvers (or *turning movements*)
- the Segments (or *approaches*)

My personal recommendation would be to create an exhaustive layer of all of the possible intersections, turning movements, approaches and directional (N-S) flow arrows for the entire road network²²⁴. This needs to be done only once and requires updating only when a new road/intersection is created. Once everything is drawn and labeled, the data that are produced either with ATRs or with TMCs, either internally by city workers, or externally by developers' consultants can all be connected to these spatial representations that can in turn be immediately useful to city managers and traffic engineers.

In the traffic databases that are associated with these GIS elements, each record will typically represent the counts within a specific 15 minute interval on a specific date across a specific maneuver at a specific intersection. Additionally, *n* fields of each record could represent the counts for *n* types of vehicles (autos, small trucks/SUVs, large trucks, mopeds, motorcycles, bicycles, etc.). An alternative, simpler and more flexible format

²²² Butler and Dueker (2001) present an in-depth approach to the creation of such an infrastructure for automotive traffic.

²²³ See <u>www.census.gov</u>.

²²⁴ Butler and Duecker (2201) are of similar persuasion, though their GIS-T is more geared toward geometric modeling than actual management of traffic data.

[rigorous data-collection methods]

[spatial geo-scaffolding for activities]

[automatic instruments]

[scheduled updates]

[free updates]

for the traffic data would only comprise the date, time, location, maneuver, vehicle type, and count, so that there would be more than one record per 15' interval, namely one record for each vehicle type that was counted in that period. The database structure in this latter example would be the same regardless of the number of vehicle types one decided to monitor, thus making it truly universal.

lessons from our boat traffic studiesAs already discussed in previous sections, dynamic process require
periodic updates. However, unlike gradual natural processes – like
sedimentation – or cyclically predictable phenomena – like hydrodynamics –
traffic contains a more difficult variable that makes it harder to model it
reliably over time: the human factor. Traffic is a human activity and as such
it is subject to the vagaries of human volition and behavior. Modeling traffic
is useful for short-term predictions – which way will traffic go if we close this canal?
– or simulations – how much traffic will we get if we change this canal to one-way only?
– yet the longer term can only be vaguely guessed by extrapolating trends
that may or may not reflect future motivations for individual or group
choices and the attendant consequences on transportation of people and
goods.

Because of the fickle nature of traffic, we focused on developing a solid traffic-counting methodology and we also worked on the development of automatic traffic-counting devices. So lesson one in this section is that if the data are deemed to be truly useful and if the dynamic phenomenon lends itself to automation, then automatic devices should be employed to collect the needed data because of the cost-savings.

If automation is not possible, then a rigorous methodology for data collection and a strict schedule of updates ought to be put in place, as long as there is a clear commitment to acquiring these data. Lesson two is that these "manual" updates can be farmed out to third parties, by modifying existing regulations or administrative processes, so that they happen more or less free-of-charge²²⁵.

Although activities generally imply a dynamic "movement" through space, it is indeed quite possible to harness traffic data into a spatial geoscaffolding, as was shown. By exhaustively representing and coding road intersections, as well as turning movement arrows and bi-directional flow vectors, each traffic datum can be made to fall into its proper spatial pigeonhole²²⁶. The generic lesson is to look for spatial "hooks" onto which dynamic data can be geocoded. This geospatial infrastructure for activities also makes the collection of "free" data updates that much easier, as will be demonstrated later²²⁷.

²²⁵ See also Note 317 and Gage *et al.*, 2003.

²²⁶ See, for example, Butler and Dueker, 2001.

²²⁷ See Note 225.

ENVIRONMENTAL CONDITIONS



he Venice Inner Canals project included the analysis of environmental **L** conditions in the waterways of Venice, wherein, after all, most of the urban sewage is still unloaded to this day. Due to the complexity of some of

the bio-chemical analyses that are needed to provide an accurate assessment of the environmental quality of the waters, our role in this aspect of the project was limited to the mapping of pointsource discharge locations and to the collection of samples for other scientific teams that participated in the UNESCO-MURST project.

An important informational foundation to these studies was the identification and inventory of all sewer outlets through which domestic sewage is still dumped daily into the inner canals so that it can be carried out to sea by the circadian tidal cycles. Our inventory process entailed visually inspecting both sides of each canal

sewer outlets



segment at low tide and mapping and photographing each outlet²²⁸, while recording some key pieces of information, like its condition and activity level. The cyclical nature of the astronomical tides dictated that our activities had to take place in the wee hours of the morning, from 1am to about 8am for the most part, since that's when the most "usable" low tides occur during the spring and summer months when our students were operating in Venice. Collection during the day was made impossible by the constant boat traffic in the canals and only on some occasions were late afternoon and evening windows of opportunity available.

We needed to work during

extreme low tides so that the lowest of the sewer outlets would be revealed, but at the same time we also needed enough water in the canal to allow our row boat to float²²⁹. We used a row boat to carry out our data collection so that we could reduce our draft to the bare minimum, but also because we wanted to conduct our measurements as quietly as possible, given the ungodly hours during which we were forced to operate. I personally manned the oar on many of these nightly excursions, but we also were helped by a group of Venetian gondoliers who were concerned with the deteriorating conditions of the canal walls. In fact, the inventory of sewer

[row boats and gondoliers]



²²⁸ The photo on this page, depicting me with four WPI students was published in the August 1999 issue of National Geographic Magazine, p. 100 (reproduced with permission).

²²⁹ In those years (early 1990's) the amount of sediment that had accumulated in the canals during over 30 years of neglect made it quite possible for a canal to be completely dry during the lowest tides, so that not all low tides were really usable for our studies.

photometrics

mapping sewer outlets

outlets was conducted together with an inventory of wall damage along the same canals.

Each photo that we took included in its frame a scale bar, which we used to subsequently measure the dimensions of the outlets. Photometric techniques were employed for this purpose, based on the knowledge of the length of the yardstick included in the picture (50cm in our case).

Keeping track of these point-sources on a GIS was complicated by the dearth, in the existing basemaps, of sufficiently recognizable features



along the canal walls at a scale that would permit a precise pinpointing of the outlets' locations. Nevertheless, we were able to create the first detailed maps of these openings, which later led to several follow-up studies of great importance for the City. The mapping process began in the field, where paper maps were used as initial records of the identified locations. Each outflow was labeled on the map and a corresponding record on a field form was tagged with the same label. On the same field form we also recorded additional information about the outlet, such as its shape, its condition (damaged or undamaged), and its level of activity (active or inactive).

coding sewer outlets

Each outflow was uniquely tagged with a composite numeric code that included the island number and a sequential enumerator to distinguish



among the outlets found along the perimeter of each island. These sequences started from the northernmost discharge location, which was number 05, then proceeded clockwise along the perimeter of each island, in intervals of 5, so that the next outflows were numbered 10, 15, 20 etc. These gaps of 5 units in the sequence of codes allows for the addition of intermediate outlets at a later date, as necessary, while preserving a modicum of order to the system.

In all, we recoded and validated a total of 2,725 sewage release points in all of Venice's *sestiert*²³⁰. Though thousands more had been inventoried, they were never confirmed by subsequent inspections. Although we never attained 100% coverage of all canals, this study

still represents one of the most complete reconnaissance of sewer outlets ever conducted in Venice.

public health

Knowing where all the sewage is being unloaded has great implications for studies of the effects of canal waters on public health. In fact, one must remember that every day there are hundreds of people who

²³⁰ Gallo, 1999.

environmental health

[organic pollution]

[pathogens]

come in contact with these waters in the course of their jobs. Therefore, one of the questions that the UNESCO project addressed was whether there was any cause for concern for those of us who come into contact with these waters on a regular basis.

A complementary question was whether – or rather to what degree – the environmental health of the canal network was compromised and what effect the urban discharges have on the surrounding lagoon ecosystem.

To answer both of these questions, several teams of scientists from a variety of scientific and health organizations, local and international, participated in extensive campaigns to ascertain the health of the Venice inner canals. Each campaign was able to furnish insights into the level of pollution in the canals' waters and in the bottom sediments. The main concern was organic pollution deriving from the discharge of excrements from residences, offices and hotels. The microbiology of these discharges was studied²³¹ to look for pathogens, viruses and bacteria, that could cause harm to humans. Indeed some highly dangerous pathogens were found, though their ability to spread disease was called into question, due to their inability to survive for long in the hostile saline environment of the canals.

Most of the organic pollution that could be harmful to humans is frequently beneficial to plant and animal life in water. Fecal excrements are used as fertilizers everywhere in the world, so many of the Venetian discharges are playing the role of manure for life forms in the canal network. More problematic for the environment are chemical pollutants, which were also studied in the course of the UNESCO-MURST project²³².



²³¹ Aimo et al., 1999.

[fertilizing]

water auality	In all in addition to the high presence of nutrients (nitrogen and
1	phosophorus primarily) the studies found that the city waters contained
	chemical pollutants in concentrations that were two orders of magnitude
	chemical politicality in concentrations that were two orders of magnitude
	greater than the levels found in the lone lagoon sampling site, although the
	exact effect of this pollution on the lagoon ecosystem was not ascertained,
	though we do know that the city only contributes 4% of the nitrogen and
	15% of the phosphorous that ends up in the lagoon ^{233} .
[salinity]	Meanwhile, scientists have been using an interesting proxy
	measurement to ascertain the organic pollution in the canals due to sewer
	discharges. Salinity, as it turns out, is lowered by the freshwater that is
	flushed down toilets and drains, so measuring the salinity level is tantamount
	to measuring the concentration of sewage in a canal.
	Along the same lines of thinking, knowing how much water is
[water consumption]	consumed in a household allows us to estimate how much organic pollution
	is released by that household into one of the canals near the house. We used
	this simple proxy as a way to estimate the total organic pollution released
	into the <i>rii</i> by the homes and businesses on each island. This in turn allowed
	us to estimate the solid waste that would be contained in the sewage, which
	lead to our first estimate of the total sediment being deposited in the canals
	by the precipitation of solids in the waste stream
	Sedimentation is a never ending process which leads to the periodic
sedimentation	need for dredging to remove the excess mud that accumulates on the bottom
	of canals. The sediment does not just precipitate to the bottom as seen as it.
	is uploaded into the senal but rather it fleate to the bottom with a sentein
	is unloaded into the canal, but rather it hoats to the bottom with a certain
	rate of precipitation which depends on what the suspended solution are made
[sediment transport]	or. If the canal has strong currents, a lot of the solids will be carried
[oodinion: Lanoport]	elsewhere before they have a chance to settle on the bottom. Boat propellers
	will also re-suspend the sediment even after it has finally settled down.
	However, due to the topology of the network, most canals are just as likely
	to receive stuff from adjoining ones as they are to export their own stuff
	onto others. The bottom line is that much of the sediment gets trapped in
	the tortuous waterways and very little floats of it out to sea with the liquid
	waste.

²³² Idem.

²³³ *Il Gazzettino*, October 15, 2003, p. III.

[sediment sources]



A specific study we conducted in 1999 explored the sediment sources that contribute to the sedimentation in Venice²³⁴. We estimated that the majority of sediment actually comes in from the

lagoon and gets trapped during the daily tide cycles in the sieve that is the inner canals network. According to our preliminary study, more than 80% of the deposit originates this way. About two thirds of the remaining muck (i.e. 11% of the total found in the canals) derive from the precipitation of solids in the sewage inflow. The last 6% of the sediment was estimated to be generated by the slow crumbling of plasters and by other debris originated by urban materials.

outlet clogging

Over time, the accumulation of residue on the bottom of canals, if neglected as it was from the 1960's until the 1990's,



leads to the clogging of sewer outlets – traditionally placed at 4 Venetian feet (approx. 1.2 meters) below mean sea level, to ensure that they would always be submerged.

The congestion of the outlets caused internal raptures within the old sewer pipes and forced the relocation of the outlets to a higher elevation, to avoid blockage. The height of the sewage outlets is therefore an important parameter to keep track of since it could (or even should) have an impact on the scheduling of periodic dredging maintenance²³⁵.

All of the aforementioned UNESCO studies considered both pollutants floating in the canal waters, as well as those immobilized in the canal sediments and slowly released into the system. Some of the worse chemical pollution from heavy metals dates back to the 1960's and 70's when the factories in nearby Marghera were releasing huge quantities of toxic materials into the lagoon without any significant public oversight. This negative environmental legacy is still "archived" in the deeper sediment layers, which trapped some of the worst heavy metals (like mercury, cadmium and copper) for posterity.

sediment quality

²³⁴ Borrelli et al., 1999.

 $^{^{235}\,}$ See also page 115 and following for more details about the clogging process and it effect on canal wall damage.

current situation

vacuum sewers for Venice



The current situation in Venice has greatly improved thanks in large part to the stricter controls on the industries in Marghera and also in part thanks to the installation of septic tanks for 1200 hotels, 450 businesses, and 2700 residences²³⁶. Nevertheless, the lack of a "modern" sewer system in the historical center of the city of Venice remains a source of pollution, and thus a cause of concern as well as embarrassment for Venetians.

To address this major shortcoming in Venice, we proposed a vacuum sewer system in 1997, with an award-winning project that exploited a US patent held by a WPI alumnus²³⁷. Several proposals for the first implementation of a HI-FLOTM system were prepared since 1997, the latest of which is being considered for the collection of sewage from the neighborhood of S.Elena in Venice. To some degree, this is also an example of *plan-demanding* knowledge because the preponderance of data at our disposal suggested this project to our sponsor and to us.



From the point of view of City Knowledge, the collection and organization of urban environmental information can once again be separated into two distinct aspects: the inventory of permanent contributors to environmental degradation and the monitoring of dynamic conditions that measure the health of the environment.

We have seen how it is possible, albeit arduous, to identify and map all of the point source sewage outflows that are the gateways through which urban refuse flows into the canals, negatively affecting the water quality in Venice. So the lesson again²³⁸ is to look for the "permanent" spatial objects that relate to the dynamic processes (in this case environmental pollution), so that space can once again act as the "glue" to keep information organized.

[urban environmental information]

lessons from our environmental studies

[mapping point sources]

²³⁶ Idem.

²³⁷ Felices et al., 1997. The alumnus' name is Alan (Chip) Hassett.

²³⁸ Similar to the last lesson in the traffic section, on page 88.

We have also seen how proxy measurements of salinity – a much [proxy measurements] easier and cheaper measurement than biochemical analyses - can be used to measure the presence of fresh water flushed down from municipal drains. The lesson is therefore to consider proxy measures that adequately reflect the phenomenon we want to monitor, whenever the "ideal" measurements are impractical or too expensive to conduct on a scheduled basis. Finally, we have seen how administrative information – namely the [administrative data] water consumed by residents and businesses - can also be used to determine the total amount of sewage discharged, which in turn can lead to the estimation of the quantities of "black sewage" and thus allow us to gauge the solid waste that will be released into the water to contribute to the sedimentation problem. This lesson extends the last one in that it suggests that some of the proxy data that we could use for our urban maintenance, management or planning may be already collected by some public agency (or even by some private company) and thus could be tapped into fairly easily and reliably, as long as some agreement was made with the owners of these existing administrative data sources²³⁹. Instead of continuing with the plethora of canal examples that I have in store, we will now switch to a more "derivative" application of city knowledge in Venice - one related to Venice's most publicized ailment: acqua

alta (high water) and its effects on the stones of Venice.

²³⁹ Singh, 2004.

PROTECTING VENICE FROM THE TIDES²⁴⁰

his chapter looks at a particular set of issues that are important for urban maintenance, management and planning in the city of Venice, namely the effects that high tides and flooding have on the physical upkeep of the city²⁴¹. It provides a very concrete set of examples of the benefits of City Knowledge and begins to illuminate the difference between ad-hoc data collection and a systematic approach to information accrual, which leads to returns that are unforeseen, yet very tangible, as the following sections demonstrate.

flooding in Venice



[urban features affected by flooding]





Flooding affects the physical infrastructure in Venice in a variety of ways, most of which have been recognized since the early days of the city's existence. Manuscripts in the Venice archives chronicle the frequent requests for maintenance along the inner canals of the city ever since records were kept²⁴². Natural erosion due to fluctuating tidal water levels is a fact of life in a place like Venice²⁴³. Construction materials are gradually weakened by the constant wet-dry cycles and by the natural salts and unnatural pollutants contained in the tidal waters.

A simplified taxonomy of the primary elements of the city that are negatively affected by exposure to the salt water of the lagoon and canals includes:

- - \oplus Streets and Pavements
 - ♦ Bridges
 - Docks
- ⊕ Underground Infrastructure
 - Utilities
 Utilitie
 - ✤ Sewers
- ⊕ Private and Public Buildings
- - ✤ Churches
 - Palaces
 - ♦ Convents
 - Public Art
 - ♦ Street Furniture
- ⊕ Canal Walls

While there is no doubt that these elements of the built environment are to some degree harmfully impacted by the gradual, but incessant, assault

 $^{241}\,$ The choice of focus was not mine, but that of the organizers of the Cambridge conferences on Venice in September 2002 and 2003 (Cambridge University, 2003).

²⁴³ So much so that we very recently collaborated on an interdisciplinary research project to explore the fluctuations of sea levels over the centuries, using archeological, biological, artistic (Canaletto paintings) and semiotic indicators (Angelini *et al.*, 2004). The pictures on this page come from that study.

²⁴⁰ This chapter is adapted from a refereed paper entitled *City Knowledge as key to understanding the relation between waters and stones in Venice* that was recently accepted for publication (Carrera, 2004).

²⁴² Caniato, 1999; Dorigo, 1999; Piasentini, 1999.

of the waters of the lagoon, the precise extent of the overall impact of flooding on the state of conservation of today's architectural and urban structures is hard to measure and the costs nearly impossible to quantify.

What is clear is that there are several concurrent factors at play in the undermining of Venice's built environment. Perhaps flooding is not the most destructive of all of the forces participating in the constant interplay between the liquid and solid components of the city. Many see "*Moto Ondoso*" (motor boat wake) as a major player in this arena²⁴⁴. Another potential – though perhaps unexpected – culprit is sedimentation, which is accused of engendering damage on canal walls through the clogging of underwater sewer outlets, leading to underground ruptures and thus to seepage and weakening of the mortars that bond together the bricks and stones of the canal walls²⁴⁵.

Without aspiring to actually quantify the damage done to these elements of the urban landscape, this chapter will instead use these pressing issues to delineate a path that would make these and other analyses much more feasible in the long run. In this manner, this chapter will attempt to demonstrate that Venice, like any other city in the world, would benefit from espousing the systematic approach I call City Knowledge.

The complexity of the relationship between the stones of Venice and the waters of the Lagoon is a great demonstration of the types of issues that could be better understood once a plan-ready City Knowledge infrastructure becomes available. The rest of this chapter briefly explores the nature of the interactions between natural and human-caused phenomena vis-à-vis the maintenance of the aforementioned elements of the Venetian built environment. The entire discussion will then focus on the indispensable foundation of information that is needed whenever we try to explore complicated relationships such as the one between stones and water in Venice. This chapter is therefore designed to highlight the knowledge infrastructure that can support such complex analyses.

As mentioned, since 1988, the Venice Project Center of the Worcester Polytechnic Institute (WPI)²⁴⁶ has been at the forefront of the exploration of the causal relations that cumulatively produce the physical damage that is visible everywhere in Venice. In collaboration with UNESCO and other agencies, the Center has systematically collected a wealth of information about the phenomena connected with architectural damage and decay, both along the canals and elsewhere. Though none of these data connect flooding to structural damage *per se*, numerous correlations were tested out and verified, by relating a variety of independent and dependent variables that link the "waters" with the "stones". These include: traffic levels, boat wake-loading, sedimentation, hydrodynamics, construction materials and maintenance.

The numerous databases and Geographic Information System layers that have been created since 1988 make it possible to test many assertions

[no "true" City Knowledge system]

the case for City Knowledge

"moto ondoso" in Venice

²⁴⁴ Pulliero, 1987; Mencini, 2000, Carrera, 2001.

²⁴⁵ Carrera, 1994. See also previous chapter, page 93.

²⁴⁶ See <u>http://www.wpi.edu</u>.

and draw useful conclusions, but, despite their sophistication, they only hint at what could be possible if a true City Knowledge infrastructure were created and maintained in Venice. This chapter now sketches out the type of information that one would need to have accrued in order to measure the "before and after" of flooding situations and thus begin to hypothesize about the "cause and effect" of phenomena that can – at best – be treated as "natural experiments" over which there is very little design control.



Fabio Carrera

f one considers the "public domain" only, then the above-ground infrastructure in Venice that is affected by flooding can be succinctly defined as: streets, bridges and docks. Moreover, Moto Ondoso (motorboat wakes) also damages all three elements, although streets are only marginally affected. The causal nexus between flooding, moto ondoso, and the corresponding damage to these artifacts is extremely complex to isolate, but one can start by simply knowing as much as possible about these three elements of the public realm that are subjected to the destructive force of water. The Venice Project Center has teamed up with a Venetian company called Forma Urbis²⁴⁷ to complete: (1) the mapping of over 1 million square meters of Venetian street pavements for Insula (top left); (2) the inventory of all of the 472 bridges in the city also for $Insula^{248}$ (center left); and (3) the catalogue of all 1321 public docks in the city for the city's department of public services²⁴⁹ (bottom left).

These three major physical inventories create the backbone of a possible study of the effects that tides and *moto ondoso* have on them. By adding the digital elevation maps²⁵⁰ that the *Magistrato alle Acque* has developed, through the *Consorzio Venezia Nuova*²⁵¹ (1988), it is possible to produce maps of the flooding of the streets of Venice at a succession of tide levels (bottom right).





²⁴⁷ This is the for-profit company that I founded in 1997 to carry out some of these City Knowledge activities in Venice. See more at page 185.

- ²⁴⁸ After an initial project by Bahn et al. 1998.
- ²⁴⁹ Felices et al., 1994; Doherty et al., 1995.
- ²⁵⁰ All elevations in Venice are from the "mareographic zero" of 1897, a.k.a. the "Punta Salute" datum.
- ²⁵¹ This is the consortium of construction companies that is in charge of the "floodgate" project.

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Knowing how frequently these various tides occur leads to the identification of what portions of the city's streets, bridges and docks get wet and how often. So, with only a modicum of approximation and

extrapolation, it would be possible to arrive at reasonable estimates of the damage that can be caused by mere flooding.

It must be noted that these data-gathering efforts have not been aimed at simply producing these maps, but also entailed painstaking surveys of the artifacts inventoried. Each of the Forma Urbis catalogues has resulted in an information system application that brings together the permanent (left) and ephemeral (bottom) characteristics of both the bridges (bottom) and the docks (left). In fact, whereas the state of conservation of an artifact will change and thus will need to

be collected repeatedly over time (allowing the measurement of "damage"), the permanent aspects will never have to be recorded again, which is one of the advantages of a City Knowledge system.

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These user-friendly, multimedia information systems make it possible for the dynamic data to be maintained up-to-date through the creation of a new,

me-stamped, statef-conservation sessment every time intervention (or ere inspection) takes ace. One can begin see how useful ch "plan-ready" formation would be it were accessible to cientists and decision akers as well as to e frontline users ho are in charge of e upkeep of the hysical artifacts.

This section shows how plan-ready information which is

September 2004

lessons from infrastructure analysis	already useful in and of itself for the maintenance of various infrastructure elements can also become useful for second-order analyses such as this one
[second-order re-use]	about flood damage. The "emergent qualities" of City Knowledge are
[separating permanent and ephemeral]	The section also shows how useful it is to separate the "permanent" aspects of our maintainable municipal assets from the "ephemeral" ones, such as condition assessments. In fact, the condition assessments and the log of physical maintenance interventions to ameliorate the assets' conditions can be themselves useful to measure damage over time and possibly correlate
[include update functions]	 it with potential causes, such as flooding. A true City Knowledge system should always separate the slowly-changing from the fast-changing features of municipal assets. Moreover, these systems should also be constructed with provisions for updating of the data at whatever interval is appropriate. In this case, our systems can be kept up-to-date as a consequence of repairs, which entails
[citizen reports]	that some of the conditions will actually improve accordingly. However the same system would also allow periodic check-ups of these structures to detect worsening conditions, as long as scheduled inspections were arranged by those in charge of the upkeep of these structures. Citizen reports and complaints would be greatly facilitated by the existence of a well-defined information infrastructure which attributes clear, unique labels to each object. By exploiting the standardized reference system, these reports could be logged and used as rough "condition reports", thus feeding "free" information into the City Knowledge system ²⁵² .

²⁵² See also page 183. For an interesting and potentially useful way to use cell phones to tap deeper into the world of citizen reports, see <u>www.yellowarrow.org</u>.

T he next category of items that can be damaged by water includes objects under ground, namely the infrastructure for electrical, water, gas, telephone, street lighting and sewage services, composed of pipes, ducts, valves, manholes, inspection wells, cables, etc. Insula S.p.A. has worked on these sub-systems since it was originally chartered by the four main utility companies (electricity, phone, gas and water) who own 48% of the shares – the remaining 52% being owned by the City²⁵³.

managing the underground infrastructure

One of the goals of Insula is to eventually produce a maintainable map of the underground infrastructure in Venice. The effects of flooding on subterranean utilities could be much more predictable with this sort of city knowledge at one's fingertips. Work below street level could also be coordinated in such a way as to avoid waste and redundancy. Once in place, these systems would represent practical applications of city knowledge principles. The first major system to showcase these principles was SmartInsula, the pioneering and award-winning application which formed the backbone of Insula's sophisticated information system that was developed by a UNESCO team in 1997²⁵⁴ and has since evolved way beyond that initial application.



²⁵³ As is discussed elsewhere in this dissertation (see fortnote 488), the original charter did not clearly specify whether sewers would be under Insula's jurisdiction, which has led to some friction with the department of public works from which many of the Insula staff were recruited.

²⁵⁴ I was personally involved in the initial design, later carried to completion by Cozzutto, 1997.

updating the information	The challenge that Insula is now experiencing lies in keeping such						
	rich systems up to date. Insula needs to constantly update bathymetric						
	measurements, bridge conditions, work progress and much much more.						
	Truly emergent self-sustaining city knowledge systems delegate data entry to						
	the most appropriate external user or to beneficiaries of the work – in other						
	the most appropriate external user, of to bencherates of the work – in other						
	words to the end users of the system. In fact, the major technical difficulty						
	for Insula so far has been in decentralizing the data entry, while reconciling						
	accounting systems with technical or engineering systems (frequently CAD-						
	based), and integrating them with geographical information systems (now						
	web-GIS). Many difficulties are being eliminated by forcing compliance with						
	a desired file format as part of a contractual stipulation with outside						
	contractors. Internal adherence to this standard tends to be harder to						
	enforce. As the entire GIS system is ported to the internet, web-based						
	applications to assist contractors in submitting the appropriate digital						
	documents and files are beginning to relieve internal staff of data entry						
	tasks ²⁵⁵ .						
	Another web-GIS that deals with the underground and embodies						
	some of these principles has been developed by Dr. Enrico De Polignol and						
	Dr. Lapo Cozzutto for the Environment Department of the City of Venice						
	The Sistema Informativo del Suolo (SLS) was initially dedicated to the self-						
	reporting of core sample analyses about contaminated sites in Porto						
	Marchara Drivata companies are antoring all of the data into this system						
	through a person of protocted internet browner and the data are later.						
	unough a password-protected internet browser and the data are later						
	analyzed and mapped semi-automatically by the system ²⁵⁰ . The system has						
	recently been incorporated into a more ambitious <i>Sistema Informativo</i>						
	Ambientale (S.I.A.) which is a web-GIS system that will also include						
	information about electromagnetic pollution and green amenities ²⁵⁷ .						
lessons from underground data manag	ement Exceptions did not collect data about up determined utilities						
ussons from unacigiouna auta manag	Even though we did not collect data about underground utilities						
	ourseives, the paragraphs above have illustrated now custom-made systems						
	to manage urban information of that sort can be created and can be allowed						
	to later "grow" on their own. The difficulty becomes how to keep these						
[logistical and administrative updates]	systems up-to-date. A true City Knowledge system should not only provide						
	the technical means to capture periodic updates in computer databases (as						
	discussed in the previous section), but should also include logistical and						
	administrative mechanisms to make these updates actually happen. When						
	possible, the task of keeping the information up-to-date should be left to						
	"customers" of the system, through web-based self-reporting mechanisms,						
	as was done in the S.I.S. system described above.						
[informational jurisdictions]	What is still missing, to allow a sustainable use and re-use of these						
	data repositories for more complex, higher-order analytical studies, is a clear						
	definition of "informational jurisdictions" and a mutually beneficial						
	agreement to share the information between different agencies – two basic						
	tenets of the City Knowledge concept.						
	, , , , , , , , , , , , , , , , , , ,						
	²⁵⁵ Todaro, personal communication.						

http://www.ambiente.venezia.it/sis/. Last accessed 8/19/04.
 http://www.ambiente.venezia.it/web_sit.asp. Last accessed 8/19/04.

DAMAGE TO PRIVATE AND PUBLIC BUILDINGS

damage to buildings

[58% of buildings flood with 130cm tide]

[local anti-flood measures]

[costing out anti-flood measures]

damage to stores

[67% of stores flood with 130 cm tide]

he next big category of physical objects that could be impacted by frequent floods includes all buildings: public and private. By implication, this category also includes all of the stores, shops, restaurants and all other businesses housed in these buildings. Flooding affects all buildings and businesses in its path. Moto ondoso, on the other hand, only affects buildings along the canals. Using the information systems developed, it is possible to know how many buildings are affected by floods at any tide level. For example, during a tide that reaches 130 cm., 9,124 buildings come into direct contact with the *acqua alta* out of a total of 15,486 buildings in the entire city (including the Giudecca). The system does not allow the prediction of whether or not the interior of each individual building actually gets inundated with tide water, although a specific inventory on the piani terra was conducted by the city in 1999 to answer just such a question²⁵⁸. Insula S.p.A. has been actively working to increase the elevation of public streets to around 1.2 meters – a process called *rialzi* – in order to reduce the number of buildings reached by high tides.

The owners of private buildings and commercial establishments affected by *acqua alta* are doing whatever they can to protect their property from floods: using small barriers, impermeable membranes and *vasche*²⁵⁹ to seal out the water, and even installing sophisticated drainage systems to direct the water to sump pumps that expel it from the inside of the building. Public buildings are similarly protected and access to many of them is guaranteed even during high floods, by the installation of wooden walking planks²⁶⁰.

Quantifying the damage that floods do to buildings and stores may be difficult, but the expenditure related to the local prevention of flooding building-by-building and business-by-business should be somewhat easier to calculate, by inventorying and estimating the cost of all the measures that have been put in place to either protect private and public property from floods or to make them accessible during floods. Moreover, in addition to tallying the cost of preventive measures, one could also account for all of the restorations and repairs that were caused by particularly severe floods. It may be rather difficult to do so, however, unless the government was involved in disbursing emergency relief funds for such activities and thus records were kept of the repair costs incurred.

As discussed above, City Knowledge would help us with such difficult estimates, by telling us where all the buildings are with respect to the flood lines. A map of all stores that was produced in 2001²⁶¹ shows that 2,862 shops (out of 4,263) would get flooded by a 130 cm tide. Together, these two figures, about the number of flooded buildings and number of

²⁵⁸ COSES, 1999

²⁵⁹ Literally "tubs", which are basically concrete underground chambers.

²⁶⁰ By VESTA, the local public-private Water and Sanitation authority.

²⁶¹ Duffy, 2001.

[anti-flood permits]

flooded shops, represent a necessary place to start in an estimate of flood damage to private and public property.

Since permits are necessary to install local barriers or to raise the ground floors by adding a step or two to the entrance, an estimate of the overall citywide cost of localized flood prevention measures would be possible if a system was put in place to geographically archive permits that affect the external built environment. The City Knowledge framework recommends that such mechanisms for capturing administrative transactions be put in place to guarantee that the information systems are maintained upto-date as piecemeal changes to the urban fabric are allowed through the permitting process. Together with Dr. Pypaert (UNESCO) I have been actively promoting such a self-sustaining system, by bringing together data from the former Assessorato all'Urbanistica, that keeps track of zoning and land use; the Legge Speciale department, that is in charge of disbursing restoration funds, based on specific work estimates; the Edilizia Privata department, which administers permits; and the Soprintendenza, which updates the "vincoli" that restrict modifications to registered historic properties²⁶². All these organizations provide information for the benefit of the Commissione di Salvaguardia. This institution has the final word on all major modifications to buildings in the historic city and would greatly benefit from such contextual knowledge at its fingertips when making important decisions²⁶³.

Being one of the institutions with a representative in the *Salvaguardia* commission, UNESCO had a vested interest in bringing about such a confluence of information from all of these sources, but so do all Venetians, who are in the end affected by the permanent changes that are approved by this regulatory body.

Dealing with this aspect of flooding would have been much easier if the data collected by a myriad organizations were already coordinated and interconnected. If that was the case, we would not only be able to know exactly what effects a flood would have on the *piani terra*, but we could also begin to estimate the cost of local flood protection by tallying up the permits to install miniature flood gates at one's doorstep or to raise the entrance one step higher, etc.

The first lesson for City Knowledge we glean from this section is that each organization that is in charge of some aspect of building construction, restoration, preservation or permitting should get its house in order first and foremost, as Dr. Pypaert and I have been trying to propose, so far unsuccessfully²⁶⁴. If the various departments listed above had operational information systems in place within the boundaries of their respective informational jurisdictions²⁶⁵, changes to the city of Venice would happen more cogently, thanks to the ability of these agencies to deliberate

coordinating building restoration efforts

lessons about building data management

[self-serving interests first]

²⁶² Halloran et al., 2002.

²⁶³ See also Mancuso, 2003.

²⁶⁴ Halloran *et al.*, 2002.

²⁶⁵ Mancuso (2003), using primarily VPC datasets and layers, put together a web-GIS that encompassed all of these jurisdictions, which can be found at <u>http://www.intelligencesoftware.it/unesco/venezia/</u>. Last accessed 8/19/04.

about permit applications while having all of the appropriate contextual
information in front of them. By serving their own interests, these
organizations would make their own job easier and would provide a better
service to the citizens that foot their bills.[second-order uses emerge later]The other lesson, which repeats a refrain that already appeared in
previous sections is that after the public agencies have independently taken
care of their own affairs, they can coordinate with each other to provide
value-added benefits to each other and to the city, such as, in this case, the

ability to estimate costs incurred for the local protection from high tides.

DAMAGE TO PALACES, CHURCHES AND CONVENTS



cultural heritage catalogs

Right after the 1966 floo



S ome of the buildings which are part of Venice's more prestigious architectural heritage, such as palaces, churches and convents, are also touched by high tides. Being more important than others, they have

received more attention from public authorities and from philanthropic organizations such as the socalled "private committees".

Venice owes much of its fame to its aqueous *forma urbis* and to the art and architecture it contains. In 1987, the whole city was inducted by UNESCO into the list of World Heritage Sites as a treasure that belongs to all humanity; the first city to receive such an honor in its entirety. When it comes to damage due to floods, the parts of Venice's heritage that stand to suffer the most are palaces and churches, which tend to have ground floors containing more elaborate craftsmanship and more precious materials.

1966 flood, UNESCO funded the creation of catalogues of Venetian Palaces, Churches and Convents. In the three decades since then, these catalogues have proved invaluable as a knowledgebase supporting the relentless efforts for the restoration of the priceless treasures of art and architecture first inventoried in the late 1960's. Starting in 1999, teams of WPI students began the task of revisiting and computerizing the UNESCO catalogs²⁶⁶. These efforts allow us to say, for instance, that out of the 383 *palazzi* in Venice, 308 get wet with a 130cm tide (top map at left), as do 46 out of 59 convents (center map).

Similarly, we can identify all of the churches that would get flooded with the same 130cm tide. Out of a total of 113 churches in Venice (including Giudecca), 86 are affected by this *acqua alta* (bottom map).

Nevertheless, in order to convert the knowledge of what gets wet at the various tide levels into a more useful estimate of the damage incurred by these artifacts when they get flooded, it is necessary to know a lot more about what's inside these historic buildings.

²⁶⁶ Donnelly et al., 1999; Halloran et al., 2002; Marchetti et al., 2003

City Knowledge

church floor artifacts

addition to being frequer found vulner riddled where which floor's perme constr waters rapidly recycle

Starting in 2002, we began recording the tombstones, inscriptions and artifacts that are embedded in church floors²⁶⁷ (see photo at left). In addition to being frequently at lower elevations due to the age of the original

foundation, churches have the added handicap of being vulnerable to flooding through their floors, which are riddled with tombstones. The underground cavities where the entombments took place are a conduit through which high tides can quickly reach the artifacts on the floor's surface. This process is abetted by the high permeability of the bottoms of the tombs, which were constructed in such a way as to purposely allow tide waters into them, so that the mortal remains could be rapidly washed away and the tomb could be promptly recycled and reused.

The photo below clearly shows the huge gaps purposely left between the planks laid at the bottom of a tomb recently excavated under the church of San



Samuele²⁶⁸.

Once this additional city knowledge catalogue of church floor artifacts is finished (over 80% of the surveys have been completed), a more accurate assessment of the potential damage inflicted upon church floors by frequent floods will be possible. Arriving at a similar inventory for the ground floors of palaces and convents would also be useful in this regard.

The overall impact of flooding on churches, convents and palaces can thus include a better estimate of the damage to their floors, but should also include the deleterious effects of salt water on any other artifact that may be touched by tidal waters in the interior of these historic structures. Appropriate monitoring of the decay by the *Curia* and *Soprintendenza* could help maintain these catalogues up-to-date and thus prevent catastrophic damage to these important artifacts.

²⁶⁷ Delaive et al., 2002; Hayes et al., 2003;

²⁶⁸ Courtesy of Dr. Luigi Fozzati, *Soprintendenza Archeologica* and Dr. Marco Bortoletto, archeologist.

lessons from palaces, churches and convents	This topic does not yield many new lessons, but is more of a
	"refresher course". It reminded us of the permanent/dynamic dichotomy
	and it reaffirmed the usefulness and re-usability of systematic catalogs.
[truly pormaport catalogs]	Nowhere is the advantage of separating the "permanent" from the
	"dynamic" more clear than when dealing with cultural heritage. These
	historic artifacts have been around for centuries and such ancient relics only
[never-ending condition assessments]	change by subtraction, not by addition. No new artifacts are ever added, yet
[nover chang contaitor accessments]	some may disappear or dissolve to dust. Cataloguing historic assets is
	therefore a finite process, but monitoring their state of conservation is not.
[be thorough and complete]	The biggest lesson we learnt with these and similar projects is that it
[really pays to be thorough and complete when cataloguing antique artifacts.
	In this day and age, such a process could indeed be done once and for all.
[share results to avoid duplication]	The key to avoid duplication of effort in the future is to disseminate the
	results widely and openly. Today's internet technologies can help eliminate
	redundancy as long as people are amenable to sharing their inventories freely
	and willingly. The avoidance of duplication should free up some time that

can be put instead into periodic checks of the conditions of these objects to

detect degenerative processes that may lead to their complete loss.

DAMAGE TO OTHER CULTURAL HERITAGE

A fter the flood of 1966, most, if not all, precious paintings in Venice have been moved up and out of the reach of even the highest high tides. Practically all damage to heritage would now be limited to fixed and immovable structures, such as floors, bases, pedestals, columns, steps and other artifacts within a 2-meter band from ground level (which translates to over 3 meters above sea level)²⁶⁹.

endangered artwork

With the exception of our aforementioned recent work on church floors²⁷⁰, there are no systematic assessments of the artistic or historic heritage contained in this "danger zone" in the entire city. Common sense suggests that everything that could be moved away from this perilous band should have been already moved, though it is quite possible that some artwork might still be in a vulnerable location to this day. Estimating just how many works of art still remain within the "danger band" is arduous at best, whereas a fully-developed (utopian?) City Knowledge system could provide the answer to this enigma in a few seconds. Under such a system, the various authorities in charge of heritage collections (like the municipal, provincial and regional governments, the Curia, the *Soprintendenze*, the *Archivio di Stato* and the two main libraries – Querini and Marciana) would have already catalogued all of the objects that they are respectively in charge of, namely the buildings, properties, church floor artifacts, paintings, mosaics, manuscripts, parchments, books etc..



²⁶⁹ This measure has been picked somewhat arbitrarily to reflect the approximate height of the theoretical maximum tidal surge. A one meter threshold would reflect the actual street flooding during the historical maximum level of 1.92, recorded in 1966. The exact dimensions of this "danger zone" are irrelevant to this discussion.
The information contained in the Venice archives and in the historic libraries would be even better protected if electronic transcriptions of the manuscripts were produced using the Emergent Transcription Assistant System²⁷¹ (left) and the Ultraviolet Scanner²⁷² that we have been concurrently developing at WPI²⁷³.

With some foresight, these computerized catalogues could have included a field for the height of the artifact from the floor, which in turn would allow us to simply select all objects whose distance from the floor was less than 2 m.



- ²⁷⁰ Delaive et al., 2002; Hayes et al., 2003.
- ²⁷¹ Ho et al., 2003; Calhoun et al., 2004.
- ²⁷² Dehri et al., 2004.
- 273 More information at www.wpi.edu/~carrera, under WPI research.

public art

As partial demonstration of the benefits of having city knowledge systems in place, it has been possible to select, from the 2,930 pieces of outdoor sculpture that have been catalogued over the last decade (figure at left), the ones within 2 meters of ground level²⁷⁴. This search instantly reports that 69 artworks are on public display at a height of 2m or less.



²⁷⁴ The reason for including the height from the ground in the database in the first place was to allow us to calculate the cost of scaffolding. It should be noted that the height from the ground does not correspond to the actual elevation above the standard sea level of 1897.

wellheads and flagpoles

General Pedestal

Public

Similarly, one could also include in the 2-metre band all 232 wellheads from the wellhead catalogue (bottom of page), since they all sit at ground level, as do all 22 historic flagpole holders that dot the city (left).

More specifically, with the same 130 cm flood used as an example, 122 of the 232 wellheads would get wet (detail below).

Fortunately, though, most of the 4.500+ pieces of public art and street furniture



lessons from cultural heritage	Once again, the availability of a City Knowledge system would make
	many of these preliminary assessments instantly possible, as long as each
[inventory within jurisdiction]	institution in charge of artistic treasures had developed its own catalogue
	according to the aforementioned informational jurisdictions. It is also
	obvious that a disaster relief agency, such as the Italian Protezione Civile,
	would greatly benefit from a distributed, yet interconnected City Knowledge
	system that was able to direct emergency crews to the exact locations where
	works of art were in danger of being flooded during an <i>acqua alta</i> ²⁷⁵ .
[no centralized know-it-all system]	The key here is not to focus on creating a centralized know-it-all
	system, but to foster the emergence of a distributed network of smaller (and
[emergent distributed network]	more manageable and maintainable) systems, through a process that I chose
[no data management mediators]	to call "middle-out ²⁷⁶ ", to differentiate it from "top-down" or "bottom-up",
	both of which have demonstrated severe shortcomings. It may be that the
	information could be actually housed in a single server somewhere ²⁷⁷ , but
	each different agency will be managing the data updates independently,
	without an overarching entity mediating the data management.
	Data input, on the other hand, <u>could</u> be farmed out to a central
	agency (like an MIS department) to achieve some cost-savings, especially
[minimize in-house data input]	when specific skills are required, such as for GIS mapping. It is important to
	remember, however, that the goal of an efficient City Knowledge system is
	to outsource most data input to "customers" or contractors in order to
	basically get it done for free, or at least to minimize the costs of in-house

data input.

 $^{^{275}}$ In fact, we began to work with the *Protezione Civile* in the summer of 2004 precisely to prepare for these types of catastrophic events.

²⁷⁶ This term has been used before by many to mean several different things. I personally first heard the phrase from Prof. Joseph Ferreira who used it in a paper (Ferreira, 1998) but in a different context and with a somewhat different meaning.

²⁷⁷ As was the case for Mancuso's (2003) web-GIS.

DAMAGE TO CANAL WALLS

I n concluding this brief excursus into the various points of contact between waters and stones in Venice, this section discusses what is perhaps the most critical interface between these two fundamental elements: canal walls.



"deep knowledge"

This section illustrates how a systematic and methodical approach to the accumulation of urban information can yield "deep knowledge" about the causal nexus between phenomena.



Back in 1998, Babic *et al.*, using the accumulated storehouse of knowledge on traffic, wall damage and bathymetries, concluded that the root cause of wall damage is lack of dredging, which is only later compounded and exponentially accelerated by traffic and wakes²⁷⁸."

Based on this knowledge, in the year 1999 a further study was conducted²⁷⁹ to quantify the relative and absolute contributions for a variety of possible sediment sources, including the debris produced by crumbling masonry, to the accumulation of sediment at the bottom of canals. This study led to the proposal for a Sedimentation Model to predict the rate and location of mud accumulation at the bottom of canals, which would allow a

more effective and efficient scheduled maintenance before more wall damage was generated by the clogging of sewer outlets.

²⁷⁸ Babic et al., 1998.

²⁷⁹ Borrelli et al., 1999.

wake-loading

turbulent discharges

In 2002, the concept of a "moto ondoso index" was developed, that translates levels of boat traffic (i.e. number of boats) to levels of "wake-loading" (how much wake energy is discharged in the canal), which helps to better correlate traffic to damage²⁸⁰.

More recently, WPI students²⁸¹ designed and successfully tested an instrument that maps the locations where motorboats discharge energy into



the canals when maneuvering to make turns, or otherwise stopping abruptly by shifting into reverse when an approaching boat threatens a collision, or even when moving back and forth near a dock to tie up the boat and unload people or cargo. This custom device is equipped with a differential GPS, a triaxial accelerometer and an RPM meter and will produce the first ever map of "turbulent discharges" in the inner canal network, further facilitating the prediction of future damage along canal walls.²⁸²



²⁸⁰ Chiu *et al.*, 2002; see also page 82.

²⁸² See page 83 for a map produced by this instrument.

²⁸¹ Chiu et al., 2004.



The application of city knowledge principles has paid off dramatically in another project related to *moto ondoso* entitled *Re-Engineering the*

*City of Venice's Cargo System*²⁸³. The project has demonstrated the plausibility of "plan-demanding" knowledge as a consequence of "plan-ready" information, in opposition to the traditional modus operandi of "plan-demanded" data collection.

Here, work on the optimization of canal closures²⁸⁴, which produced plan-ready information on the amount of cargo delivered to each Venetian island, has led directly to the spontaneous emergence of the need to develop a plan (hence the term "plan-demanding") to restructure the way deliveries are conducted in Venice. The 2001 award-winning project was conducted with and for the former *Consorzio Trasportatori Veneziani Riuniti* (a group

representing about 70% of all cargo boat drivers in 2001) and resulted in a proposal to redistribute merchandise "by destination" instead of "by product".

We estimated cargo demand by inventorying all shops and stores in Venice and by surveying representative samples of each typology of commercial establishment to quantify the number of parcels delivered to each store of that type everywhere in the city.



²⁸³ Duffy *et al.*, 2001. This is the same project mentioned in the "Plan-Demanding" discussion on page 37 ff.

²⁸⁴ Amlaw et al., 1997.



This effort led to the aggregate depiction of the total demand of dry (yellow) and refrigerated (blue) cargo for each island in the city.

The research also proposed the creation of a cargo warehouse (*interscambio merci*) in the Tronchetto area to allow for the sorting of the merchandise arriving by truck. We envisioned that the city would be divided into 16 zones with commensurate delivery demands. The warehouse would mirror such a division, reserving a loading bay for each zone.



In the end, it was possible to estimate the total number of boats (for dry and refrigerated goods) that would be necessary to deliver all necessary merchandise to all the stores in each zone.

reducing wall damage with knowledge

Boat drivers were repeatedly engaged in public meetings as well as surveyed and interviewed during the development of this plan. This participatory process created consensus over a plan that would make all licensed drivers shareholders of a single, large logistics and distribution company delivering most of the goods in the city. Boat drivers would be



able to deliver to their destination dock at a set time and without interference from other cargo boats. Vacations and sick days would now be possible without the fear of losing clients. The great majority of boat drivers that participated in the public meetings found the benefits of such a system advantageous.

Presently, the municipality of Venice is moving forward with the actual implementation of this plan. This proposal will reduce cargo-generated *moto ondoso* by a substantial amount while preserving non-seasonal jobs. Point-to-point cargo journeys will be reduced to one or two per boat, instead of the dozen or more segments traveled each day under the current system. A reduction of the order of 90% of the wall damage induced by cargo boats is therefore not implausible²⁸⁵.

In the summer and Autumn of 2001, the proposal was presented to the Mayor and the Vice Mayor who espoused it. The project, which is currently well on its way to being realized, was a

triumph of City Knowledge principles, demonstrating the "plan-demanding" potential that such an approach entails. A plan-demanded study dedicated to minimizing disruption to deliveries during canal closings for maintenance and dredging operations led to the accumulation of enough plan-ready information about the inefficiencies of the system of deliveries "by product" to spur the inception of a follow-up study to explore the boat-drivers' perspective on the revolutionary approach of deliveries "by destination" that

²⁸⁵ Carrera, 2002.

	was proposed. The project went full-circle, from plan-demanded to plan- demanding. Although we have "deep knowledge" that tells us that timely dredging is more important than reducing wake-loading, nevertheless, whatever damage motor boat wakes do induce upon the canal walls <u>will</u> be reduced by a fraction that is proportional to the wake-loading that the number of cargo boat transits being eliminated would have caused as a percent of the total wake-loading induced by <u>all</u> boat types in each canal segment.
lessons from "moto ondoso" analyses	This section manifests the ultimate power of City Knowledge, i.e. the ability to create wholes that are bigger than the sum of their parts. Here
[value-added]	is the ammunition for the "value-added" argument that should provide the final clinching proof about the efficiency, effectiveness and efficacy of City Knowledge.
[efficiency]	The efficiency of City Knowledge is demonstrated here by the lack of redundancy in the datasets and the smooth collation of information needed for the plan-demanded study, which mirrored the idealized situation of non-overlapping informational jurisdictions envisioned by the City Knowledge approach. Of course, the fact that the VPC functioned as a single overarching entity and not as a distributed cadre of information- producers may be taken as evidence of the possible primacy of the centralized approach versus an emergent decentralized one. The fact is that the data that were used in these examples came from a variety of sources, administrative, academic, municipal, as well as our own data collection. The upkeep of the fundamental datasets for each one of the aspects we dealt with in this example could be easily attributed to one agency or another, based on informational jurisdictions.
[effectiveness]	We could measure the "operational effectiveness" of the example discussed in this section according to Budić's indicators ²⁸⁶ . She selected a sample of GIS practitioners in 125 county and municipal governments in four south-eastern states. According to that sample, our Cargo Project would be very appreciated by 63.6% of GIS professionals because of the instant accessibility and availability of the data we used to arrive at our reengineering proposal. Validating the accuracy of the data would make 27.3% additional users very happy. A well-crafted City Knowledge system should therefore be very effective operationally. As far as "decision-making effectiveness", the plan-demanded example discussed herein should have made clear the power of the GIS tools to communicate the information pertaining to the cargo delivery system. This alone would have been highly desirable to half of the sample of GIS practitioners surveyed in Budić's study. It could also be argued that the example discussed herein showcased both the ability to aid in the identification of conflicts and also in the confidence in the analyses that produced our radically re-designed delivery system, making it even more effective for decision makers.

²⁸⁶ Budić, 1994, p. 252, Table 4.

[efficacy]

The efficacy of our framework in terms of the measurable consequences of our proposals in the "real world" cannot be quantified quite yet since the proposed delivery system has not been put in place as of this writing. Measures of efficacy may include the financial benefits or quality-oflife gains of the citizens of Venice <u>after</u> the inauguration of the system.

THE PROMISE OF CITY KNOWLEDGE

This paper argues that not only should Venice entertain the notion of a 'central bank'²⁸⁷ guaranteeing the free flow of data, to be open to all and transparent, but that the city should more importantly employ a sustainable methodology to allow such a bank to emerge from the middle out (not from the top down or from the bottom up) as the sum total of the data produced by a whole variety of contributors distributed in the territory. For such an endeavor to really have staying power and to take on a life of its own, it will be necessary to forego the old-fashioned notion of a "central bank" and replace it with the principles of City Knowledge introduced in this paper.

The basic tenets of City Knowledge which are aligned with some of the most recent trends in Geographic Information Systems, suggest the adoption of a middle-out approach based on clear "informational jurisdictions" assigned to the producers of urban information, starting with the plethora of municipal offices which, through the approval of permits or the assignment of licenses or other administrative acts actually cause – or more frequently allow – the city to change ever so slowly.

Intercepting these administrative transactions will enable City Knowledge systems to maintain the information up-to-date more or less automatically. Self-interest is the fuel that will make the City Knowledge system thrive, since all offices will have self-serving incentives for making their operations smoother and more citizen-friendly. Once a number of departments in the City have embarked in the full life-cycle analysis of the information flows that guide their actions, leading to the identification of their specific jurisdictions, and once the backlog of existing information is captured in databases and GIS, scholars and scientists, planners and decision-makers, as well as citizens at large, will be able to enjoy the benefits of the synergic, emergent properties of a connected and shared City Knowledge system²⁸⁸.

Although the path to a full City Knowledge system will suffer from typical implementation woes, such an approach would create a virtual 'central bank' on everyone's desktop and would make Venice a model for sustainable municipal information systems all around the world.

²⁸⁸ As partially demonstrated by Hart et al., 2004, who analyzed the information flows in the Environment Department of the City of Boston, specifically with respect to the Boston Landmarks Commission and the Boston Conservation Commission.

middle-out from each jurisdiction

intercept administrative transactions

creating a virtual central bank

²⁸⁷ This was proposed as a conference recommendation (Cambridge Conference, 2003).