A feasibility study of close-range photogrammetry for the survey of building facades along canals in Venice, Italy

by

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Presented to:

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Oh Venice! Venice! when thy marble walls
Are level with the waters, there shall be
A cry of nations o'er thy sunken halls,
A loud lament along the sweeping sea!
Ode on Venice, Lord Byron, 1816.

I. Introduction

This study was initiated to assess the application of photogrammetry to monitor and record canal walls, and building facades along the canals in Venice.

In 1989, Ing. Fabio Carrera, consultant for the UNESCO Venice Inner Canals Project, asked archaeologist Dr. Lawrence Desmond for information concerning his use of photogrammetry to record important Maya architecture in Mexico. The World Heritage Site of Chichen Itza, with its ancient Maya buildings and pyramids, is as much at risk as Venice from a combination of human and natural causes. In Carrera's opinion, the technology used to record buildings at Chichen Itza might also find application in Venice to help in the preservation of its monuments and canals.

Carrera had already carried out a number of projects to assess the impact of natural and human effects on the outdoor art and architecture of Venice through the Worcester Polytechnic Institute Venice Projects Center. UNESCO, in support of its mission to foster education, science, and culture had taken a special interest in Venice through a number of preservation projects, including Carrera's Inner Canals Project, and had designated Venice as a World Heritage Site.

In the summer of 1991, at the invitation of Carrera and with funding from the University of Minnesota, Desmond came to Venice to investigate the potential uses of photogrammetry in the Venice environment. It soon became clear that a broad study would be needed, and that UNESCO might be a possible source of funding because of its previous support of photogrammetry and other scientific methods for historic preservation.

Funding from UNESCO was received, and field work, meetings and research were carried out in Venice from August 27 through September 20, 1994. From September 21 to 27, consultations were held in York, England concerning the Venice field data, technical problems, and photogrammetric building survey strategy with Mr. Ross W. A. Dallas, Bsc, FRICS, a leading specialist in measured buildings surveys and architectural photogrammetry.

II. Background: Photogrammetry and its history, technical developments, users, and systems.

Photogrammetry is defined as the ability to take measurements from photographs, and close-range photogrammetry pertains to non-topographic subjects such as architecture and archaeological sites, and other objects on the order of life size sculpture or smaller.

A. Historical overview

1. Pre-1945

Close-range photogrammetry, as a method for recording and monitoring architecture, had its origins in the work of Albrecht Meydenbauer, a German architect, who used the "graphical intersection" method beginning in 1867. A true pioneer in the use of photogrammetry, he is credited with the first photogrammetric recording of Islamic architecture in the Middle East in the 1870s. He established a school for photogrammetry in Berlin in 1885 which he called the "Messbildanstalt" or the metric photography establishment. His photographs and survey data of German architecture, archived safely until after the second world war, found invaluable use in post-war restoration projects. His method, "graphical intersection," was very labor intensive and, thus, found little application outside of the Messbildanstalt.

Photogrammetry's use of stereo photographs developed early in the 20th century, but was still little used for architectural surveys before World War II in-spite-of the extensive field and drafting time required to make drawings from hand measurements, and that method's potential for measurement errors.

2. After 1945

After the war, in 1945, conservators began to insist on precise and accurate recording of buildings prior to their conservation and restoration, and so looked to stereo-photogrammetry as a solution. Since the 1950s important historic buildings have been recorded increasingly using photogrammetry, and in the words of Hans Foramitti founder of the Austrian Bundesdenkmalamt, "in a perfectly objective and complete manner, including all the irregularities, whether wanted or not, important or not, of aesthetic, technical, or historic interest." His statement reflects very closely the philosophy of Article 9 of the 1964 Charter of Venice resolution on historic preservation, and was the basis for the formal adoption of photogrammetry by the International Council on Monuments and Sites (ICOMOS) for historic preservation in 1987.

The International Charter for the Conservation and Restoration of Monuments and Sites of 1964 (Charter of Venice), Article 9, also led to the establishment of the International Committee for Architectural Photogrammetry (CIPA), which was established in 1970 as a sub-committee of ICOMOS and the International Society for Photogrammetry and Remote Sensing (ISPRS).

Since 1970, CIPA has worked with a number of ICOMOS preservation programs at World Heritage Sites recording important monuments. In 1980, the architectural photogrammetry practices of CIPA were reviewed at a three day meeting held in Paris. The papers given at that meeting were published by UNESCO in six languages under the title, "Optimum practice in architectural photogrammetry surveys."

In 1987, the 8th General Assembly of ICOMOS finalized photogrammetry as its choice for architectural recording by adoption of Resolution 2, "that photogrammetric recording techniques be applied for all World Heritage Sites." It should be mentioned again that Venice and the Venice Lagoon are listed in UNESCO's "Le Patrimoine Mondial" as World Heritage Site #140, and that UNESCO has been a serious financial

supporter of the use of photogrammetric recording at World Heritage Sites.

Photogrammetry scholar Maurice Carbonnell points out in his chapter "Architectural Photogrammetry," in the book Non-Topographic Photogrammetry, that: UNESCO, which recommended the use of photogrammetry, took charge of actions relating to education in this field, contributed to the establishment of laboratories to undertake surveys, and made the decision to require photogrammetric surveys as a prerequisite for all large international operations for safeguarding monuments or sites.

B. Technical developments and users

UNESCO's adoption of architectural photogrammetry came at an important turning point in photogrammetry's development. From the 1980s a revolution in architectural photogrammetry has taken place with analog stereoplotters (optical mechanical drawing equipment), once considered as state-of-the-art, now replaced by analytical stereoplotters. The new analytical plotters are computer controlled with software designed to speed up and simplify the production of drawings without loss of accuracy. The new software also makes field operations simpler by correcting the perspective of a drawing when different camera angles are required, by reducing the amount of field survey data needed to measure a photograph in three dimensions, and allowing the use of non-metric cameras for photography. Other innovative photogrammetric systems employing advanced software and desk top personal computers have been developed to utilize non-stereo photographs. These systems replace the stereoplotter with a digitizing board and hand controlled cursor to make drawings.

The latest addition to the field of photogrammetry is called "softcopy" where drawings are made from digitized photographs while being viewed in stereo on a video monitor. It is expected that within a few years data capture by a digital camera for direct input into the softcopy system will become economically feasible.

The field of architectural photogrammetry is continuing to change with the development of new software and computer technology, and we are witnessing only the beginning of important advances that will give greater access to an increasing number of users and provide new and improved products.

Let us now examine more closely the purposes of photogrammetric documentation and identify its users. Ross Dallas, in his recently issued Factsheet titled, "The role of modern measured survey in the repair, recording and presentation of historic buildings," provides a broad overview.

To meet "works" requirements. Whether for major repair or ongoing maintenance, survey drawings are required. They will be used by the Architect to mark up and specify pairs and alterations, by the Engineer to calculate strengths and loadings, by the Quantity Surveyor to estimate costs, by the Contractor to plan out the work, and not least by the Administrator and Committee Member to chart progress and find out where we are!

> To help understand the history of the building. Modern conservation recognizes that the specialist should not proceed blindly to repair and conserve, without a clear understanding of the construction, alteration and history of the building. This assessment work is often described nowadays as analytical

> recording. For this work carried out by the architectural historian and increasingly the archaeologist, accurate measured survey is fundamental. We also recognize today how valuable it is to present information to the Public on the history of a building, and again survey drawings will underpin this work.
>
> To record for posterity the condition and appearance of the building. The very solidity and age of a building often deceives and conceals just how much change and alteration may have taken place over the centuries. Yet often this work is unrecorded, leaving today's specialist to puzzle out what may have happened even in the quite recent past. Also, it is astonishing how many major buildings have quite inadequate records available of them. We owe it to future generations to make records of all our historically important buildings and keep these records safely [Dallas:1994 Factsheet].

While there are different types of measured drawings such as floor plans, sections, and records of plumbing, electrical systems and air conditioning, we are primarily concerned in this study with elevations drawings. These drawings help researchers learn the historical background of a building and, if monitoring techniques are used, changes to a facade can be detected. When restoration or conservation of a historic building is to be carried out, facade elevation drawings are a basic tool used by architects and contractors alike.

C. Systems

1. Rectified photography

There are a number of photogrammetry systems available, but before summarizing those systems we should first consider rectified photography as a simple, and straightforward method for providing elevations drawings of buildings with flat surfaces. Some three dimensionality in a building, such as a porch or buttress, is obvious; but problems arise in recording buildings with rectified photography when there are subtle curves or bulges not easily identified. In these cases a rectified photograph cannot be used to make a true scaled drawing. Should the building be flat then an accurately measured drawing with great architectural detail can be made.

A view camera with a 4 x 5 inch negative and a 150mm lens is generally used to make the rectified photograph. The camera is leveled and its etched ground glass grid is aligned with a horizontal level rod or leveled targets on the building. The photo is made measurable by placing a scale on the facade or by measuring between two predetermined locations (targets or natural features) which can be seen in the photo. Until the development of CAD programs, a scaled photo was printed with a standard enlarger and a drawing traced from the photo. Today a drawing can be made from the photo on a digitizing board using a CAD program or the photo can be digitized and a drawing made while viewing it on a video monitor. These new software programs allow for some corrections to perspective and scale, but a flat facade is mandatory for accurate rectified photographic drawings. This requirement is quite different from photogrammetric systems where any architectural element can be measured in all three dimensions.

2. Stereo-photogrammetry

As was mentioned earlier, stereo-photogrammetry is not a new development, but with the advent of desk top, low cost, high powered computing systems, analytical stereoplotters have made measured drawings available to more users. Where one-of-a-kind drawings were produced by analog systems, we now can modify and correct drawings by adding CAD "levels" to any drawing and, if needed, print the drawing in color from a computer file.

The process of stereo-photogrammetric documentation is complex, but straight forward. First, selected locations on a facade are measured using a surveying instrument called a theodolite, it is then photographed with a metric (calibrated) camera so that each photo overlaps the other creating a three dimensional image. Documentation work can cease at this stage with the photographs and survey information stored to form a permanent archival record. Or, the photographs and survey data can be used to make accurate and detailed line drawings of the facade.

Strictly speaking any camera can be used for stereo-photogrammetry, but metric cameras designed for photogrammetry are preferred because of their superior lenses, film distortion control, and they require fewer targets to be surveyed for dimensional control. Large format cameras such as the Wild P31, Zeiss UMK 1318, and Linhof Metrika are used by most government funded photogrammetry organizations such as English Heritage in the United Kingdom and the General Inventory of the Monuments in France, and by private photogrammetry companies where very precise measurements are required for industrial or aerospace applications.

To make a drawing, an optical-mechanical instrument called a stereoplotter is used. The operator places photographs of the facade in the instrument and views them as a three dimensional image. Then an elevation drawing is made by carefully tracing the detail of the stonework, cracks, doors, arches, or architecture. The stereoplotter is linked to a personal computer running a CAD software program which captures the digitized data in a computer file. From the computer file the drawing can then be printed on paper or the file can be modified with the addition of layers of field information from a number of specialists including architects, engineers or archaeologists and then printed at some future time to include their additional specifications.

Stereoplotters, made by companies with long experience such as Leica, International Imaging Systems, Adam and Officine Galileo Digicart, can provide drawings to match the skill of the best operators.

4. Other systems

Convergent line or point-by-point photogrammetry systems such as Fotomass, Rolleimetric, Leica's Elkovision, and PhotoModeler do not use stereo photos, but rather photos of the subject taken from a variety of angles. While it is not absolutely essential, it is generally recommended that control targets be surveyed for dimensional control as is required for stereo-photogrammetry. The photos are taken with a partial-metric camera, and enlarged and printed. Subject matter of interest in the print is then measured on a digitizing board with a cursor by hand, point-by-point, and the software, running on a desk top computer, then generates a three dimensional drawing. This

approach has never replaced stereo-photogrammetry, but does provide an excellent supplement where plain and uncomplicated elevations are required.

Softcopy systems have been developed by many of the same companies that have been involved in the production of traditional photogrammetric equipment such as Leica, Intergraph and Zeiss. But, newcomers such as DAT/EM Systems have entered this expanding field and provide equally as sophisticated equipment. These systems allow the operator to trace an image in a manner similar to that of a stereoplotter, but the digitized stereo photos are viewed on a video monitor in 3-D. Another advantage of digitized images is that they can be enhanced or processed in a number of ways by software or linked to create a single seamless image from many photos. Digitized images taken directly from a camera and entered into a software drawing program are not in common use to date, but within a few years these images will replace film, and all the darkroom work that is associated with it.

A new generation of surveying instruments complements advances in close-range photogrammetry. For example Leica's Wild DIOR 3002S theodolite is a reflector free distance measuring instrument. It allows difficult subjects such as facades on the narrow canals of Venice to be measured where reflecting targets cannot easily be placed, and even at extreme angles and distances. The distance, angle and elevation of points on a facade are recorded using an attached portable field computer, and software programs can provide the user with real time three dimensional drawings of the object surveyed. With this new theodolite system the operator uses the laser dot seen on the facade to draw a simple elevation by tracing architectural elements while viewing the dot through the theodolite telescope. Because the distances, angles and elevations read by the theodolite are transformed into measurements by the instrument in real time and the laser system requires no survey targets, structures such as churches and mosques with very high interiors can be surveyed easily, and structures subject to deformation such a bridges and bell towers, like those found in Venice, can be monitored for change.

III. Synopsis of field observations and local resources

An important segment of this study was to attain what archaeologists call "ground truth." Ground truth in Venice entailed making observations of the canals, streets, bridges, outdoor art and architecture on foot and by water. Priorities were set before hand to facilitate the field work and to eliminate those locations considered of lesser importance.

In 1992, a program to renovate canals was developed by the City of Venice, and then published under the title "la manutenzione urbana della citt' di Venezia" in 1993. As part of the plan, priorities were set for a sequence of renovations with the most important areas designated 1st priority. Early on in this study a meeting was arranged by Carrera with the public works director for the city of Venice and a coordinator for the canal renovation project, Ing. Giovanni Sandri, to acquaint him and his staff with our project objectives, determine the work schedule for canal renovation, and to understand his requirements as a potential user of photogrammetric recording.

Venice, Italy. Courtesy of Google Maps, 2015.

A. Observations

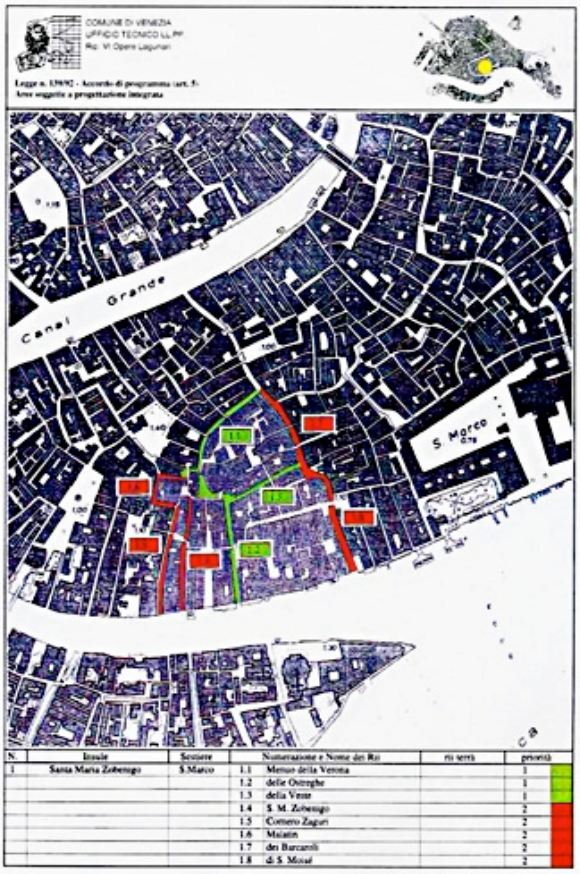
Detailed observations on foot and from a boat were made to assess: 1) the condition of fabric of selected buildings facing canals, 2) the general condition of canal walls above water, 3) locations for surveying instruments and photogrammetric cameras, 4) the width of canals, and 5) the approximate height of buildings along canals in the four 1st priority areas listed below.

1. First priority areas:

1) Insula Santa Maria Zobenigo
2) Insula Santa Maria Formosa
3) Insula San Zaccaria
4) Insula Ghetto-Chiovere

a) Insula of Santa Maria Zobenigo

In addition to field notes and measurements, non-metric 35mm stereo photos were taken of all canals



Insula of Santa Maria Zobenigo

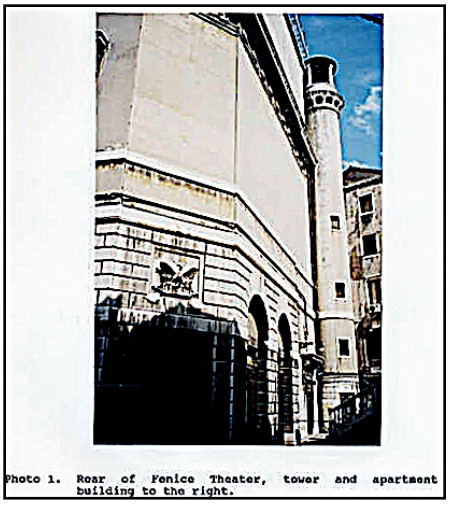


Photo 1. Rear of Fenice Theater, tower and apartment building to the right.

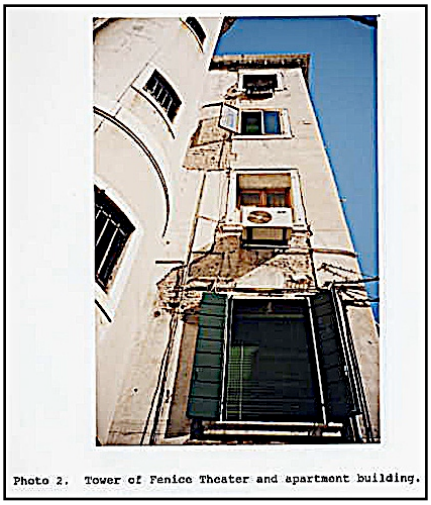


Photo 2. Tower of Fenice Theater and apartment building.

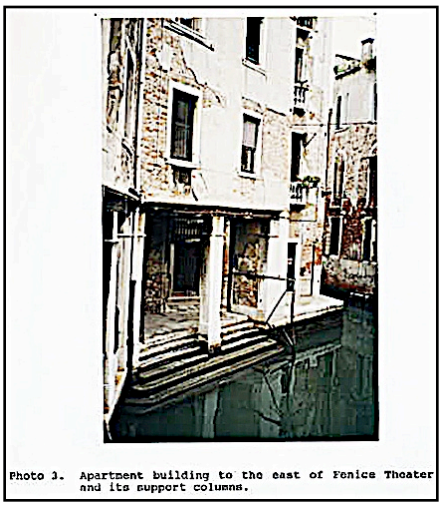


Photo 3. Apartment building to the east of Fenice Theater and its support columns.

of the Insula of Santa Maria Zobenigo , and in other first priority insule of special interest, from crossing locations such as bridges or other vantage points. The field study focused on the area of Santa Maria Zobenigo because it is scheduled first for renovation, historically important and is representative of challenges to photogrammetry found in other areas of Venice.

The Insula of Santa Maria Zobenigo has about 1.3 kilometers of canals and includes the following rii: 1) Menuo o della Verona, 2) delle Ostreghe, 3) della Veste, 4) S.M. Zobenigo, 5) Corner-Zaguri, 6) rio Malatin, 7) dei Barcaroli, and 8) di S. Moisè.

Photo 4. Apartment building to the east of Fenice Theater.

The condition of the canal walls and other architectural features to the rear of the Fenice Theater were of particular interest because of the unusual height of the theater (approximately five stories), and the five story apartment building adjoining to the east (Photo 1). Both put more weight on their foundations and canal walls than other buildings in Venice which usually average only three to four stories in height. This area is also architecturally complicated with new buildings, renovated buildings and very old buildings side-by-side, and at various levels of conservation. Several canals meet here, there are numerous bridges, and heavy power boat and gondola traffic.

While this is not a study of structural defects in buildings, obvious cracks in the fabric of the apartment building and at the base of its load bearing columns and buttress, and cracks in the base of the Fenice Theater tower signal a strong reason to monitor this area when canal renovation takes place (Photos 2, 3, and 4).

Specifically, a number of large cracks were observed in the bottom three meters of the Fenice Theater tower, and also in the step at the base of the tower (Photos 5, 6, and 7). This tower is not free standing, but is built into the theater on the southeast side and abuts the five story apartment building east of the theater. Some older cracks have been covered cosmetically, but a small piece of what appears to be recently sheared building material from the upper corner of the tower door, right side, may indicate structural change or deterioration of building material (Photo 8).

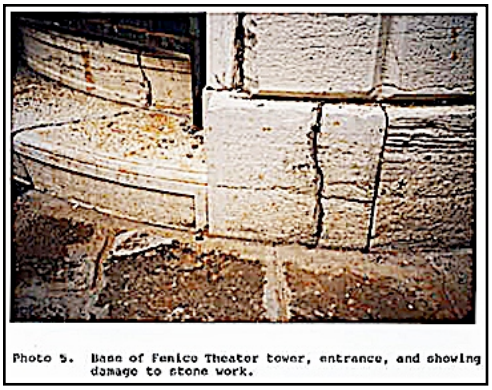


Photo 5. Base of Fenice Theater tower, entrance, and showing damage to stone work.

Photo 6. Entrance to Fenice Theater showing damage to stone work.

Photo 7. Tower of Fenice Theater and apartment building. Cracks are noted in the window area.

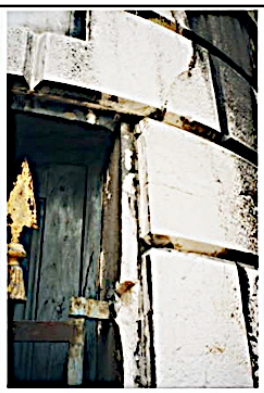


Photo 8. Door of Fenice Theater, right side, showing crack in upper right corner and loss of building material on lower right side of door edge.

Photo 9. Damage to base of column of apartment building.

Photo 10. Apartment building buttress.

Photo 11. Building at the intersection of Rio delle Veste and Rio dalle Ostreghe showing deterioration of building fabric. This is an area of high boat traffic.

Photo 12. Corner of rio Menuo and della Verona (east side) showing cracks and other damage to fabric of building.

Photo 13. Corner of rio Menuo and della Verona (south side) showing cracks and other damage to fabric of building.

Cracks were also observed at the base of several of the columns which support a portion of the five story apartment (Photo 9), and in the very tall buttress adjacent to rio della Veste where rio delle Ostreghe joins it (Photo 10). Further inspection revealed a number of other buildings in the area with cracks and fabric deterioration evidenced by

Photo 14. Canal area to rear of Fenice Theater viewed to the east with walk ways, theater on the left, and five story apartment building beyond bridge.

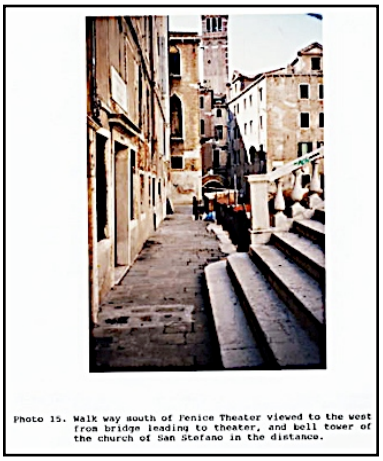


Photo 15. Walk way south of Fenice Theater viewed to the west from bridge leading to theater, and bell tower of the church of San Stefano in the distance.

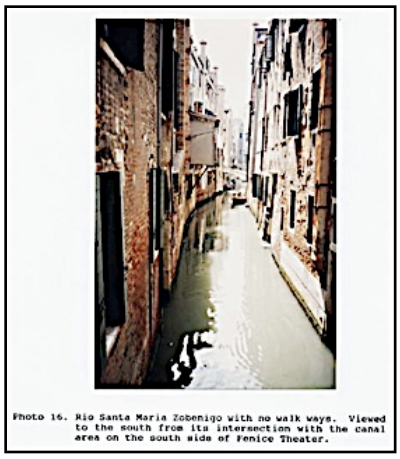


Photo 16. Rio Santa Maria Zobenigo with no walk ways. Viewed to the south from its intersection with the canal area on the south side of Fenice Theater.

broken or missing bricks near where the walls of canals and building facades meet (Photos 11, 12, and 13). These buildings might benefit from monitoring with a surveying instrument and photogrammetry, and an analytical inspection by structural engineers and architects before canal renovation is begun.

The south wall of the Fenice Theater and the apartment building north of the walk way on the south side of the canal can be recorded photogrammetrically with little difficulty because of the many good locations for a camera and surveying instrument (Photos 14 and 15). Building facades on the south side present a more difficult problem because the walk way is not wide enough for useful camera angles, but there are potential locations across the canal on the north side.

The other canals in this insula present varying degrees of difficulty for documentation. For example, rio della Verona east of the Verona bridge, does have a walk way on one side, but most other canals, like rio Santa Maria Zobenigo south of the Fenice area, have no walk ways (Photo 16). None of the canals have the convenience of a walk way

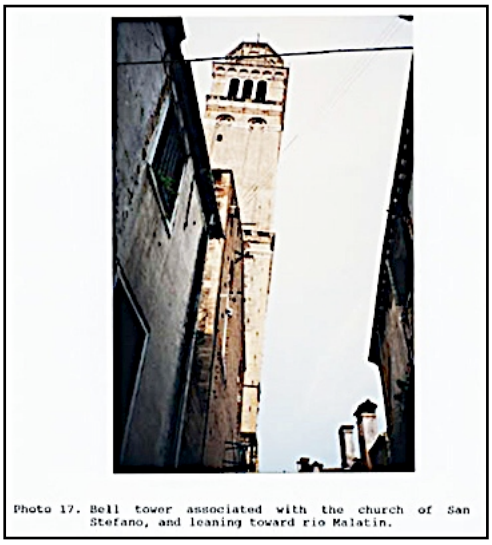


Photo 17. Bell tower associated with the church of San Stefano, and leaning toward rio Malatin.

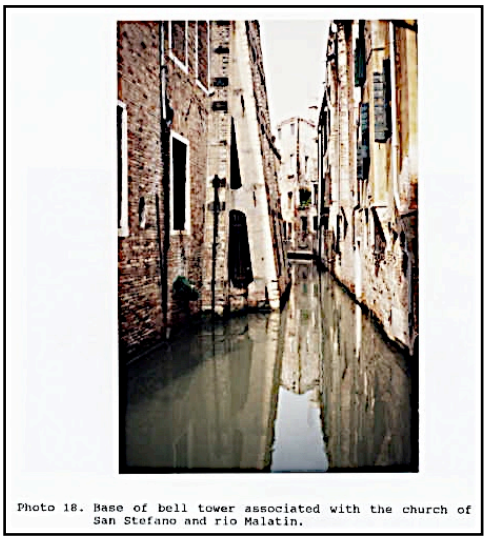
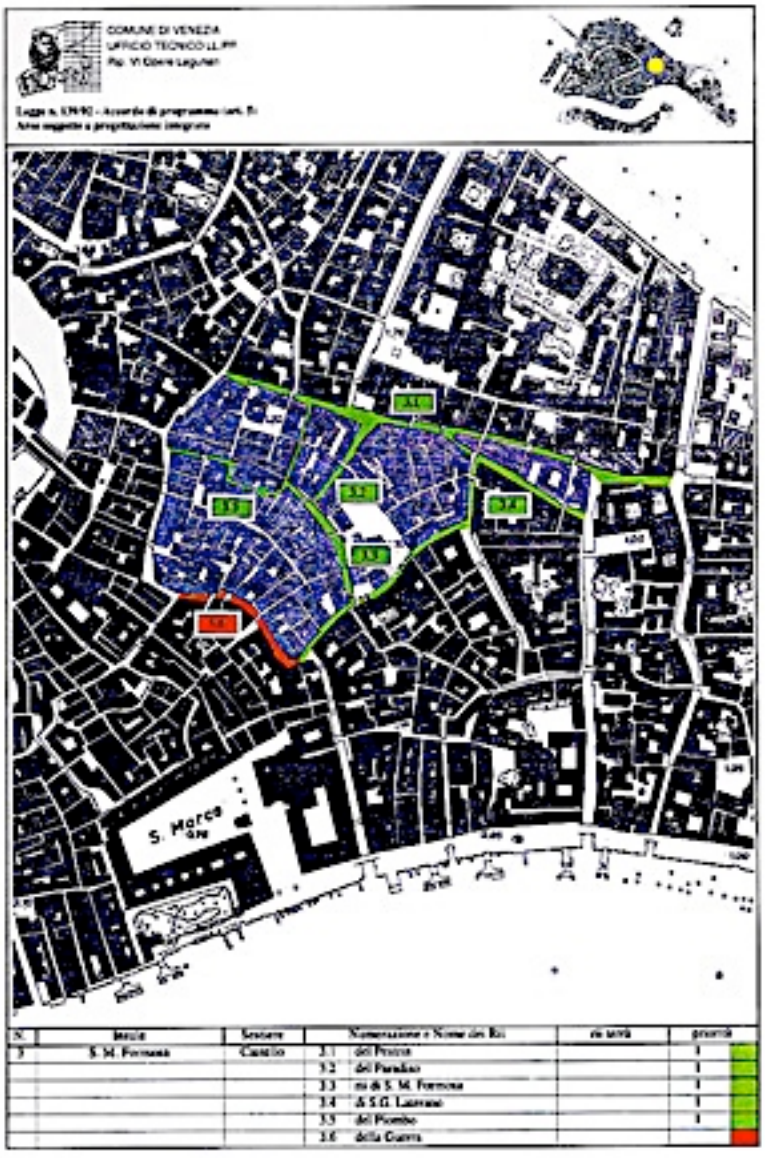


Photo 18. Base of bell tower associated with the church of San Stefano and rio Malatin.

on both sides so methods and equipment would have to be devised to find or create convenient camera and survey instrument platforms. In general, this important area does not present any insurmountable problems for photogrammetric recording.

The bell tower that is associated with the church of San Stefano and fronts on rio Malatin, leans in the direction of the canal (Photos 17 and 18). And, while rio Malatin is of second priority, it is important that a plan for monitoring of the tower be developed prior to any work carried out on the canal.

b) Insula of Santa Maria Formosa



Insula of Santa Maria Formosa

Within the Insula of Santa Maria Formosa, the Campiello Querini Stampalia area is considered an area of architectural importance because of its unusual setting with four

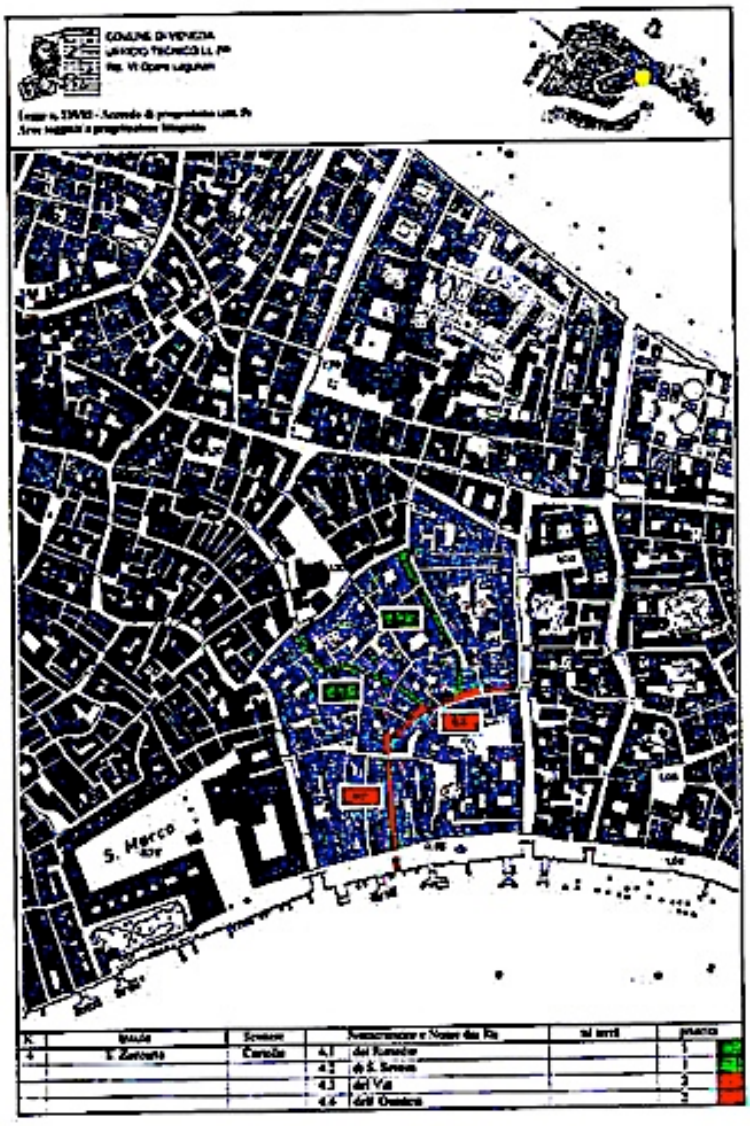
Photo 19. The historic Campiello Querini Stampalia of the Insula of Santa Maria Formosa with its four bridges and boat traffic.

Photo 20. Rio del Rimendio or rio de S. Zaninovo with walk way on west side viewed to the south from the west bridge in the Campiello Querini Stampalia area.

bridges in close proximity (Photo 19). It should receive photogrammetric recording because of high boat traffic which is likely to increase deterioration of the canal walls. The recording of buildings and bridges in this unique area would not be difficult because of the many convenient instrument and camera platforms.

c) Insula of San Zaccaria

Joining rio Santa Maria Formosa from the south is rio del Rimendio or rio de S. Zaninovo, and to the east is rio di San Severo in the historic Insula San Zaccaria area. Rio dei Rimendio has a walk way on the west side for the first part south of Campiello Querini Stampalia (Photo 20), but the balance of the canal to rio dell' Osmarin has no walk ways. Rio di San Severo has a walk way on the east side for most of its length providing an instrument platform for recording of west side facades and canal walls.



Insula of San Zaccaria

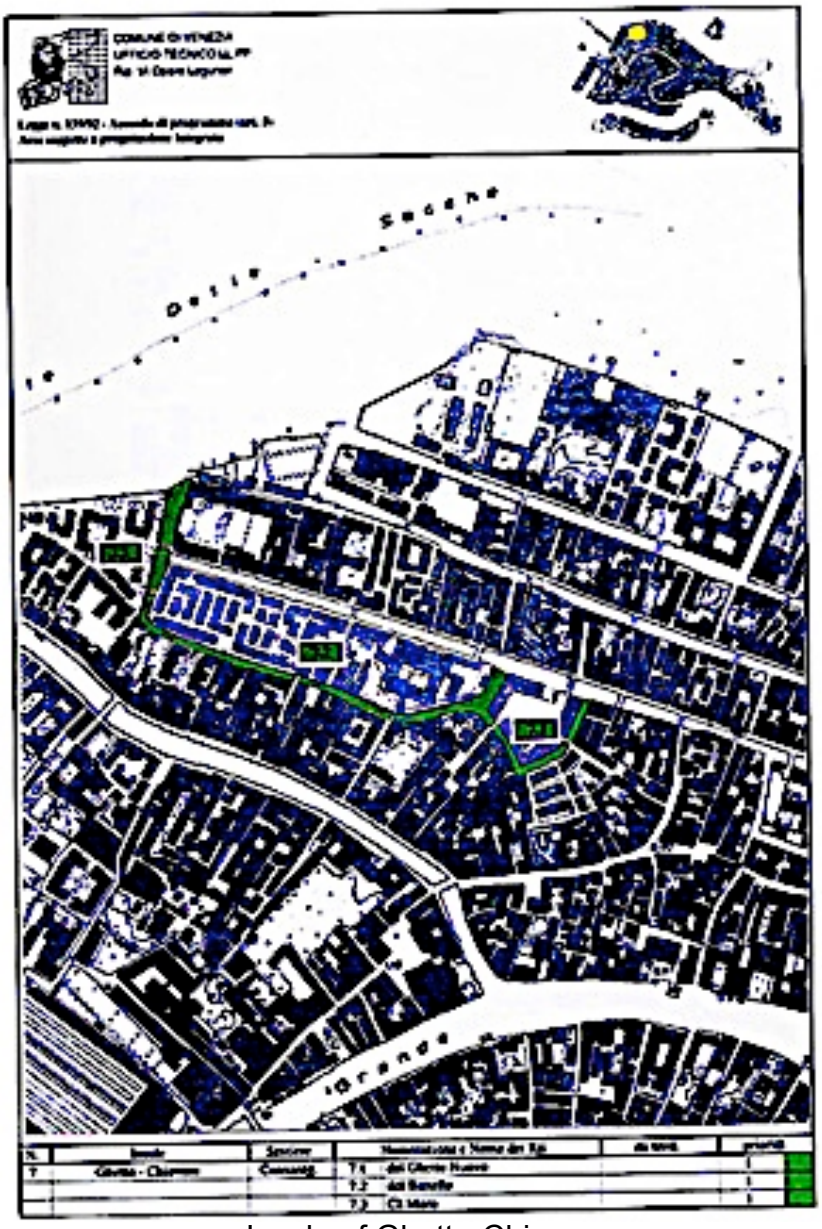
d) Insula of Ghetto-Chiovere

The Insula of Ghetto-Chiovere is internationally important because the Ghetto has a deep history as a center of Jewish culture. This area presents no difficulties for photo-grammetric recording beyond those noted in other insule.

2. Other areas

While not first priority areas, the following locations were also considered important and were inspected.

1) Rio dei Greci
2) Canale di Cannaregio
3) Canale dell' Arsenale
4) Rio della Pietà
5) Rio di Santa Caterina (west from the Gesuiti bridge)
6) Rio di Sant' Andrea (west from the Sartori bridge)
7) Murano. Building the east side of rio dei Vetrai about 100 meters from the south entrance.

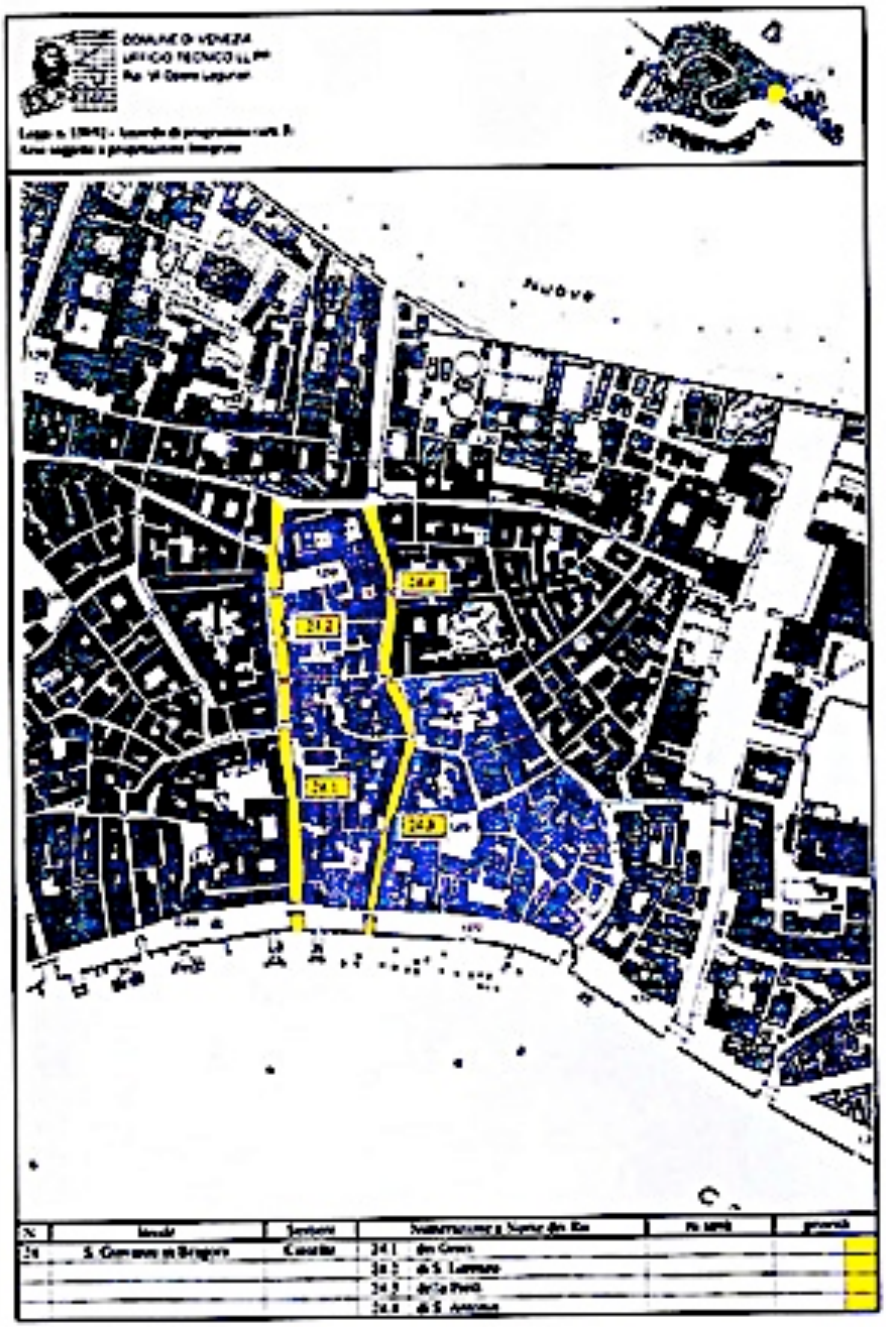


Insula of Ghetto-Chiovere

a) Rio dei Greci

The bell tower of the Greek Church adjacent rio dei Greci is out of plumb in a westerly direction (Photo 21), and the small structure attached to the base of the bell tower in the church yard leans in another direction which may indicate an unstable sub-surface. The upper edge of the canal wall next to the tower appears to be lower than to the north which may indicate subsidence of the area (Photo 22). If renovation of rio dei Greci is carried out, careful monitoring of the tower should be planned.

b) Canale di Cannaregio



Canale di Cannaregio

On the south side of Canale di Cannaregio, free standing attached buildings numbered 554 and 555 are a good subject for future testing of long distance cross canal photogrammetry recording (Photo 23). The walk way on the north side of the canal is an excellent platform for survey instruments and photography.

Photo 23. Canale Cannaregio with buildings 554 and 555. These buildings would be a good subject for testing of cross-canal photogrammetric documentation.

c) Canale dell' Arsenale

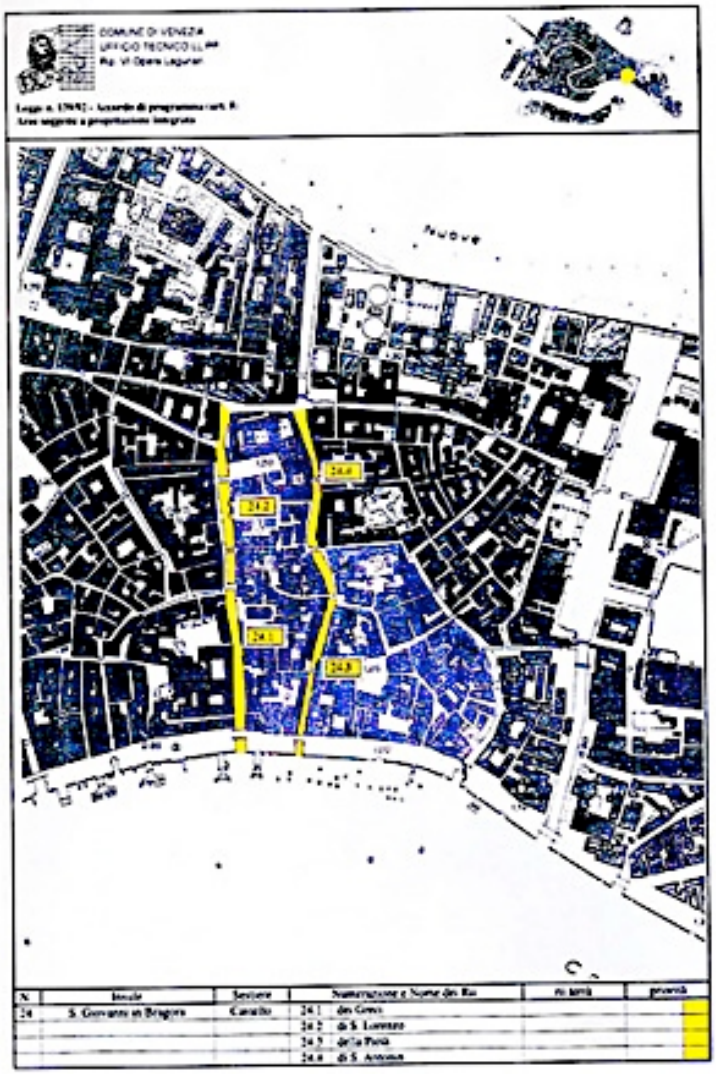
Canale dell' Arsenale

The Canale dell' Arsenale is a third priority area for renovation, but it does provide excellent platforms for photogrammetric instrumentation. The buildings on the west side of the canal, about 100 meters from the Becino di S. Marco, have visible damage to their walls near the interface of the walls with the canal (Photos 24 and 25). Damage will probably continue due to heavy public transportation (ACTV) and other power boat traffic.

Photo 24. Canale dell' Arsenale, viewed to the west, showing damage to brick work on lower part of buildings about 100 meters from the Becino di S. Marco.

Photo 25. Canale dell' Arsenale. Close-up of damaged area of building shown in Photo 24.

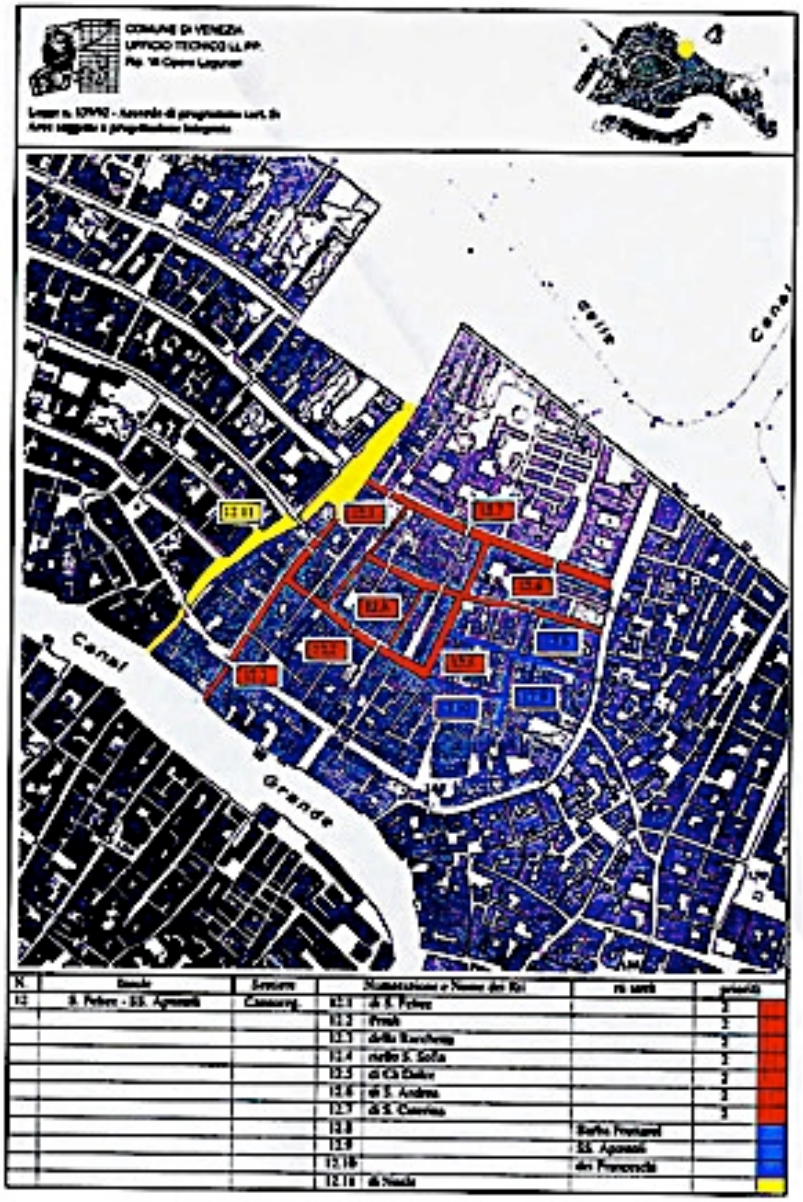
d) Rio della Pietà



Rio della Pietà

The fabric of the residential building on the east side of rio della Pietà, about 50 meters from the Grand Canal, appears badly damaged and the canal has been closed at the first bridge to the north to reduce boat traffic. Monitoring of this building with a surveying instrument and photogrammetry should have a high priority when renovation of the canal is carried out.

e) Rio di Santa Caterina and rio di Sant' Andrea



Rio di Santa Caterina and rio di Sant' Andrea

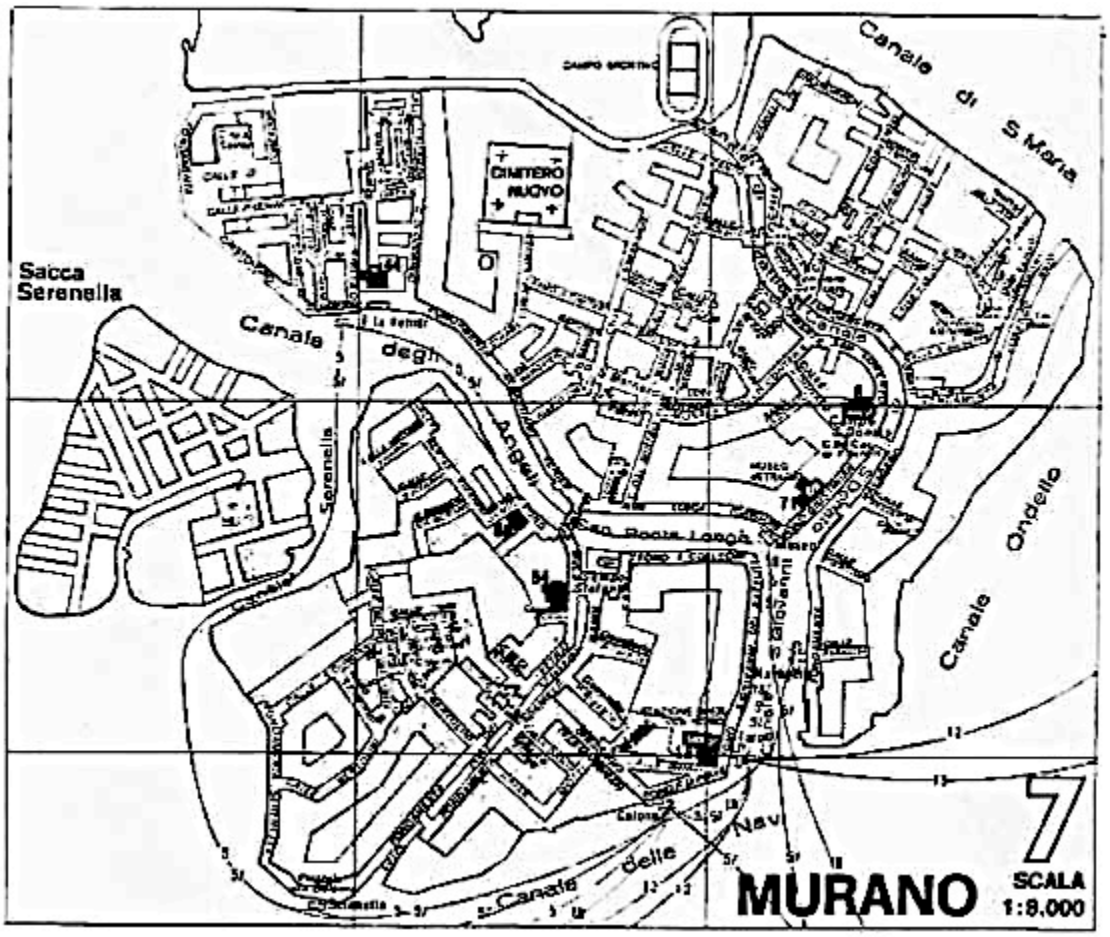
The south sides of canals S. Caterina and S. Andrea (second priority) in the north of the city, near the Jesuit church, are convenient subjects for photogrammetric recording with walk ways on the north side of each canal along good portions of their

Photo 26. Rio di Sant' Andrea viewed to the west from the Sartori bridge with walkway on the north side.

Photo 27. Fabric of residence on the south side of rio di Sant' Andrea undergoing repair.

lengths. About 20 meters west of the Sartori bridge, on the south side of rio di S. Andrea, the brick work of a building facing the canale is undergoing repair and the wall is being plastered (Photos 26 and 27). A lack of platforms for survey and photographic equipment present typical difficulties for recording of buildings on the north side of these canals.

f) Murano



The city of Venice is not alone in having damaged canal-side architecture. A survey of Murano quickly revealed one building under repair about 100 meters north of the south entrance, east side, of the rio dei Vetrai (Photo 28). Work is underway to stabilize the structure, and there are probably other buildings of historical importance on Murano that are damaged in more subtle ways.

Photo 28. Murano. Building on east side of rio dei Vetrai about 100 meters from south entrance showing extensive deterioration.

B. Local resources

1. Photogrammetry laboratory

The photogrammetry laboratory of the University of Venice, Institute of Architecture has up-to-date photogrammetry equipment including a Rollei Model 6006 medium format partial metric camera, surveying instruments, a Calcomp drawing plotter, Officine Galileo Digicart stereoplotter for 3-D image plotting, and a complete Rolleimetric convergent line photogrammetry system for making point-by-point generated line drawings (Photo 29). Support equipment includes 486, 66 Mhz personal computers, 19 inch color monitors, photogrammetry and computer assisted drafting (CAD) software, and digitizing boards.

Prof. Clemente di Thiene who is responsible for the laboratory has carried out a number of photogrammetric studies in Venice, and his recently completed survey of the topography of San Marco plaza is of great importance to flood

Photo 29. The photogrammetry laboratory of the University of Venice Institute of Architecture. Shown is the hardware used in the convergent line Rolleimetric system including a digitizing board with mouse and photos in place, color monitor, and keyboard.

control managers who are concerned about the volume of lagoon water entering the plaza during high water.

2. Centro Previsioni e Segnalazioni Maree

A meeting with Ing. Paolo Canestrelli, coordinator of the Centro Previsioni e Segnalazioni Maree for the city of Venice, was arranged by Carrera. This important office tracks the tides and climatological factors such as wind strength and direction, storms, and the condition of the Adriatic Sea. These data provide a basis for predictions of water levels in the city and, if needed, warning sirens in various parts of the city are activated from this office when the water level reaches predetermined heights. The warnings are intended to protect the citizens of Venice, but also to allow time for protection of important monuments and works of art. Little can be done to stop the high water levels without gates at the entrances to the sea, but photogrammetric documentation can provide a baseline of survey data on monuments which might be damaged or made unstable by high water.

IV. Conclusions and Recommendations

A. Conclusions

Photogrammetric recording of buildings and canals was found to be feasible in all areas of Venice inspected for this study. And, while some canals provide few platforms for photography and surveying, innovative solutions to those problems can be developed (Photos 30 and 31). For example, a telescopic camera lift fitted to a barge would be sufficient as a platform for photography. The same barge fitted with retractable legs to reach the shallow canal bottom could act as a stable platform for a surveying instrument. Building heights are ideal (averaging 12.5 meters), and the narrowness of the canals (8-15 meters) presents no technical problems for surveying or photography.

While this study has focused on the areas scheduled for renovation, it should be kept in mind that photogrammetric recording in, or out of the canal areas requires the same

Photo 30. Doorways as potential instrument platforms on the north side of rio della Verona as viewed from the Ponte de la Malvasia Vecchia.

Photo 31. Boat landing under the Ponte de la Malvasia Vecchia, south side of rio della Verona, as a potential instrument platform. New laser theodolites can be used effectively in very constricted locations such as shown in this photo and Photo 30.

basic techniques with similar time requirements. Recording from barges may not necessarily be more time consuming that working in the streets and plazas of Venice, but the task of recording and producing drawings of all facades in a renovation area is a large one.

For example, to take the needed 3,600 photographs for stereo-photogrammetry coverage using a medium format metric camera (6x6 cm negative), and survey control targets on all facades of the canals of the Insula of Santa Maria Zobenigo would require two persons approximately 30 days. A larger, or smaller format camera would alter the coverage, the number of photos, and the field time requirements. If 1:20 scale drawings are made of each facade, four stereoplotter operators would take about one year to complete drawings for all of the Insula of Santa Maria Zobenigo.

As was mentioned previously, photogrammetric projects have been carried out in Venice by a number of specialists and researchers including Prof. Clemente di Thiene of the University of Venice's Institute of Architecture.

The question is not whether photogrammetry can be used to document architecture in Venice, that has been answered in the affirmative, but which photogrammetric system or systems best fit the needs of the users? The question is a complex one for both users and specialists to resolve, and is especially important because the system adopted must face the test of time where future technology may find additional uses for data gathered today. An example of this type of advance, albeit tangential, is English Heritage's use of stereo-photogrammetric data from Stonehenge for a virtual reality exhibit in their new visitor center. Clearly, users must be part of the process of photogrammetric documentation, and resources need to be made available so that they can determine which system best fits their needs.

In another example, the public works department of Venice under the direction of Ing. Sandri has expressed a great deal of interest in photogrammetric recording because the department, for legal and preservation reasons, needs an accurate record of buildings along canals prior to renovation. The condition of each facade would be recorded before and after work, and should structural or fabric problems develop in association with the canal renovation program very precise photogrammetric data would be available to assess the original condition of the building and measure the extent of new damage. Presumably, the photogrammetric survey carried out on behalf of the public works department would also have to stand up in a court of law. And, while the city of Venice public works and legal departments have some understanding of the products and methods of photogrammetry, it may not be thorough enough at this time for them to make an educated decision as to which system best meets their needs. A good understanding of the systems is especially important if legal issues are involved.

Other potential users of photogrammetry in Venice should be mentioned such as architects, conservators, contractors, engineers, university researchers, art historians, urban planners and archaeologists--to name the obvious. Thus, users with projects to be carried out in any of the Venice environments must understand what the different systems offer, and then decide which system best satisfies their requirements from both a technical and financial standpoint.

Not only are the requirements of special interest users important, but international preservation organizations with very broad objectives such as the U.S. National Park Service's National Center for Preservation Technology and Training (NCPTT), the Getty

Conservation Institute, UNESCO, and ICOMOS must understand and be guided by knowledge of different photogrammetric systems, their costs, and how they are applied in Venice.

The Committee for Architectural Photogrammetry, in its 1981 report Optimum practice in architectural photogrammetry surveys, made the following statement on the importance of user requirements in determining how a particular building survey should be carried out.

In the work of determining the optimum conditions for the making of architectural photogrammetry surveys, overwhelming importance attaches to the way such surveys are envisaged, programmed and organized...a survey must provide knowledge of the effective form of the building at a given moment and measurement of that form, so that its current state may be diagnosed and its architecture may be analyzed. However, this common basic conception may and does lead in practice to widely differing applications according to the purpose of the
survey; according, that is, to the requirements of its user, which will determine its intended degree of accuracy, its scale, its degree of completeness and its manner of expression.

B. Recommendations

1. Monitoring of selected structures

As Ing. Sandri pointed out, the draining of canals, as part of the renovation process, may pose a threat to the structural integrity of some buildings situated next to canals. Field examination in this study indicated that the following structures should be closely monitored to detect change when adjacent canals are renovated: the Fenice Theater, its tower, and the five story apartment building to the east, the bell tower of the Greek Church adjacent rio dei Greci, the bell tower of the church of San Stefano that fronts on rio Malatin, and the residential building on the east side of rio della PietB (about 50 meters from the Grand Canal).

Structures should be recorded and monitored using stereo-photogrammetry, and a total station surveying instrument so that the condition of the fabric of the buildings can be documented to provide the graphical and mathematical data needed for analysis by structural engineers, conservators, and the public works department of Venice.

The area of the Fenice Theater and apartment building, the bell towers of San Stefano and the Greek Church can all be recorded or monitored with little difficulty because of convenient locations for instruments. The residential building on the east side of rio della Pieta does not have easy access for instruments, but that may be solved by working from the bridge area to the north, or within, or on the roofs of adjacent buildings. Because recording is limited, and in areas where camera and theodolite platforms are available, there would be no need to design and construct a special platform for use in the canals.

To carry out monitoring, permanent surveying markers must be placed in the walk ways or other secure locations. This requires no more than driving a thin steel bar into the walk way so that the surveying instrument can be returned to that same exact location. In addition, survey targets are placed on the buildings and remain there during

the monitoring project, but targets can be eliminated, in some cases, by using a laser surveying instrument which measures the location of architectural features.

The survey of a building also provides the three dimensional coordinates needed by stereo-photogrammetry to measure photos for making architectural drawings. Camera locations need only be approximate each time a building is recorded. Thus, once a building is surveyed, to record it with a calibrated camera takes little added time, and provides an enormous amount of additional visual and analytical documentation.

The use of stereo-photogrammetry under these circumstances is based on the assumption that this system, considered a standard of the industry, can conform to the most stringent of user requirements. Stereo-photogrammetry is the system used by English Heritage and The General Inventory of Monuments of France, and is used for most industrial applications such as aerospace where extremes of precision are the order of the day. Other systems can provide excellent results and do have an important place in architectural recording, but stereo-photogrammetry, a system well tested over time, offers the user an approach that can meet all reasonable standards and can produce drawings from intricate to simple tracings.

In addition to technical considerations, it should be noted that the budgetary constraints of users such as the public works department of Venice, the City of Venice legal department or the Venice Inner Canals Project must be taken into account. The recording of an individual facade, typical of those along canals, including field work and the making of an architectural drawing at a 1:20 scale could cost as much as $8,000 if done by an international photogrammetry team. But, costs can be reduced by employing local surveyors and photographers familiar with photogrammetric methodology, and by producing a drawing of part of a facade. A local resource, the photogrammetric laboratory of the University of Venice's Institute of Architecture, indicated it would be willing to discuss further the possibility of collaboration in a recording and monitoring project.

An additional advantage of local collaboration is that a group such as the Institute of Architecture's photogrammetry laboratory, and the Venice Inner Canals Project can work closely with the City of Venice to provide systems information and incorporate the requirements of the city into this project which is limited to a few structures. It would not be advisable to initiate a complete survey of canal renovation areas until the department of public works has added understanding of available photogrammetric systems.

This leads us again to the important point that a system should fit the user, and a user must understand the capabilities of different photogrammetry systems to be able to make a proper selection. But, it is not only the system that needs to be understood in this complex selection process, it is the parameters within a system that need also to be known. To paraphrase Carbonnell, we need input from the user to determine accuracy, scale, completeness of a drawing and the manner of its expression. How, then, can Venice users, such as the public works department, come to a better understanding of systems and their capabilities?

2. Photogrammetric pilot studies and platform design

The Inner Canals Project has carried out scientific projects in Venice over a number of years, and is in a position administer close-range photogrammetry pilot studies made in the Venice environment. Technical reports, articles and standards on photogrammetry are important, but relatively useless to non-specialists. The pilot studies recommended here would be designed provide an in-depth examination of systems for utilization by non-specialist users of photogrammetry.

Four photogrammetric systems, and a Leica Wild DIOR 3002S (or equivalent) total station theodolite with real time drawing capability should be examined in the pilot studies. One facade should be selected for study in the Insula of Santa Maria Zobenigo near the Fenice Theater where walk ways provide adequate room for instruments. The following systems would be tested: 1) stereo-photogrammetry, 2) rectified photography, 3) convergent line (point-by-point) photogrammetry, 4) softcopy photogrammetry, and 5) Leica Wild DIOR 3002S.

A report, in non-technical language, of each study would be published to include, 1) a description of the methodology used, including parameters of accuracy, types of final product expression, and potential level of detail, 2) description of field work, 3) times required to carry out individual activities, 4) equipment required in the field and laboratory, and 5) an elevation drawing at a scale of 1:20, and a scaled drawing generated by the total station theodolite based on the distance to the facade to be determined at the time of field work.

It is important that persons be selected for pilot studies who are known for their expertise in one of the systems suggested for testing. For more general project guidance, this author, Mr. Ross Dallas, Prof. Clemente di Thiene or Dr. Harrison Eiteljorg II, director of the Center for the Study of Architecture at Bryn Mawr College, represent the type of scholar with broad knowledge needed as a technical consultant to develop and review project standards, reports and drawings. Administrative requirements such as overall project management, budgetary control, publishing, editing and interface with UNESCO would be carried out through the Venice Inner Canals Project.

Once the pilot study project is completed, the Venice Inner Canals Project would act as an on-going educational and information focus for activities concerned with close-range photogrammetry. Seminars, workshops, conferences or individual consultations could be offered to disseminate information on photogrammetric systems developed through the pilot studies.

In addition, a project to design a camera and survey instrument platform for use in the canals of Venice should be included in the pilot studies program. Funding should be allocated for design only, with purchase of equipment and construction deferred to when a full monitoring and documentation project is funded.

A detailed proposal for the pilot studies and platform design project should be submitted to UNESCO through the Venice Inner Canals Project. An estimated $70,900 would be needed for technical consulting, the pilot studies, design a platform, administer the project, and provide for preparation of publication of the results. Appendix A gives a brief description of personnel and their duties, and a budget of salaries and expenses for the project.

3. A Venice colloquium on photogrammetry

Upon completion of the pilot studies and platform design project, and publication of its conclusions, a colloquium, approximately three days in length, should be organized to address issues concerning the application of close-range photogrammetry in Venice.

Such a colloquium would provide a forum for a deeper understanding of applications of close-range photogrammetry through closely focused scholarly responses to the findings of the Venice Inner Canals Project pilot studies. The colloquium would bring together in Venice, under one roof, photogrammetry specialists and users from a variety of disciplines to focus on the use of photogrammetry as part of the preservation process.

The specific purposes of the colloquium would be to, 1) develop a broad understanding of photogrammetric systems for use in Venice, 2) generate cross-disciplinary scholarly feedback on the systems tested, 3) develop a strategy for a long term photogrammetric recording program in Venice, and 4) develop a strategy for long term funding.

The invitees would include members of the International Committee for Architectural Photogrammetry (CIPA), surveyors with practical and theoretical knowledge of advanced surveying systems, specialists in the measured survey of historic buildings, building conservators including engineers, academics working on conservation projects in Venice such as art historians, biologists, chemists and engineers, architects, contractors, archivists, and representatives of international funding and conservation organizations. Prior to the colloquium the written reports of the pilot studies would be sent to each participant.

A selected number of participants would be asked to prepare papers in response to the pilot study reports, and an open discussion would be scheduled after each formal response. Discussions would be recorded and later transcribed for publication along with written papers. Other colloquium papers, not in direct response to the pilot studies, would focus on broader concerns such as future uses of Venice photogrammetric studies, archival systems for storage and retrieval of photogrammetric data, issues related to archival access, and the role of international organizations like UNESCO, ICOMOS, NCPTT and the Getty Conservation Institute in the preservation of Venice.

The proceedings of the colloquium would be published in a volume that would include papers and round table discussions, and the resolutions of the colloquium.

The colloquium should be limited to approximately forty participants in the following categories:

CIPA:..... 4
Pilot study specialists..... 7
UNESCO..... ...5
ICOMOS..... 3
International Conservation organizations.....5
Users.....16

An estimated $97,425 would be needed for organization of the colloquium which would include part-time staff, participants' transportation, food and lodging, colloquium facilities and equipment, and the editing of papers and responses for publication. Some administrative activities might be carried out through a local organization such as the Venice Inner Canals Project to facilitate organization and reduce logistical costs.

Appendix B provides a list of organizing personnel and brief descriptions of their duties, a budget of salaries and expenses for organizing personnel, and estimated expenses for the three days of the colloquium.

To develop a detailed proposal for the colloquium and its funding, an ad hoc committee, drawn from the specialties and organizations noted above, would be formed to provide expert assistance and institutional support. If UNESCO has a development officer on staff that person could work with the committee, or UNESCO could provide a small grant to a development consultant to collaborate with the committee to develop a proposal for the colloquium.

V. Acknowledgements

Quite a number of persons and institutions deserve thanks for their contribution to the success of this project. They provided an enormous amount help and advice which substantially aided the completion of this study. In the end, of course, I must take full responsibility for any errors and omissions, and the recommendations and conclusions.

First to come to mind is the support, suggestions and insights of Prof. Angelo Marzollo, UNESCO project officer in Venice. Without funding from UNESCO this project could not have been carried out--I extend my most sincere thanks.

To Fabio Carrera, who has worked intensively on historic preservation projects in Venice for many years, I would like to extend many thanks for his unceasing help and vision in the organization, development and carrying out of the project. And exceptional hospitality was always forthcoming from all the Carreras--Fabio and Jackie, and Cino who welcomed me at al Cubo. Abundant Venetian hospitality also was extended by Prof. Gerolamo Fazzini, president of the Venice section of the Archeoclub d'Italia, who made my stay on Isola del Lazzaretto Nuovo a splendid experience--with many thanks to his family and club volunteers who I shall not forget for their many kindnesses--and marvelous meals. Thanks also to Nick Eiteljorg of the Center for the Study of Architecture for his many suggestions about the pilot studies and colloquium.

Great thanks are also due to Ross Dallas for important technical advice, and taking time from his very busy building survey schedule at Hampton Court to review and discuss, in great depth, the Venice study. And, to his family including Pam and Sarah, most sincere appreciation for making my stay in York a culinary delight.

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