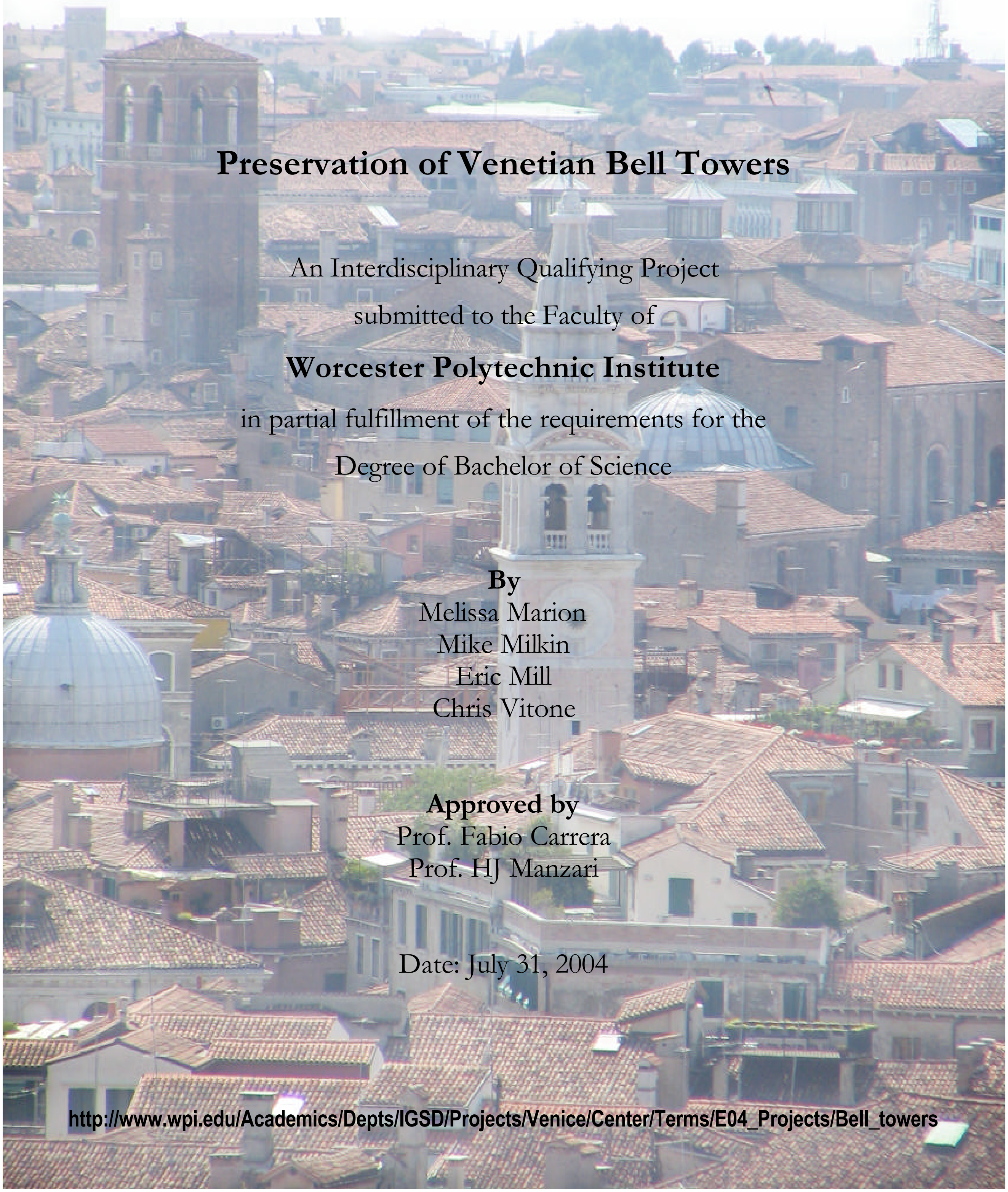
VENICE PROJECT CENTER



Preservation of Venetian Bell Towers

An Interdisciplinary Qualifying Project

submitted to the Faculty of

Worcester Polytechnic Institute

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

Melissa Marion

Mike Milkin

Eric Mill

Chris Vitone

Approved by

Prof. Fabio Carrera

Prof. HJ Manzari

Date: July 31, 2004

http://www.wpi.edu/Academics/Depts/IGSD/Projects/Venice/Center/Terms/E04_Projects/Bell_towers

Abstract

We have worked to preserve Venetian bell towers by improving the method for cataloging and analyzing the towers. We investigated the feasibility and benefits of expanding the methodology to include monitoring the towers' structural integrity with specialized instruments, to give deeper insight into the state of a tower. We have standardized the process for cataloging towers by revising and finalizing the methodology for visually assessing them, and by unifying all prior bell tower work into a master database which can be easily used by all future projects. Our project will make the Venice Project Center's work on preserving bell towers vastly more efficient, organized, and focused.

Acknowledgements

We had the help of numerous individuals throughout the course of this IQP, without which we could have done nothing but stay in our apartments and play with ideas. First and foremost, Professor Fabio Carrera was tireless in getting us access to towers, arranging for permission from the church hierarchy of Venice to operate, and in general giving our project a lot of guidance. Professor H.J. Manzari also deserves recognition. He had very valuable opinions and suggestions for us when it came to our presentation and our writing. Either he or Professor Carrera came with us to each bell tower we visually assessed to make sure entrance was smooth.

Another key figure was Adriano Boccardi, who traveled two hours from Trento to meet us countless times. He taught us how to record data about bells and came to many of the towers with us to record further details and aid us if we needed it. We would like to thank architect Paolo Tocchi for showing us around the bell tower and church of San Giorgio Maggiore, and Don Antonio for allowing us access to his church's bell tower. Without Don Aldo Marangoni, we would not have had permission to enter many of the bell towers we visually assessed, and we thank him for his support.

Table of Contents

List of Tables

List of Figures

1 Introduction

Since the fall of the Republic of Venice, the city has preserved some aspects of its culture and neglected others. Because of the high tourist economy, much of its focus has been on maintaining outward appearances, and Venice has tended to ignore various parts of its architectural infrastructure. By putting so much expense and energy into preserving the immediate and interactive cultural elements of the city, less resources and motivation are left for the distant, secluded, and private, leading to large scale neglect. Venice is risking the decay of various parts of its body, most of which are not being paid much attention, and thus the danger and potential loss won't be known until it is too late.

Venetian bell towers are an example of a part of Venice which is being neglected to a dangerous level. In the past, bells were rung frequently, to call people to mass, celebrate national events and holidays, even just to keep time. There is at least one bell tower in every neighborhood and typically, the citizens look upon their local bell tower with great pride. Bell towers are a symbol of unity for both small regions, and the city as a whole; Saint Mark's bell tower is viewed as an icon of all of Venice. Now, they are simply high above the tourists in the streets, closed to the public, and expensive to maintain. They are unprofitable, making it unappealing for the city to take care of. They have been neglected to the point where many bell towers simply no longer ring, and many more ring substantially less often than they once did. Even when care has been given to restore the outer walls of a tower, often the inside is left effectively untouched. They are being left behind, and are suffering heavily for it.

Without proper maintenance, the structural integrity of the towers will become compromised and there is an increased risk of the towers' collapsing, which can damage surrounding buildings and injure or kill people in the area. Several bell towers have already collapsed, including the famous bell tower of St. Mark, in 1902 (it has since been rebuilt). Besides risking damage and injury to its surroundings, bell towers are the only vertical structures in the otherwise horizontal landscape, making them a distinctive architectural aspect of the Venetian skyline, as well as the only buildings from which one can see an expansive view of the city. Their height and isolation also gives them the potential to serve other purposes if desired; for example, a prior group has determined that using bell towers as cell phone towers would be feasible. If these towers continue to be ignored, the city of Venice will surely suffer physical and cultural damage.

The Venice Project Center began studying the current state of bell towers in the Venetian lagoon in 1992, though it was a small and rather informal study. In 1994, an IQP student group developed a primary methodology for the assessment and cataloging of bell towers, and examined ten towers using it. A follow-up IQP project group in 1995 revised and enhanced the prior group's methodology, and examined an additional twenty-three towers using it. They also created a system for ranking the bell towers by need of restoration by combining the information about the general state of the tower with the determined importance of the tower. In 1995, 1996 and 1997, teams of Earthwatch volunteers helped study bell towers under the guidance of Fabio Carrera, and examined many more bell towers using the methodology designed by the 1995 IQP group. A bell towers IQP group in 2000 investigated the feasibility of using bell towers as cell phone receivers, and did partial examinations (external measurements only) of fifty-four towers. Most recently, an art historian named Adriano Boccardi specializing in Venetian bells improved the methods for cataloging technical information about bells in 2001. Unfortunately, the data accumulated by these groups has been inconsistent (due to the procedures evolving and changing under each group), and often incomplete. Additionally, this data can come in many different mediums, such as paper forms, video tapes, computer databases, and electronic maps.

We unified all data from previous projects into a master database, and standardized the data within so that useful queries to the database could be made. We also investigated the feasibility of a more technical examination of towers, using instruments designed to monitor structural integrity. We used the results of these experiments to recommend procedures for technical monitoring, as well as when it is appropriate to use them. We also cataloged several more bell towers using the existing methodology, and revised this process, making our own (and hopefully the final) modifications to the methodology. Finally, we produced a comprehensive guide to cataloging bell towers which future groups can use to continue the cataloguing of bell towers completely and efficiently.

2 Executive Summary

The Venice Project Center is working to, among other things, restore artifacts of the city's history and culture that may be otherwise lost. Bell towers have always been a staple of Venetian culture and society. They have served the community around them as a clock, as a reminder to come to mass, to celebrate major victories, and because of all this, they bring pride to the people around them. As their social necessity and importance has dwindled, so has the attention given them, and they now are starting to have visible signs of decay, and are a danger to the areas around them. Because of the cost to build and maintain them, they have even been considered a luxury and they are no longer being built when a new church is constructed. Their neglect is to the extent that not only are they in varying states of decay, but that it is not even understood which ones are in the most danger. The Venice Project Center began work in 1992 to document as much important information about bell towers as possible in an effort to understand their condition, to use this information to create a useful database for any entity that could help the bell towers of Venice, and to foster an attitude of caring for the towers to counter the trend of apathy that has brought them to this condition.

We aim to preserve Venetian bell towers by significantly revising and enhancing the current methodology for cataloging bell towers and prioritizing their need for preservation, and using this methodology to continue the work ourselves. The first way we did this was to focus on how to make more in depth studies of bell towers' structural integrity. The second was to take the scattered and varied data from past projects and unify them into a common database and format.

Prior student groups from WPI and independent groups from Earthwatch have cataloged information from the internal and external features of bell towers, and technical and general aspects of the bells inside them. They had done so using an evolving process which changed in ways both superficial and significant from group to group. Thus, their data was not congruous. The most useful database to anyone who could help preserve bell towers in Venice is one which is unified, standardized, and complete.

Upon arriving in Venice, we gathered all the past bell tower data the Venice Project Center had and set to determining the nature of all of it. We figured out what information we had about every tower in hardcopy, while simultaneously analyzing and comparing the softcopy (Access database) information that was present. We developed a master database design which could encompass all information, and merged the information together into a complete unit. Since it is intended to be used as the sole database used by any future projects involved with cataloging bell towers, further data collected using the existing methodology can be easily added to this new database.

The existing standard methodology for cataloging bell towers was reliant on a set of visual measurements that had been refined over several different groups. We aimed to further refine the visual measurements, as well as provide a more technical methodology that could be used to discern more in depth information about a tower's need for preservation. We researched what information about a bell tower's structural integrity would be valuable to understand whether preservation action is needed, and about what instruments could be used to collect this information. We decided that measuring the vibrations of the bell, the strain of the walls pulling apart at the cracks, and the wind force against the tower would be most useful and feasible. We obtained accelerometers, strain gages, and an anemometer and used them to record technical data about the tower of San Giorgio Maggiore.

Using this data, we created a procedure based off of our experience and some further recommendations that could be used to instrumentally monitor a bell tower. We also continued the cataloging of visual measurements on nine towers, including San Giorgio Maggiore. We used our experience cataloging towers to revise this methodology, and to determine what factors should be looked for in the results to recommend using our technical methodology.

With a unified system, an enhanced methodology, and the possibility of performing serious monitoring of towers' structural integrity, the work of the Venice Project Center to collect information about towers and analyze their need for restoration will be significantly improved, and will help bring more attention and effort to their preservation.

3 Background

The city of Venice contains one hundred and seven bell towers. The oldest bell tower, being on the island of Torcello, was built in the seventh century and rebuilt in the eleventh in its current location. An image of this tower is shown in Figure 1.

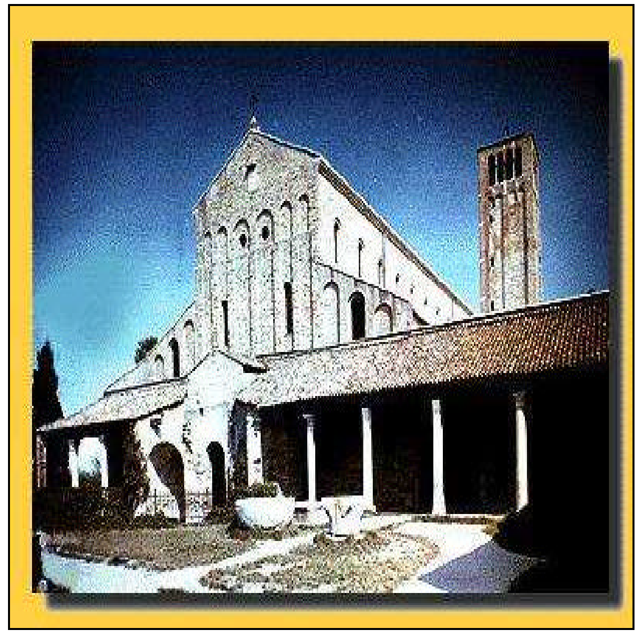


Figure 1- Santa Maria Assunta di Torcello

The newest bell tower, the bell tower of San Marco, is located in San Marco's square across from the Doge's palace. It was built in the 9th Century but then collapsed and was replaced by an exact replica in 1912. Towering at 314 ft above the piazza, the tower San Marco is by far the tallest building in Venice. This bell tower is shown in Figure 2.

Figure 2- Campanile di San Marco [1]

Venetian bell towers are a very important part of the city's history. Bell towers are some of the only tall structures in the city, which allowed them to be invaluable surveying posts during times of war. In the past, these towers have been built as a display of strength, ability, and faithfulness to God. Their purpose lay in pointing to heaven and looking forth to survey. In times of peace, the towers were rung for celebration and mourning, to mark the hours, and in correlation with the Christian festivals. In the past, Venetian bell towers were rung every hour. However, now most bell towers are rung only three times a day, if at all.

With the passage of time, it has become evident that the towers have lost their major social function on the city. Another change leading to the

[1] Rutter 22 April 2004

state of bell towers today is the installation of automatic ringing mechanisms for the bells. Years ago, bell ringing was always done manually and priests would monitor the state of their towers. Now it has become common that the bells are played automatically, and there is no reason for a bell ringer to inspect them. Since there is no bell ringer visiting the tower daily, there is no one there to monitor the towers' condition and the towers can easily fall into a state of disrepair.

Figure 3- Tower of Pavia[2]

Many are in states of disrepair and have become a nuisance and danger to the surrounding neighborhood. In fact, on March 17, 1989, the Civic Tower of Pavia collapsed. An image of the tower after collapse is shown in Figure 3.[3] This caused a lot of concern within the city of Venice. We will make it a priority to look into the monitoring of bell towers, so the city of Venice can attempt to repair them before such tragedies occur.

When researching the history of bell towers with the WPI "Urban Evolution of Venice" project group, we discovered many towers that no longer exist. Many of them were knocked down by Napoleon when he conquered Venice, though a few have collapsed on their own. Figure 4 shows a graph of all bell towers that have existed in the history of Venice. The picture shows all of the towers still standing in blue, and all of the ones that are no longer there in red.

[2] Binda 26 April 2004.
[3] Ibid., 209

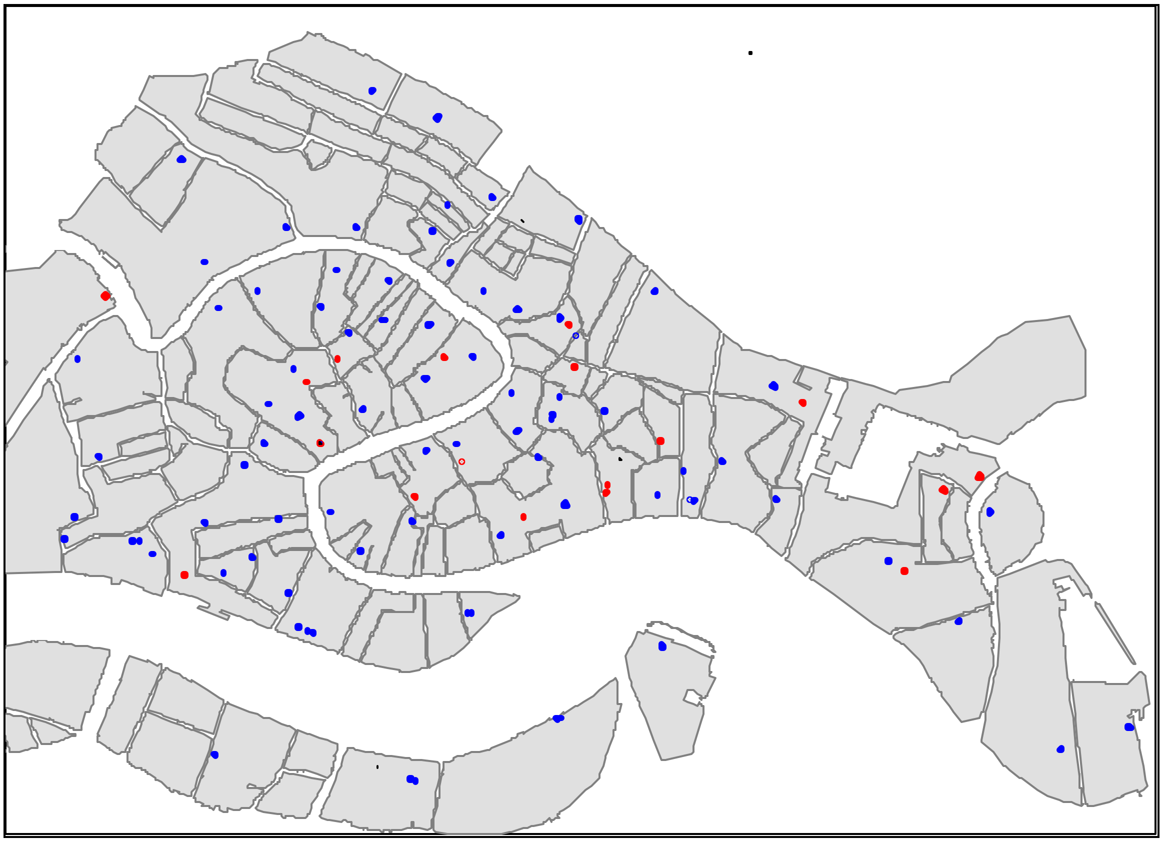


Figure 4- "Campanili_2004_collapse" Map Window

3.1 Features of Bell Towers

To evaluate a bell tower's need for restoration, it is important to have a clear understanding of the different sections of bell towers. The foundations and the ground floors of a tower are composed of heavier and thicker walls than the parts of the tower at the top, near the belfry.[4] The most important parts of a bell tower are the base, the shaft, and the belfry which are displayed in Figure 5.

The base is usually the heaviest part of the bell tower, constructed of a non-porous material that was strong enough to support the structural pressure of the tower, and is immune to submersion in salt water.

[4] Ruskin 1885 207

The shaft of a bell tower is by far the largest physical component of the tower. There are staircases and/or ramps that traverse the shaft, often with several landings on the way up. The shaft is usually constructed of brick joined by mortar.[6] The type and strength of the brick used varied based on the year the tower was erected, as brick makers improved the formula for bricks over time, allowing their products to withstand higher pressures. The properties of the bell towers' mortar also varied depending on the year the bell tower was built. In some bell towers, metal was used to add flexibility and support to the bell tower shaft.[7]

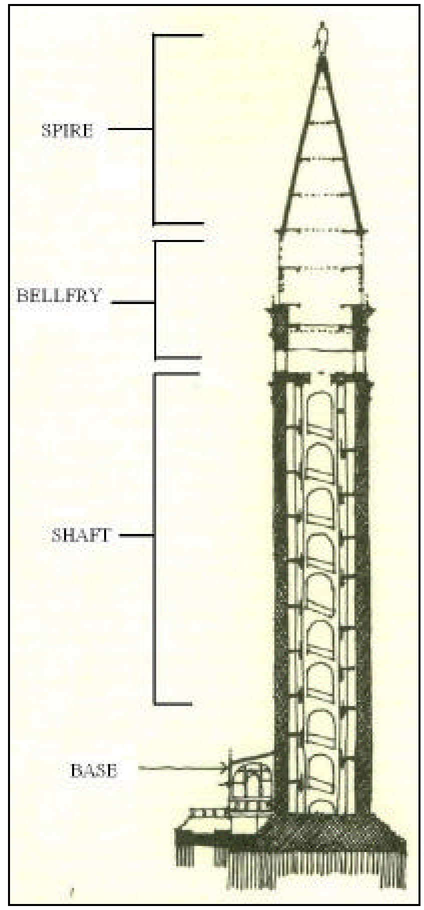


Figure 5- Diagram of Bell Tower Parts[5]

The belfry is the large open area at the top of the bell tower where the bells are hung. The belfry was often constructed using bricks, as a means of support, and in many cases featured elaborate decorations of stone or clay.[8] Generally, inside the belfry, wood was used to support the bells, but some of the more modern bell towers use metal. This adds to the deterioration of a tower, since the vibrations pass through the metal frame into the supporting brick walls.

Some bell towers have another area above the belfry called the attic, generally reachable by some kind of ladder, or possibly a stairway. The attic can have many purposes, such as storage, or providing an avenue for maintenance workers to reach the top of the tower. It also often provides access to the balustrade, a railed stone balcony that surrounds a tower, giving a beautiful view and more maintenance access.

3.2 Structural Integrity Issues

Many different forces that can potentially affect the structural integrity of bell towers. In our research, we have found three to be very important. The first two forces, the force caused by the swinging of the bells and the force from seismic activity are the most promising forces to be measured as their driving frequencies are close to the natural frequency of the towers. The third force, wind, is much less likely to be an issue due to its comparatively high frequency. These are

[5] Levy 1992 210
[6] Idem
[7] Carlson et al. 1995, 23
[8] Ruskin 1885, 208

discussed in greater detail in section 7.4, Recommendations, along with the proposed procedures for monitoring them.

3.3 Instruments for Structural Integrity Monitoring

Figure 6- Weather Station

The anemometer is a mechanism designed to measure airflow and air temperature. It measures air speed by passing air over a propeller or some type of blade. A photograph of an entire weather station is shown in Figure 6. The anemometer is the tool on the far left. Next to it is a temperature censor, and to the right of that is a rain gage. Those parts of the weather station connect into the base, shown near the bottom, which connects into a laptop and can record data to it over long periods of time.

Figure 7- Accelerometer [9]

The accelerometer, shown in Figure 7, is a device that measures acceleration. There are different kinds, but the one we are using is a black square that is affixed to the surface of the object you are measuring. When the surface moves, moving the accelerometer with it, the acceleration of this movement in Gs is calculated. A strong adhesive is necessary to affix the accelerometer is securely. Ours actually report back amounts of voltages through bare wires, and the translation to G's is accomplished on the software end, using the translation rules in the documentation provided by the accelerometer manufacturer. Other accelerometers may use different methods, but all end up calculating acceleration in G's.

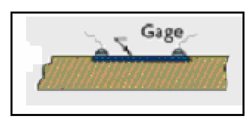


Figure 8- Strain Gage [10]

Strain gages, such as the one shown in Figure 8, are used to measure the strain an object is undergoing. Strain in an object is the force being placed on an object to be displaced or deform. The kind of strain gage we are using is a small strip of plastic and metal to be affixed to the surface to be measured. If you place a strain gage across a crack in a wall and affix it firmly, the gage will measure the force of the walls pulling apart and report back in units of strain. Again, it is actually reported back in voltages and translated with software in accordance with the manufacturer's documentation.

3.4 Past Work

Worcester Polytechnic Institute has been working for many years to help the city of Venice by collecting and categorizing data relating to the bell towers. Several of the projects relate to finding

[9] Vernier Software and Technology. 2 May 2004
[10] Omega Engineering Inc. 2 May 2004

new uses for the towers. If the towers were put to some new use, it is possible that the city of Venice would devote more time and effort into restoring and maintaining these beautiful and important structures.

One of the earliest projects sponsored by WPI's Venice Project Center relating to bell towers was the 1994 Interdisciplinary Qualifying Project, A Method for the Evaluation of Venetian Bells and Bell Towers. This was then followed by a similar project in 1995, called Computerized Catalog of Venetian Bells and Bell Towers. Their most recent project that documented Venetian bell towers was the 2000 IQP, Cellular Bell Towers, which primarily focused on finding new uses for the bell towers instead of collecting data. The Venice Project Center utilized the resources of a nonprofit organization called EarthWatch to conduct further documentation of Venetian bells and bell towers in 1995, 1996 and 1997. Most recently, in 2001, the VPC was able to obtain some data from an art historian Adriano Boccardi. With his knowledge of bells and his procedures for recording the information on them, combined with the work that had been done in prior years by student groups and EarthWatch teams have defined a reliable methodology for bell monitoring.

3.4.1 1994 WPI Project

The WPI project entitled A Method for the Evaluation of Venetian Bells and Bell Towers, written by Morillo and Rosas, focused predominantly on creating a methodology that defined a concrete set of measurements to be taken at each tower. After reviewing historic and structural writing, this project was able to develop a list of fields that thoroughly covered important aesthetic and structural elements of the tower. This project was not only concerned with the fields that need to be documented but also with the manner in which they should be recorded. They defined step-by-step procedural instructions for collecting data.

The group then went out and tested their methodology on a sample population of bell towers. From their findings they were able to make suggestions for the urgency of any restorations that needed to be completed on the bell towers they visually assessed. They were also able to prioritize the bell towers according to their "importance" and state.

3.4.2 1995 WPI Project

The 1995 WPI projcect entitled Computerized Catalog of Venetian Bells and Bell Towers, written by Carlson, Prince and Roosa, was concerned with the same issues that the 1994 project group was concerned with. This project revised and improved the methodology created in the previous year. The methodology created by this group is what defined the procedures of later projects and EarthWatch. Their methods drastically improved on those developed by the 1994 group. This group then tested their methodology on a population of eight bell towers.

They developed MapInfo layers for the towers they visited and designed a Microsoft Access database to store their data. The final goal of the project was to brainstorm and provide potential alternative uses for the aging towers. One of their suggestions was to retrofit the bell towers with fire fighting equipment and have them serve as a means to extinguish fires throughout the city. By running a water hose up through the tower, one could use them as a lookout point, and could theoretically put out any fire very quickly. Although this suggestion sounded plausible, it turned out there were a few details that this group was disappointed to find that made their proposal impossible. The salt water, as well as the velocity of the water falling from the height of the bell tower would cause more harm than good to the aging Venetian buildings.

3.4.3 EarthWatch

The EarthWatch project groups from 1995 to 1997 gathered data using the methodology provided by the 1995 WPI project. These groups are responsible for the largest part of the total internal data collected by the Venice Project Center. Since the EarthWatch groups were not focused on or responsible for providing any solution to the decline in the importance of bell towers, they were able to focus all their effort on data collection.

3.4.4 2000 WPI Project

The 2000 WPI project, Cellular Bell Towers further developed alternatives to the past uses of Venetian bell towers. The main purpose of this IQP was to explore the idea of putting cell phone receivers in some strategically selected towers throughout Venice. To develop an understanding of how practical their idea of cell towers was, they visited 54 of the bell towers in Venice and completed external measurements on them. The idea of using bell towers as cell towers was feasible since bell towers are very tall structures and are distanced from the general public, but was never implemented due to resistance from the clergy owners of these bell towers.

This group also made some minor modifications to the methodology of the external visual assessment. They augmented the data field sheets by including fields concerned with the bell tower's location and the relative importance of the church that it was attached to.

3.4.5 Adriano Boccardi

In 2001, Adriano Boccardi took the methodology developed by past IQPs and improved the methods for recording the inscriptions and decorations for each bell. Being bilingual, he transcribed all of the Latin inscriptions of the bells onto paper with great accuracy. He photographed each of the bells and sketched all of the decorations and engravings in detail. His work increased our bell data dramatically.

4 Methodology

Our project has several distinct goals, which were often achieved in parallel. All of them together provide a more powerful set of tools for groups concerned about the preservation of Venetian bell towers to work with. Our primary objectives are:

1. Organize all existing bell towers data into a complete, standardized, and easily usable data repository.
2. Finalize the methodology for visually assessing bell towers, and using it to catalog and rank more towers.
3. Produce a recommendation and analysis of the feasibility and methods of monitoring a bell tower's structural integrity.

Since our objectives are very distinct and separate, and each substantial enough in its own right, there is a section of this report dedicated to our work on accomplishing each of these objectives and what was gained from them.

In addition to accomplishing our primary objectives, we also made several other accomplishments. In an attempt to help keep future visual cataloging of bell towers consistent and complete, we created a comprehensive guide to cataloging bell towers for future groups, which can be found in a separate document titled "Bell_Tower_Guide_E04.doc", and is referenced here as Appendix E. We created a full report of the data in our database, for use in showing to churches or anyone who is interested in the usefulness of our work, which can be found in a separate document titled "Bell_Tower_Database_Report_E04.pdf". We also created some simple maps of the locations of bell towers of Venice in a web-accessible format, which also contains some simple information about each bell tower, such as its formal and common names, sestiere it is located in, and the year(s) in which it was monitored. These maps can be found at http://www.wpi.edu/Academics/Depts/IGSD/Projects/Venice/Center/Terms/E04_Projects/Bell_towers/maps/index.htm.

4.1 The Bell Towers Data Repository

The data collected by the Venice Project Center through its collaboration with IQP project groups and outside people and organizations is large and spans many formats. Each group has left its own individual sets of data, with no way centralized and useful way of accessing them, or querying all of the data at once to answer questions and solve problems. We took each type of information and created standardized systems and unified places for cataloging each kind. The results of this work are, naturally enough, quite large and complex, and are generally included as appendices. For a more detailed methodology and discussion of results, see Section 5.

4.2 Visual Assessment of Bell Towers

To be qualified to change anything about the current methodology definitely requires us gaining experience using it. We monitored the towers of San Bartolomeo, San Francesco de la Vigna, San Giorgio Maggiore, Santa Maria dei Miracoli, Santa Maria di Nazareth, San Michele and San Salvador using the current forms and procedures. During the process we kept track of fields which seemed unnecessary or improperly structured.

We analyzed what we had noticed and comprehensively went over the forms, and made what should essentially be the final version of this methodology. We updated the database schema we were working on concurrently to reflect these changes, and updated the bell tower form files themselves as well. Then, using our new modified methodology, we visited the towers Santa Maria del Carmine and San Stae and visually assessed the condition they were in. All nine of the towers we visited are shown in the map in Figure 9.

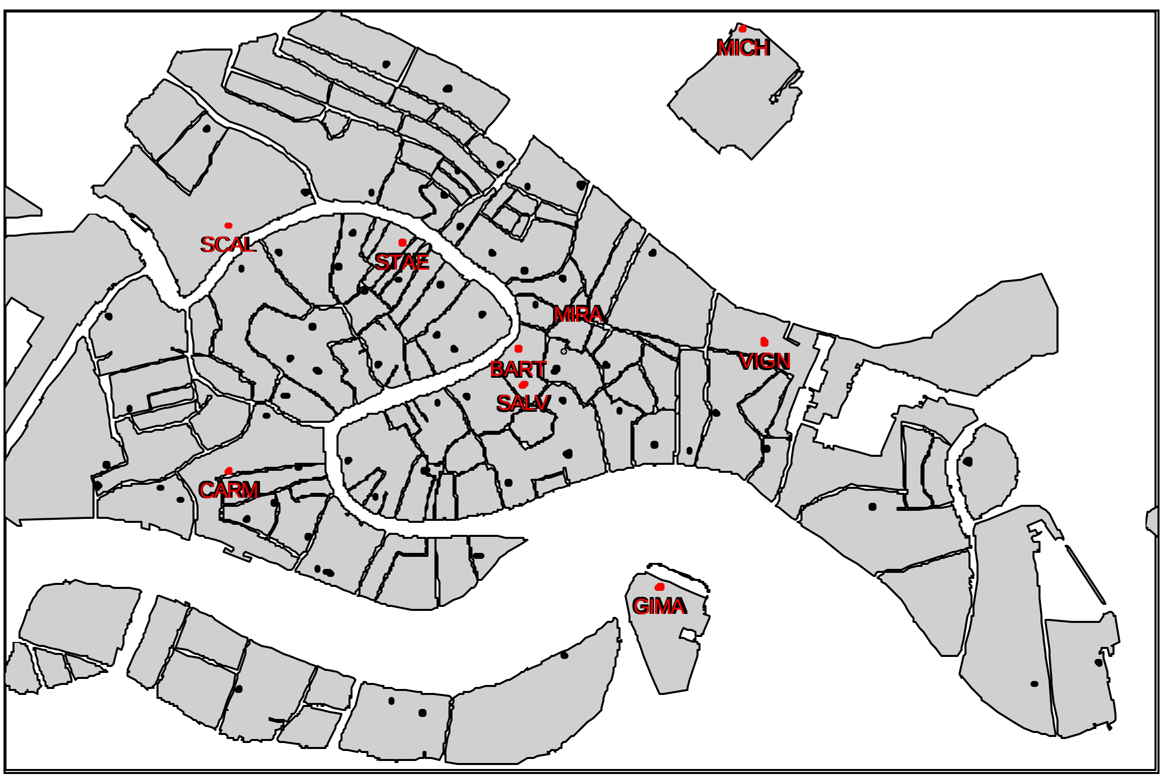


Figure 9- Towers We Monitored

Inside our database, we set up a framework which will allow anyone who wants to experiment making formulas to calculate the restoration priority of a bell tower to do so with ease. The formulas would have to be of the type that chooses appropriate coefficients to multiply by the numerical rankings recorded to generate a final ranking of a section or the entire tower. Once coefficients are chosen, they can be plugged into our system and the rankings given instantly.

4.3 Instrumental Monitoring

After researching the possible structural problems of a Venetian bell tower, we determined what issues we could reasonably obtain appropriate instruments to analyze. We obtained these instruments and experimented in the tower of San Giorgio Maggiore.

4.3.1 Placement of Instruments

We wanted to use our accelerometers to see how the vibrations of the bell traveled through the bell frame. We had two accelerometers, a 50G and a 25G. The 50G accelerometer would detect higher accelerations than the 25G, but was less sensitive. We decided to put the 50G accelerometer on the largest and most used bell in the tower, and our 25G on one of the beams of the bell frame beneath the belfry. This way, we could see how strong the vibrations were at the source, and compare it with how strong of a vibration reached the bottom part of the frame.

The accelerometers were wired to a hardware system that connected to a laptop. The software system LabVIEW was required to read, record, and translate the data coming in from the accelerometers. LabVIEW programs called "virtual instruments" were needed to be written, and were programmed by us. Further details on our work with LabVIEW can be found in Appendix C. Our virtual instruments were set up such that we could leave the laptop in the tower and have it record from the accelerometers continuously for days at a time, and save the data in a form which could be analyzable at a later time.

Our anemometer was placed on the balustrade (upper balcony) of the tower, in the open air. It was placed on the corner where the wind was known to blow the most at the tower. It connected directly to the same laptop the accelerometers did, which used the software program HeavyWeather to record the data.

4.3.2 Supplies Needed

For both the accelerometer and anemometer, it was necessary to string wire down the elevator shaft, and secure them alongside some preexisting wires so that they would not interfere with the elevator. For that, we needed to procure two long extension cords; one of standard 4-color wires for the accelerometer, and one of standard phone wire for the weather station. We used duct tape to hold the weather station fast to the balustrade, and electrical tape to keep the accelerometer wires together and not touching each other. We used a non-dampening adhesive with a tensile strength of 2400 lbs to hold the accelerometers firmly in place.

We needed a standard-to-industrial electrical socket adapter to use the socket underneath the belfry. We used it to plug in a power strip, which provided power to our laptop, accelerometers, and weather station. The accelerometers needed a DAQ card , a PCMCIA laptop card, and an AC adapter to function and report data into a computer.

5 The Bell Towers Data Repository

WPI and related organizations have gathered six years of data concerning bells and bell towers that are spread across multiple media formats and locations. Much of this were in Microsoft Access databases, created from field data these groups had written on their forms. The past research groups have also collected a vast amount of collateral material in their assessments of bell towers in addition to the visual measurements. This includes photographs of towers, photographs of the bells, and audio of the bells ringing. There were also assorted MapInfo layers from each group showing which towers they had done, but no centralized table linking these together. In addition, all of these were aggregated by the fact that the set of unique codes used to identify bell towers was in inconsistent form.

We revised and standardized the set of codice, and brought all database, media, and MapInfo data together into an organized repository of bell tower data.

5.1 Finalizing Codice

Each bell tower has a code that it is referred to by. We call these codes the "bell tower codice". The codice is helpful for many reasons. Most of the bell towers in Venice are known by several names. Many times there is an official Venetian name, a regular Italian version of this name, and a common, more well-known name. When organizing data or photographs from a tower, it is necessary to have a standard code for how to refer to each tower in order to avoid confusion of towers.

The list of codice that has been used in the past is not very standardized. For example, most of the codes have four letters, while others have five or six. Some codice are derived from the common name of the corresponding church, and the rest are taken from the formal name. Many of the codes even start with the letter S, for "San", which is pointless since just about every tower starts off with San, Santa or Sant'. For all of these reasons, it was evident that a more standardized list of codice needed to be created.

We worked with the WPI Church Floors project team to develop a finalized list of codice that was more organized than the one in existence. Some examples of codice that we changed are shown in Table 1. For the complete name of any tower, refer to Appendix B.

New codice	Old codice	New codice	Old codice	New codice	Old codice
ANGE	ANGEM	ERAS	RASM	PIAP	SPIEA
ANGM	SANGM	EROS	EROSI	PIVI	LAPI
ANTN	ANTO	FAVA	CONS	SCAL	NAZA
ANTP	ANTOP	GESU	ROSA	SIMG	GRAN
ASSG	ASSU	GIMA	SGMI	SIMP	PICC
ASSM	ASSUM	LAZZ	IMEN	STEM	STEFM
ASST	ASSUT	MARB	MARB	TROV	GERV
CATM	CATEM	MICH	MICHE	VALV	LEMI
CROA	CROC	NICO	NICOL	ZANI	NOVO
DONA	DONAT	OGNP	OGNISP		
ELIS	SMEL	PAUL	PAOL		

Table 1- Codice Changes

5.2 Unified Database

Much of the information that was collected was recorded onto paper forms and, in most cases, was later entered into a database. The use of a database allowed the previous groups to easily mine their data to determine trends across all bell towers examined that year. It also facilitated the creation of a ranking system that ordered bell towers by a set of criteria that the groups established. The criteria used included such things as 'need of repair', 'possible area of damage', and 'importance of bell tower'. However, since each research group created their own databases for the information collected during that year, there was no manner to compare information from one year to another. There was also no way to use the ranking methods to create a global ordering for all previously assessed towers.

One of the goals of this project is to organize all materials collected concerning the visual assessment of bell towers into a unified, digital format that will facilitate a global analysis of all previously recorded data. The steps needed to achieve this goal are to map the existing databases to determine the content and format of their data, to design and create a master database schema to warehouse all existing and future data, and the creation and execution of a migration path to pull all data into the master database. The details of these steps are discussed in the following sections.

5.2.1 Preparing a Global Schema

The first step in the creation of the master database was to examine the databases created by the past research groups. There have been five databases created during the last ten years to organize data collected in the field into a concise, electronic format. However, since the databases were created for the sole purpose of organizing the data collected for that research project their schemas differed from project to project. In some cases, research groups decided to collect additional information whereas in other cases they collected completely different information. We therefore needed to analyze each of the databases and document each of the tables and the types of information that each encompassed.

The next step was to examine each of the data types in turn and create a list of fields that would exist in the master database for that type. A second matrix was created that documented the master database fields, a brief description of each, and which of the original database fields for each research group contained this information. We used this matrix to assist us in determining the location of the data when it came time to import the data into the master database. Once the master database's list of fields was created, we grouped the fields into tables based upon the types of measurements and in manner that allowed for efficient storage and data entry.

5.2.2 Combining of Existing Data

The last phase in the creation of the master database was to import all of the existing data from both the existing databases and the paper forms into the master database. We consulted the database matrix and the paper matrix to determine the location of the data. In all cases we first attempted to locate the needed data in the existing databases before manually retrieving the data from the paper forms. However since we only had databases for five of the ten years of research we needed to manually enter a large amount of data from the field forms. In some cases we needed to resolve conflicts where the same data for a bell or bell tower resided in multiple locations. In such cases we used the data from the most recent research group. Another complication in the import process was attempting to deal with missing database or form fields. Some bell towers would have only a few measurements entered while the vast majority of the remaining fields were blank. In other cases the database would have values that appeared to outside the valid range for that data type. This prompted us to create another matrix that details which database field exists for each tower and if the existing data appears to be valid or invalid.

5.3 Audio/Visual Media

The previous research groups collected audio and visual media in addition to the databases and paper forms. Each of the research groups collected audio recordings of the bells ringing as well as pictures detailing the condition of the inside of the towers, the outside of the towers, and the inscriptions, decorations, and state of the bells. Nearly ninety percent of this data was in hard copy and needed to be recorded into electronic form in order to package it with the master database.

We scanned all pictures taken into electronic form, and created a standard filenaming scheme for all future groups to follow, which is explained in our 'Cataloging the Venetian Bell Tower' guide. The audio was more difficult, because it came in the form of full video recordings taken with a video camera. These needed to be taken from their cassette tape form and recorded electronically using special software. Then the video files needed to be compressed and encoded in order to be of manageable size. Finally, the audio track had to be separated from the video using a video to audio conversion program. The full process should not have to be repeated for future groups if they use a simple audio recorder and do not take full videos with an analogue video camera. If they take videos with a digital camera, they will only have to do the video to audio conversion.

To complete the process, we created a hierarchical folder structure on a series of compact disks organized by bell tower for the photographs and audio, and added a field to the master database that point to the location on disk where the images and audio reside. Future groups should continue the standardized archiving of the photographs and audio recordings they take, and update this field in the database appropriately.

5.4 MapInfo Table

After organizing all of the data that has been collected in the past twelve years, we felt it was necessary to create a table to show which towers were monitored each year. This completed table is shown in Appendix B. There are fields for each year that monitored was completed (1992, 1995, 1996, 1997, 2001 and 2004). The towers that were monitored in each year are marked with a "1" for that year..

This table was originally made in MapInfo, and therefore has a layer associated with it. The layer is entitled "Campanili_2004". The default map layer shows all of the towers as blue boxes. Using the table, it is possible to create queries for each of the years and then display the results of each query on the map in a different color. If you do this, you can create a map that will show which towers were monitored in each year, as seen in Figure 10. Table 2 shows a legend of what each of the colors in Figure 10 symbolize.

Black	All bell towers
Green	Towers monitored in 1992
Blue	Towers monitored in 1995
Purple	Towers monitored in 1996
Yellow	Towers monitored in 1997
Orange	Towers monitored in 2001
Red	Towers monitored in 2004

Table 2- MapInfo Color Legend

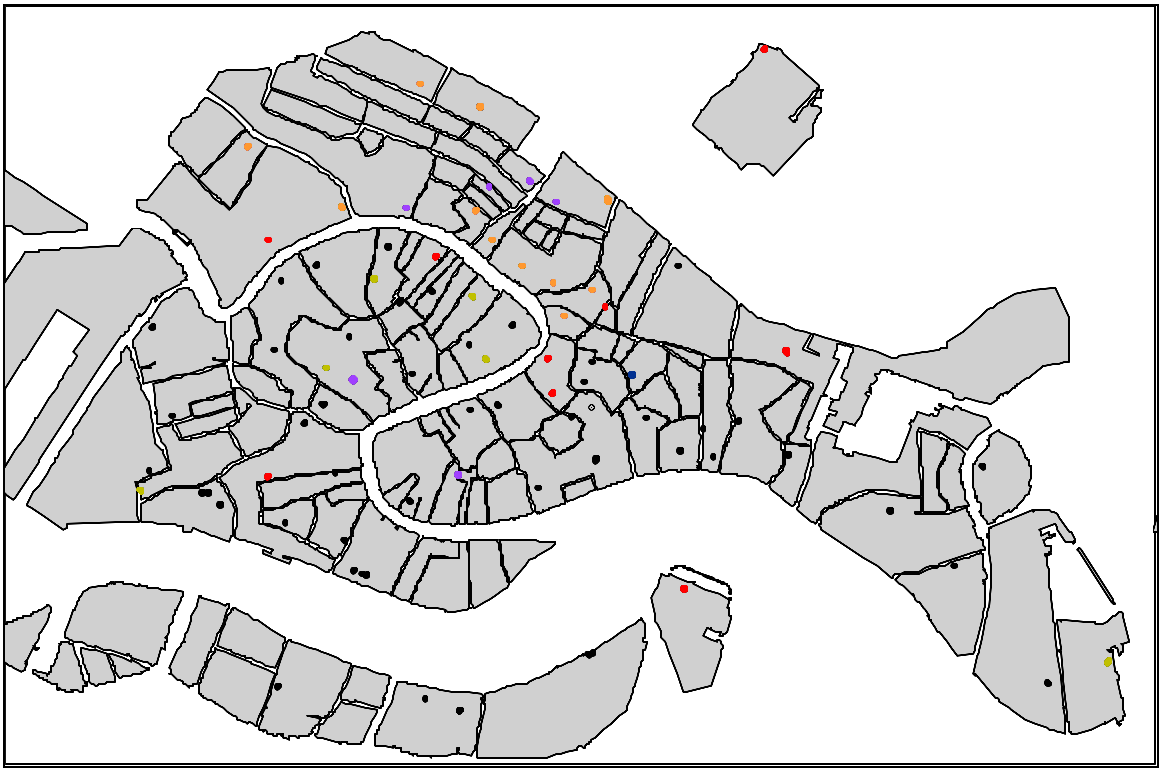


Figure 10- "Campanili_2004" Map Window

5.5 Analysis of Visual Measurements

The current methodology calls for us to examine two hundred and twenty unique attributes for each bell tower and is spread across multiple domains of inquiry such as importance, condition, and structural integrity. Collecting data at such a high degree of detail ultimately allows us freedom in the manner in which we choose to analyze it. If our goal was to analyze the information to determine a ranking of towers by order of importance, we could do it. Likewise, if we were interested in determining the towers that are in greatest need of repair then we could consult the database and create a ranking. However, the freedom that we are allowed creates a problem in its implementation; namely, how do we perform the analysis?

In a first attempt at analysis we may decide to restrict ourselves to just the attributes that we believe are relevant to our end goal and thereby decreasing the parameters under consideration. However, rarely can we make such a simplistic distinction between relevant and irrelevant attributes. As an example, consider a ranking of towers by need of repair. We could limit ourselves to examining just those parameters that deal with the condition of the tower. But in doing so, we are ignoring real-world issues such as limited funds. A different approach would be to factor in the importance of a tower, based upon parameters like location, amount of artwork, etc., along with its current condition to arrive at a listing that is more realistic. This issue begs the question of how do we determine the weights, or importance, of each of these domains. This is relevant not only on the macro scale of how to compare the importance of a tower and its condition, but also on the micro scale. How do the parameters within each domain compare to one another? This question gets at the root of the issue with our increased freedom of analysis. Continuing with our previous example, imagine that we had only three parameters to rank the condition of a tower on; landing condition, wall condition, and railing condition. In this instance we would probably decide that wall condition is most important followed by landing and railing conditions. Imagine instead that we tracked detailed information concerning the walls; number and size of cracks, amount of deterioration of brick mortar, misaligned bricks, etc. Now not only is it more difficult to determine a strict ordering, but we have also introduced the issue of potential inter-parameter dependencies. This means that we can no longer assume a linear relationship among the parameters but instead must consider the possibility of a nonlinear relationship.

Yet the aforementioned issues do not preclude the ability to perform an analysis. Multiple techniques, such as linear and nonlinear regressions and artificial neural networks, can be used to determine a ranking based upon a given criteria. Below we present a formula that would be used in a linear regression. The y value is the dependent variable and represents the score for the bell or tower. Its value is determined by summing up all of the weighted parameters. Here x represent the parameters in the database that are to be used in the ranking and w are the weights that effectively scale the attributes.

$$Y = w_1x + w_2x + \ldots + w_nx$$

The methods mentioned above require the existence of a training dataset for which the desired output, y, has been determined by a domain expert. Given that there are enough instances in the training dataset, any of the methods above can then determine the weights, w, that minimize the error between the desired output, y, and the calculated output. The remaining instances, those not in the training set, can then ranked using the determined weights.

In our case we do not have the luxury of a domain expert to classify our data for a training set. For this reason we have instead decided to focus on the creation of a framework that will allow domain experts to directly determine the weights for the parameters in our database. The user can enter a weight in the range of 0 to 1 for any numerical fields in the database and then by clicking a button on the database form can retrieve a ranking of towers or bells. Both the results of the ranking and the weights used are stored in the database so that new towers or bells can be classified as field data is obtained for them. The framework also allows uses to use multiple existing ranking methods to arrive at a final ranking. The user is presented with a list of ranking methods and again is allowed to specify a value between 0 and 1. The framework then scales each of the results from the selected rankings using the specified weights and presents the user with a final list.

6 Visual Assessment of Bell Towers

Natural disasters such as earthquakes make the ground of Venice very unstable. In the past, several towers, including the bell tower at San Marco and the bell tower at Sant' Angelo collapsed. The amount of known information relating to the structural condition of the bell towers in Venice was minimal, and this created a lot of anxiety and concern in the citizens of Venice. In order to help the citizens understand the condition of each individual tower in the city, WPI and the Venice Project Center has made it a goal to visually assess as many of the towers as possible, and record notes about the condition they are in.

6.1 Cataloging Towers with Past Methods

To develop a better understanding of the existing methodology for the visual assessment of bell towers, we visited several towers. We followed the same procedures and filled out the same field forms as previous projects performed by students of Worcester Polytechnic Institute and workers of Earth Watch. For printouts of all of the data we collected at each of these towers, refer to the printed report, in the file titled "Bell_Towers_Database_Report_E04.pdf".

6.1.1 San Bartolomeo

Figure 11- San Bartolomeo

San Bartolomeo is mixed style bell tower. As you can see from the Figure 11, the belfry and steeple are very ornate. If you look closely, you can see some of the exterior siding has chipped away on the drum and exterior of the belfry. The tower itself is in pretty good shape, aside from the chipping of the external covering and mortar on the belfry and spire. The bells of this tower are in bad shape; the frame is made of wood and in some places looks like it may give way at any given time.

Figure 12- Clean inside

The interior of the tower is in relatively good condition. As you can see in Figure 12, the tower is very clean. This photograph was taken just under two years ago. The reason the tower looks so pristine is because two years ago, the church paid someone to come in and clean the tower spotless. They did a great job, as you can see.

Figure 13- Dirty inside

Yet, at some point in time soon after the cleaning, the sliding door to the belfry was left open, allowing birds to enter the tower. This is bad not only because they covered the entire tower in feces, but because many of them died inside.

When we entered the tower, in the summer of 2004, it looked as it does in Figure 13, two inches deep in a combination of bird feces, feathers and carcasses. This shows that even if an effort is made to clean or restore a bell tower, it is not always maintained. It is evident that no one had entered the bell tower for approximately two years or else there would have been effort made to prevent or treat this problem.

6.1.2 San Francesco de la Vigna

San Francesco de la Vigna is a massive tower with a pyramid shaped attic of red clay shingles and a white stone belfry that pierces the skyline of Venice in northern Castello, as seen in Figure 14. Although the exterior of this tower shows little signs of structural weakness, the inside the tower is in desperate need of repair and structural monitoring; This tower has had minimal restoration since it was built in 1564. The interior of San Francesco de la Vigna shows signs of significant, if not critical, damage to the bricks, such as cracks and bowing of the walls. The assent of the tower was made even more perilous due to the minimal lighting in the shaft. There were a few small windows that were covered by mesh and some drop down light bulbs dispersed at the bottom of the shaft.

Figure 14- San Francesco de la Vigna

The five medium to large size bells, were all in decent condition, with no cracks or major discolorations. Through our analysis of the clapper's skid marks it has become evident to us that there has been effort made to maintain the bells condition; each of the bells has been rotated at least once, approximately forty five degrees from their original swinging location.

This tower is located close to the coast and therefore has the nicest view of Venice of any tower in the city. Figure 15 is a photograph that was taken from the balustrade towards the south-west. In our opinion if this tower was monitored and restored this would be a perfect tower for being visited by tourist.

Figure 15- View from the top

6.1.3 San Giorgio Maggiore

Figure 16- San Giorgio Maggiore

San Giorgio Maggiore, one of the tallest towers in Venice, is located on Giudecca, faces Venice proper and looks straight out onto Saint Mark's Square. The bell tower, shown in Figure 16, is in very good condition. It is extremely clean inside aside from the minor amount of dust buildup. The tower is open to the public. The belfry is only accessible through the use of an elevator to the general public. The belfry is spacious and clean and has a trap door leading down into the shaft, where the public is not allowed. The walls of the tower have had many cycles of restoration, leaving the tower in nearly flawless condition structurally and aesthetically. There is a new banister along the entire length of the ramp on the way up and artificial lighting the entire way. We are also using this tower to test our methodology for instrumental monitoring.

6.1.4 Santa Maria dei Miracoli

Figure 17- Santa Maria dei Miracoli

The church Santa Maria dei Miracoli, shown in Figure 17, is located in the Cannaregio sestieri. The bell tower was built in 1481 and has recently been restored. This work is most visible from inside the shaft of the tower where patches of concrete over brick have not been masked over with plaster as has been done on the outside to hide the damaged brick. Although the tower has been restored it is still riddled with cracks. These cracks are present all along the narrow spiral staircase that leads to the three bells in the belfry. All of the bells are all in working order and seem to be in good condition. The frame has not been damaged since it was its most recent replacement. The major issue with the belfry, attic and bells of this tower was the general cleanliness of all surface areas. There are parts of the bells that are covered in soot and pigeon feces.

Figure 18- Manual Bell Ringing

This particular tower is one of the only towers that does not have an automatic ringing system and are only rung manually. As you can see in Figure 18, there are bulky ropes used for ringing attached to the bells extending down the tower through carved openings in the stone stairs all the way to the bottom. These large gaps in the stairs make it difficult to ascend the tower.

This tower features a peculiar ground floor that doubles as a bathroom. As you can see in Figure 19, this is a fully working restroom complete with a toilet and sink. This insinuates that no one ever really climbs up the tower. These are prime examples of why this tower could not be opened to the public.

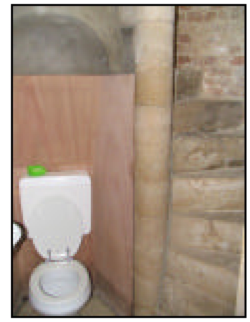


Figure 19- Restroom in Bell Tower

6.1.5 Santa Maria di Nazareth

Figure 20- Santa Maria di Nazareth

Shown in Figure 20, Santa Maria di Nazareth, otherwise known as Scalzi, was originally built in 1680. It is located adjacent to the S. Lucia Train Station in the center of Canneregio. A spiral staircase, 175cm in diameter leads up to a caged-in belfry housing two extremely discolored bells. Neither of the bells in this tower have been rung with a hammer, making it safe for us to assume that all the damage done to the tower through the ringing of the bells was done by the rotation of the wheel and the swinging of the bells against the clapper.

The brick walls inside the tower have been covered by a thin layer of concrete for aesthetic purposes. Large cracks in the walls have started to break through the concrete covering, leaving piles of cement all along the stairs. The lower parts of the shaft feature ancient graffiti that prove that the towers shaft has had no major restorations. The condition of the tower drastically worsens the higher you are, and cracks and splits in the wooden stairs become very noticeable.

There were no windows in the bottom of the tower, nor was there any artificial light. Only at the top third were there any windows to provide any lighting inside the tower. Mesh wire cages were loosely covering the windows in an attempt to keep birds out. Ironically, birds made nests on the outside of these cages and since they were not secure, the nests and the birds have fallen through the small crack between the stone and the wire into the tower. Once inside, the birds could not escape and would just die inside. This is evident from the loose cages and the many skeletons we found scattered around the floor.

6.1.6 San Michele

Figure 21- San Michele

Monaci Camaldolesi, more commonly known as San Michele, is a church on the island of Cimitare. It is well-known because it is the bell tower of the only church on the only cemetery in Venice. The bell tower, shown in Figure 21, is actually currently being monitored by an architectural firm from Trieste because of its alarming condition. When the bells were originally hung, the frame was installed incorrectly, which led to a lot of excess strain on the tower's shaft. Figure 22 shows one of the strain gages currently in the tower that the civil engineers are using to collect data. Notice the huge crack in the wall of the tower that the strain gage is placed on.

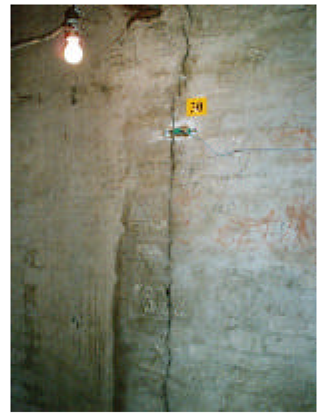


Figure 22- Crack and Strain Gage

There are four bells total in this tower: three medium sized bells across the center and one small bell on the right side, near the belfry window. The small bell, shown in Figure 23, which we labeled as Bell 1, was in absolutely awful condition. Since it was cast in 1862 it has not been maintained and has decayed to a state that makes it dangerous to the people around the tower. A makeshift safety cable has been rigged around the bell wheel to prevent it from falling off the tower. The most interesting and most important bell in San Michele bell tower is the one that was originally cast in 1777, which for our purposes of referencing and collecting data on, is known as Bell 4. From the photograph in Figure 24, you can see that the bell is extremely chipped along the edges, and quite rusty near the skid marks. More importantly, there is a large crack that is going down the length of the bell. It is pointed out by an arrow.

Figure 23- Bell 1

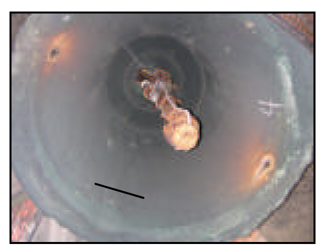


Figure 24- Bell 4 Inside

6.1.7 San Salvador

Figure 25- San Salvador

San Salvador is a sturdy brick bell tower located in one of the most central points of Venice from which you can see just about every other bell tower in the city. It is for these reasons that the tower is used as a cellular tower. In Figure 25 it is easy to see the antennas attached to this bell tower. This is due to the fact that the cellular phone company ITIM owns this bell tower and uses it to hold up its antennas, instead of having a cell tower.

The interior of the tower was in such bad condition that one of the wooden stairs towards the top of the tower was completely missing, and the stair below it was rotting through. This made it extremely difficult to ascend the tower. Because it was so unsteady, only one person could be on that landing or staircase at any given time.

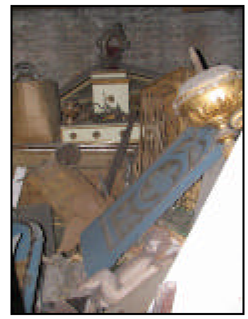


Figure 26- Storage

The tower might not have been so difficult to navigate through if it was empty, but on the lower landings and walkways, the church stores all of its random junk, including large planks of wood and decorations for seasonal holidays. You can see a picture of landing 2 in Figure 26.

6.2 Revising of Past Methodology

After studying the existing methodology, the data that had previously been collected using it, and analyzing our own experiences at the towers we visually assessed, we felt we had a good understanding of the methodology that past groups had used. After much consideration, we felt it was necessary to make a few minor adjustments to the fields of data that were to be collected. The completed new forms are shown as Appendix D. The digital version is stored as a separate document titled "Bell_Tower_Forms_E04.doc".

6.2.1 Changes to the 'External Bell Tower Data Sheet'

The first changes we made were on the 'External Bell Tower Data Sheet'. We removed the field entitled 'Importance of zone' whose details are shown in Figure 27. This table did not seem to have much relevance to visual assessment forms, particularly to the 'External Bell Tower Data Sheet'. The date of the church and the information about art pieces were repeated fields and are stored elsewhere. Any information about burials or other important items can be written in the 'Notes' section.

Date of Church:	______	
# of Burials:	______	description: ________________________________
# of Major Art pieces:	______	description: ________________________________
Other Important items:	______	description: ________________________________

Figure 27- Importance of Zone

We added two checkbox fields in the 'Other Information' section for whether or not there is a cross at the top of the steeple, and if there is a balustrade. We deleted the section entitled 'Fire Protection Info' which is shown in Figure 28. Our logic behind this was that it is irrational to expect anyone to be able to know the distance to the nearest canal, and is pointless to have them count the number of wells and canals. This information is very easily found using the MapInfo layers or any other map.

Fire protection Info
Distance from nearest canal: _____ m
and type of water source: _____ wells ____ canals

Figure 28- Fire Protection Information

We also changed several of the fields from '# of' to a ranking between 0 and 4. The fields we did this for were 'Damaged Areas', 'Cracks/Holes', and 'Plants/Veg'. We felt this change was necessary because it is difficult to analyze past data that, for example, says '# of Damaged Areas: 3', since you do not have any idea whether these areas are large areas or how severely damaged the areas are. It must be kept in mind when ranking fields such as these that a tower with many small cracks might have the same or lower ranking than a tower with one or two large cracks.

We added two more fields to the external data sheet, 'Number of Lessene' and 'Number of Arches'. These fields are to be filled out for each side (Front, Right, Back, and Left) of the shaft. We adjusted the section shown in Figure 29 to be only performed if internal access to the tower is not possible.

# of Windows:																
# Blocked																
# Barred																
# w/ Wire Mesh																

Figure 29- Windows

6.2.2 Changes to the 'Internal Bell Tower Data Sheet'

There were a few changes that were necessary to make on the 'Internal Bell Tower Data Sheet'. There used to be a field entitled 'Lighting', but we have now divided that up into two separate sections, 'Natural Lighting' and 'Artificial Lighting'. Previously, it had been unclear whether or not there was light coming in from windows or if there was artificial lighting. We added a completely new field called 'Bowing', which is filled out with a ranking between 0 and 4. Bowing has a lot to do with the structural integrity of the tower, and because of that, we felt that it should be recorded.

We deleted the '# of Misalignments' field because it is too general and the data that is collected from simply recording the number of misalignments and no details about them is not analyzable.

6.2.3 Changes Bell Data Sheets

We only made one change to the 'General Bells and Frame Data Sheet'. In the past, a diagram of the bells was drawn from the top and side, but we added a section where you should draw a diagram of the bell frame, from the top and from the side.

On the 'Technical Bell Data Sheet', instead of simply recording the 'Date on Bell', we have changed that to record the 'First Casting' and 'Second Casting'. We simply changed the field entitled 'Chiming Frequency' to read 'Ringing Schedule'. This was done for the reason that this title is more straightforward than the one previously in existence.

Part of our new methodology requires that zoomed-in photographs are taken of each of the engravings on the bells, so we added space on the data sheet for the photograph number to be recorded.

6.3 Cataloging a Tower with Revised Methods

Using this new methodology, we visited and assessed two more towers, Santa Maria del Carmine and San Stae.

6.3.1 Santa Maria del Carmine

The bell tower at Carmine, shown in Figure 30, is a prime example of a tower in desperate need of restoration. As you can see in Figure 31, the exterior of the tower shows many signs of structural weakness such as cracks, holes, missing bricks, as well as the exterior plaster shell of the tower has completely fallen off. There are many vast cracks that span the entire length of the exterior of the tower. While the exterior of the shaft is in such pour condition the exterior of the belfry is surprisingly in good condition.

Figure 30- Santa Maria del Carmine

Figure 31- Damaged Exterior

The lights on top of the belfry have not been removed from Christmastime or some other celebration that they were placed there for. The interior of the tower is in better condition than the exterior, but only slightly. Many of the landings have the same cracks, holes and destroyed brick as the exterior. The stairs are made of stone and are very sturdy, but they are littered with pieces of broken brick. Many of the wooden ties inside the bell tower have lost their usefulness due to the rotting of the wood. Assent up the stairs is made even more difficult and dangerous by the minimal artificial lighting inside the tower. The interior of the belfry is in fair shape, although the floor has not been cleaned since the installation of bird netting.

Figure 32- Automatic Ringing Mechanism

Figure 33- Inscription at inside base of tower

The bells and the bell frame are both in good condition and are the only parts of the bell tower that have had been maintained. The bell frame is wood and in above average condition with no bends, warps or cracks. Recently the bells have been retrofitted with a modern ringing mechanism. The original automatic ringing mechanism can be seen on a landing below the belfry in Figure 32. The bottom floor of the tower contains a unique inscription at the stairs of the tower. It is shown in Figure 33. Through our visual analysis we have concluded that this tower is in desperate need of renovation and monitoring.

6.3.2 San Stae

When compared to all of the towers our group has visually assessed, the tower of San Stae represents the average condition of the Venetian bell towers. As you can see in Figure 34, the exterior of the tower shows no significant signs of structural deficiencies. Through our analysis of the bricks we have concluded that this tower has gone through two to three restoration periods. The layers of new brick are located at the corners of the towers base indicating the potential for the insertion of reinforcement beams into the tower's walls. The exterior walls show few signs of deterioration, with minute cracks throughout the tower walls being the only noticeable damage. Although

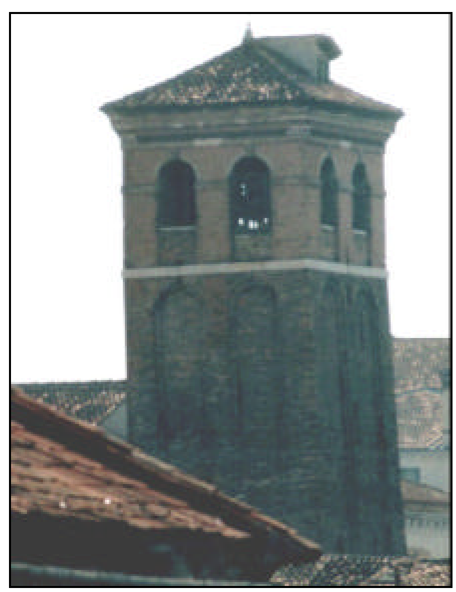


Figure 34- San Stae

these cracks might not seem very significant, small cracks often are the cause of structural instability. This can only be determined through instrumental monitoring of the ground around the tower and the tower walls. The inside of the tower provides mixed messages about the towers condition. Through analysis of the condition of each wall by landing we are able to conclude that three of the walls are in good condition and the back wall is in drastic need of monitoring. The back wall of the tower from the inside is littered with cracks of various severities. This could have been caused by many factors, such as the force of another wall pinching the back wall, or by the towers foundation shifting under that side of the tower.

Figure 35- Pristine bell

The most noticeable renovation that has been completed on the tower was performed on the belfry and the bells. The belfry was replaced within the past two or three years and is in pristine condition. The clappers of the bells are also in perfect order with no rust or rot present anywhere on the body of the clapper or the belt. Some routine maintenance has also been performed on the bells. The bells have been cleaned and detailed at the top where they were hung from the frame. The only damage that has occurred to the bells as a result of the re-hanging is that the second bell has a small chip taken out of the lip to make room for the new wheel. This may be significant because that small chip may affect the pitch of the bell. A photograph of one of the bells showing the cleanliness of the bell, the clapper and the wheel is shown in Figure 35. Although this tower has some minor structural issues, the tower is close to the canal and there for may be used potentially as a surveillance point or a tour destination.

7 Instrumental Monitoring

While we did obtain some data from our experiments, the real purpose of our monitoring was to produce a set of recommendations to more fully monitor a tower. Our experiences and the accuracy of our data have enabled us to provide an analysis of how to usefully monitor a tower's structural integrity. A financial analysis is also included.

7.1 Experimental Results

San Giorgio Maggiore has six bells, one of which is hammered every hour for the same number of times as the hour, in the 12-hour system, from 7am (7 rings) to 9pm (9 rings). A different, smaller bell is hammered once on every half hour. The large bell also rings by swinging every day (including Saturday and Sunday) at noon. This occurs a few seconds after the normal 12 hammerings. Finally, all six bells swing on Sunday at 10:45am.

In the end, the only instrument which gave us results was our 50G accelerometer, which monitored the large bell for 2 time periods: from a Friday at 5:30pm until Monday at 12pm, and from a Saturday at 4:30pm until Monday at 12pm. In each of the figures below, the axis on the left is the G's read by the accelerometer, and the axis on the bottom is an index to show the passage of time. Every time the instrument scans and reads a point of data, the index is moved up by one. We chose to read at rate of 4 scans per second. So for example, a span of 240 on the bottom axis indicates 60 seconds of reading, and that there are 240 data points seen in the graph.

Figure 36 shows our recording of the Monday at 12 pm reading, zoomed in to only the time when the bell was being hammered 12 times. The recording is a 60 second interval, and 12 distinct disruptions can be seen, one for each hammer of the bell. Similar results can be seen for every reading of the hourly hammerings. The G's are not of a very high magnitude, which is to be expected with simply a hammering of the bell.

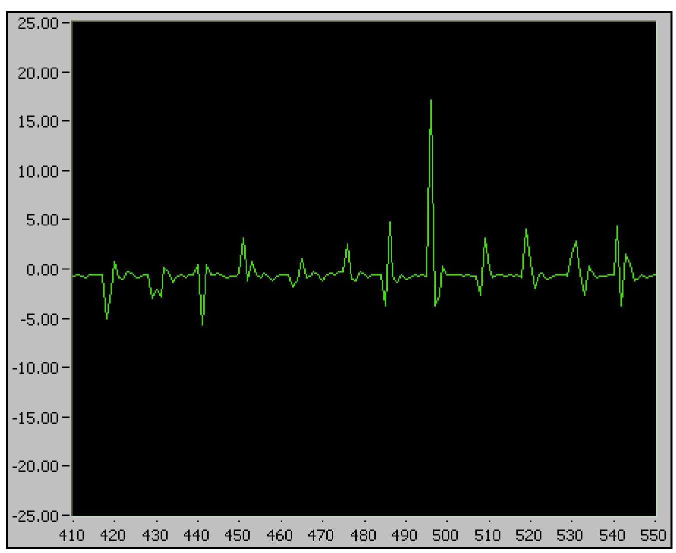


Figure 36- Hammering of noon bells

When the bell actually swings, we should expect to see significantly higher accelerations detected. Figure 37 shows another 60 second long interval of the same recording, in the time after the initial hammering when the large bell actually swings. Here acceleration is very periodic, with easily seen patterns. In particular, the span from 1224 until 1288 (16 seconds) contains at least 5 rings which have very similar vibration results.

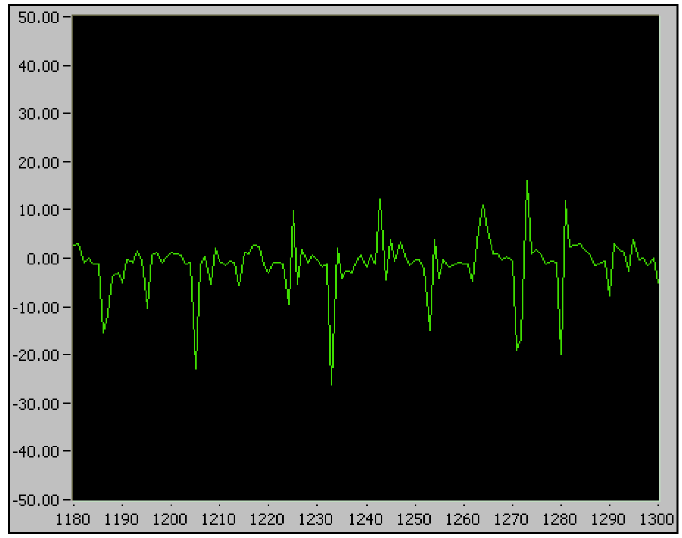


Figure 37- Swinging Bells (1180-1300)

7.2 Analysis

Accelerometers are absolutely the instruments with the most potential for useful monitoring of a tower. We did not have sensitive enough equipment to monitor the motion of the tower due to bell motion, seismic force, or wind, but we did some experimental monitoring on vibrations traveling through a bell. This was enough for us to not only determine the feasibility of a group relatively uneducated in civil engineering performing this kind of monitoring, but to also produce virtual instruments that could aid any group who decides to do this. Our results show that our methods were valid and can obtain accurate results.

Our strain gages were inappropriate for measuring the strain of walls pulling apart at cracks, for two reasons. Firstly, our strain gages were single point. This means that they take an average reading over a span of time, not a continuous set of readings that could show spikes and changes. Having dynamic strain gages which continuously report data would be more appropriate. Secondly, our strain gages were elastic, which measure the force of the wall pushing inwards or outwards (towards or away from a person facing the wall). To measure the force of the wall pulling apart at the crack, a spring loaded strain gage is needed, such as those monitoring San Michele. Our strain gages were simply not appropriate for long term monitoring of the strain around a crack. Because of this, there was no point in even using what we had, and obtaining appropriate gages would have been expensive and difficult (to do in Venice). Our initial research on strain gages was not in depth enough for us to realize that those given to us freely by the WPI Civil Engineering Department were the wrong type.

Our anemometer gave us immense technical problems and produced minimal data. However, we have learned that though wind can be a significant force on a tower, it only amplifies existing problems, and is best measured with an accelerometer. Wind will only have a significant effect if the tower is already oscillating, and will cause the oscillation to become even more pronounced, to the level where an accelerometer will detect the resulting motion. The motion of the tower is what is really important, and thus an anemometer is not necessary in monitoring a tower.

7.3 Recommendations

We were able to carry out steps needed to install instruments to monitor structural integrity in a manner that future research groups can build upon and extend.

The following sections describe each of the possible forces in detail, the methods for monitoring, and financial requirements for implementation.

7.3.1 Bell Motion

A typical bell tower in Venice can have anywhere between two and seven bells. The swinging of the bells is controlled by an electronic motor that drives the bells at their natural frequency. The bells cover an arc of 180 degrees, centered at their resting position, and have a maximum height parallel to the horizontal plane at zero and 180 degrees. When the bells rotate, they exert a horizontal force on the tower that causes the tower to begin to oscillate at the same frequency as the driving force. If the driving frequency is close to the natural frequency of the bell tower then the tower will begin vibrate with great amplitudes that can cause structural damage.

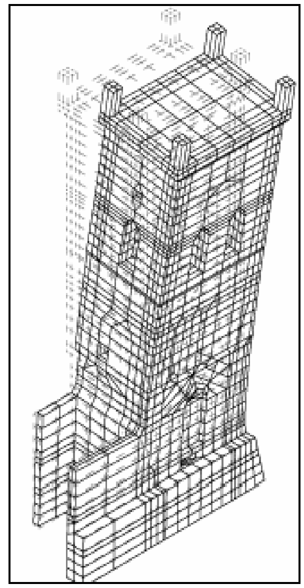


Figure 38- Finite element model of the torque of the tower

We will need to use accelerometers to measure the frequency of the bells and the response of the tower. The exact number of accelerometers needed depends on the analysis that is to be performed afterwards. If the goal is only to measure the response of the tower to the driving force then only two accelerometers are needed. If the goal is instead to perform a torque analysis on the tower, that is to analyze the manner in which different sections of the tower move in response to a driving force, such as in Figure 38, then more accelerometers are needed at each level of the tower. At the bare minimum, an accelerometer is needed on the bell that is swinging and another is needed in the belfry close to the swinging bell. Both of these motions will occur in two dimensions and will require the use of either a dual-axial accelerometer or two single-axial accelerometers. If cost is a concern, then one single-axial accelerometer can be used to first measure the motion in one direction and then measure the motion in the other direction; however, this will take two trials.

When measuring the motion of the bell it is important to make sure that only the bell that is being monitored is swinging. If multiple bells are swinging at the same time then the resulting tower motion will different and it will be difficult to compare the results between towers.

The most damage will be inflicted to a tower when the frequency of the driving force is closest to the natural frequency of the tower. A simple analysis of the data collected would be to determine the frequency of each of the bells and compare that to the analytically calculated natural frequency of the tower. The closer these two frequencies are, the greater the amplitude of the tower motion will be and the more likely that the tower will suffer damager as a result.

There is no simple way to compare the results of one tower to those of another tower. This is due to the large number of parameters that can differ between the measurements of two towers such as the frequency of the bells, natural frequency of the tower, mass of the bell, and length of the bell. If it were possible to ring the same bell at each tower then the only parameter that would differ would be the natural frequency of the tower, a parameter that can be calculated analytically. Then it would be possible to rank towers by the magnitude of acceleration measured and determine which are in the most need of repair.

7.3.2 Seismic Motion

The seismic motion of the lagoon bed influences the tower, and so is important to monitor for a couple of different reasons. The first and most important reason is to measure the potential collapse of the tower from earthquakes. Since Venice is located in a salt marsh, most earthquakes are dampened by the soft mud under the heavy ancient buildings. However, there have been incidents cataloged throughout both history and modern times of Venetian buildings collapsing due to large earthquakes. Smaller earthquakes are a relatively frequent occurrence in the adjacent provinces of Venice, as Venice is located near a fault line. The second major reason to monitor seismic activity in and around bell towers is to see how the settling and rising of the lagoon bed influences the tower. If the lagoon bed settles in a manner unsuitable to buildings in a particular area, the bell towers would be the first to exhibit structural problems, due to their height.

A tower that is influenced by the force of swinging bells is experiencing an external force acting at one end of the rigid body, the top. The tower that is under a seismic force uses the same model, as the seismic force is applied to an end of the rigid body as well, though in this case the end is the foundation.

For the monitoring of this force we will need two different types of equipment. We suggest the use of a piezometers and seismic accelerometers to record the pressures of the lagoon bed and the motion of the tower. These two measurements can later be compared so that we could gain a better understanding of the correlation between the external pressure due to the sinking or rising of the lagoon bed and the motion of the tower.

The accelerometers used for monitoring the motion of the tower due to seismic activity must be within 1000mV/g and 10V/g range of sensitivity. Due to the fact that earthquakes exhibit forces in multiple directions the accelerometers that are placed at the base of the tower must measure on at least two axes, so that they are able to pick up any oscillations or change in the direction of acceleration. This means obtaining a bi-axial or tri-axial accelerometer, or using two single-axial accelerometers, or using one single-axial accelerometer in two different trials. The latter option may not be feasible for measuring seismic activity if this activity is out of the project group's control.

These accelerometers must be placed in multiple locations inside the tower to accurately monitor the different motions within the tower. The first accelerometer should be placed at the base of the tower, so that we may monitor the force of the earthquake or motion in the bed of the lagoon. These measurements can later be correlated with the motion of the tower at different points in the tower.

The second accelerometer placement depends greatly upon if and how the tower is attached to any other building. If the tower's shaft is not attached to any other building, the accelerometer must be placed half way up the tower, and will measure any difference between the acceleration at the bottom of the tower and in the belfry. This can possibly pinpoint any significant weaknesses in the tower. If the acceleration at the top of the tower is significantly different then the projected acceleration calculated from the ground accelerometer and middle acceleration, we can conclude that there is significant damage somewhere between the halfway point and the top of the belfry. An additional reason to conduct recordings at the half way point of the tower is to map the change in motion from the base to the top. Rigid bodies that have a force applied to them at the base may start twisting, which needs to be monitored in the middle where the bowing would be the greatest.

If 35% to 70% of the tower's shaft is attached to a church or any other building, it would be more useful to place the accelerometer on the tower, near where the top of the supporting structure touches the tower. With an accelerometer reading there we will gain a better understanding of how the supporting structure is influencing the motion of the tower. If the church or supporting building is connected to the tower in any structural way, the tower will move in a completely different manner at the place where it is not connected, so we must monitor the transition point.

If less than 35% or more than 70% of the tower's shaft is connected to a supporting structure, we recommend monitoring those towers at the halfway point, the same as free standing structures. If less than 35% of the shaft is connected, then the supporting structure is not enough of an influence, and therefore a reading for the halfway point in the tower is still appropriate. If more than 70% of the tower's shaft is connected, then it does not have enough of a free standing tower to have a significantly different reading than the belfry reading. This reading could be inconclusive of the structural stability of the top of the tower or the motion of the middle of the tower, but is taken on the off chance that the tower is not structurally supported by the walls of the connected buildings.

The third placement of the accelerometer is at the highest structurally supported point in the tower, usually just below the finial of the tower. This is because the higher regions of the tower record the greatest motion from seismic force, and the area below the finial is the highest load bearing structure in the tower. This type of testing was done in the study by Roberto Meli, Dario

Rivera and Eduardo Miranda called 'Measured Seismic Response of the Mexico City Cathedral'. A depiction of their measurement methods and sample data is seen in Figure 39.

We also suggest placing four piezometers near the corners of the building to measure the difference in pressure around the corner blocks of the tower. This is particularly important for measuring the settling of the lagoon bed. If the lagoon bed rises or falls, towers will be subjected to water pressure changes around its foundations. The inconsistent pressures under each side or corner of the tower would add to the instability of the structure and allow the tower to oscillate due to ambient vibrations, such as wind. From the water pressure measurements in the surrounding soil of the towers we can accurately correlate the motion of the tower and the constant or changing pressures in the soil.

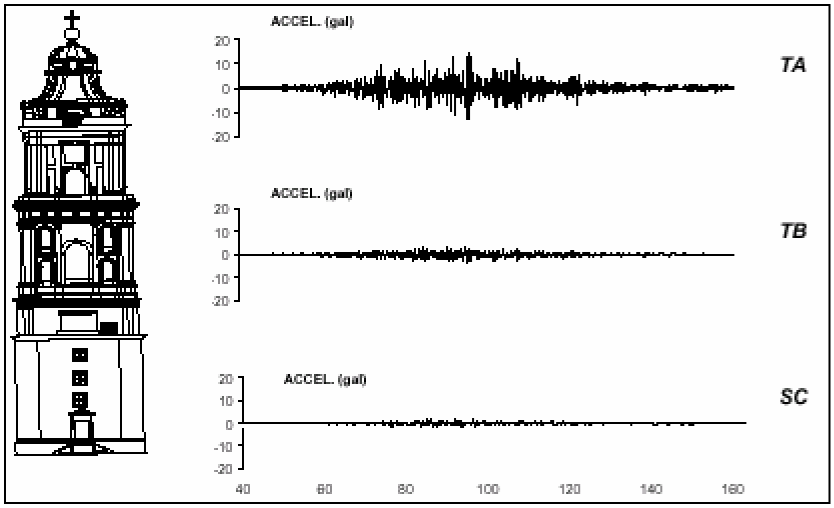


Figure 39- Measured Seismic Response Data

7.3.3 Wind

There are two types of wind force that need to be considered when dealing with wind. The first is a static force that is caused simply by the amount of surface area perpendicular to the velocity of the wind. The second force is a dynamic force, known as vortex shedding, is caused by the pressure differentials that form on the leeward side of the tower. Vortex shedding occurs at a certain frequency that is based upon the size of the tower and velocity of the wind and can cause the tower to oscillate. If the vortex shedding frequency is close to the natural frequency of the tower, the oscillations can become large and result in damage to the tower.

The static force of wind can be determined by measuring the velocity of the wind on the tower and calculating the normal vector of the surface area to the wind. An accelerometer should also be placed in the belfry of the tower to determine what the response of the tower to the wind is, if any. It is important to ensure that enough data points are collected so an equation relating the wind force and tower response can be constructed. Other towers should also be visited, and more wind data collected in order to determine how towers of different heights respond to the same wind force. A linear interpolation can then be performed to determine how towers of any height would respond to a certain wind force, which can allow a ranking system to be created that determines which towers are being affected the most by wind.

7.4 Financial Analysis

Several pieces of hardware and software must be purchased to perform the measurements and to analyze them. The pricing information below details the different items needed and their cost.

The recommended accelerometers are single-axis, low frequency, high sensitivity accelerometers that are used to detect seismic activities. At least two accelerometers are needed to be able to correlate the driving force to the response for the motion of the tower but up to four at a time could be used, in order not to repeat measurements. A junction panel and data acquisition card must be purchased to feed the signals from the accelerometers into a laptop. Lastly, the LabVIEW developer system is needed to collect and analyze all data recorded from the accelerometers. Virtual instruments will most likely have to be written for LabVIEW, but it should be possible to adapt, or at least learn much from, the virtual instruments we have constructed for this project. The VI files themselves are included with our project report, and a description is provided in Appendix C. A table showing the complete financial analysis is shown in Table 3.

Description	Quantity	Price	Total	Vendor
SCC-ACC01, 1-Channel Accelerometer Input Module	4	$295	$1,180	National Instruments
SC-2345 (panelettes, side conn, universal AC, supply incl)	1	$295	$295	National Instruments
Power Cord, 240V, 10A, Euro, Right Angle	1	$10	$10	National Instruments
NI DAQCard-6036E for PCMCIA and NI-DAQ Software	1	$995	$995	National Instruments
SHC68-68-EP Shielded Cable, 68 D-Type to 68 VHDCI Offset, 2 m	1	$110	$110	National Instruments
LabVIEW Full Dev System for Win 2000/NT/XP (English)	1	$1,995	$1,995	National Instruments
1 V/g, 0.025 to 800 Hz, 10-32 side conn.	2	$581	$1,162	PCB Piezoelectronics
			$5,747	

Table 3- Financial Analysis

7.5 Determining When to Monitor – A Suggested Formula

Our database of data collected on Venetian bell towers contains many rankings for each tower in various fields such as amount of cracks, lighting, restoration, etc. This is a very comprehensive view of the tower, but the data isn't very conclusive on its own, so we created a formula to rank towers by need for instrumental monitoring. This ranking follows the general formula "$y = m_1x_1 + m_2x_2 + \ldots + m_nx_n$", where 'y' is the calculated rank of the tower (from 0 and 4). Each value x is a particular ranked field in the database (from 0 to 4), and the value m is the weight given to each field (from 0 to 1).

There were many variables to consider when creating this formula. The criteria were generally based on evaluating the parameters that directly correlate with the structural state of the tower. The final list of parameters was based on two major categories, bell frame and an average of the external and internal assessments of the wall conditions. The parameters that we selected were bell frame missing screws, bell frame dents, bell frame cracks, tower cracks, tower damaged brick, tower inclination, and tower misalignment. Each parameter was then weighted according to its direct reflection of structural issues in the towers.

The crack rating of a tower shows the most prominent signs of structural instability, and so is weighted the maximum value of 1. To calculate an average rating for cracks in a tower, average the crack rating for the interior and average that number with the exterior crack average. To compute the interior crack average rating, average the crack rating in each landing by averaging all the crack ratings for each wall inside each landing in the tower, and then calculate the average of all landings in the tower. To calculate the average crack rating for the exterior of the tower we have to average all the crack ratings of the exterior walls of the tower.

The second important parameter is the condition of bricks inside and outside a tower. The ranking for this parameter is handled in the same manner as the average crack rating for the tower by averaging the external brick condition and internal brick condition average. Although this is an important parameter, it is not as much so as the cracks parameter. The exterior brick damage may be caused by many different factors, and not all of them are a direct reflection of the towers structural problems; therefore, the weight for this parameter is 0.5.

The leaning grade of the tower is the third parameter to be considered. In the majority of cases, if the tower is leaning then it is not distributing load properly throughout the shaft, and is in significant danger of collapse. If the tower is distributing its load in a skewed manner, it is placing one of its building components under higher strain than it was designed to do. Unless external support and corrective procedures are taken, that component will eventually fail. For this reason, this parameter is weighted by the maximum value of 1.

The next area of the tower to assess is the combination of cracks and misalignment of stones. This takes the average cracks of the tower into effect again, because the effect of the misalignments is intensified by the effect of the cracks. But if there are no cracks, then misalignments are unimportant, so if neither is present then this field should be 0. The misalignment is calculated by averaging the misalignment of each wall on each landing, and then averaging the readings for each landing. The product of these two values are taken, which will be 0 if either of the two values are 0. The weight given to this parameter is 1.

The condition of the bell frame should also be considered, because they are a depiction of the structural state of the bell frame. The bell frame is important because if the bells are functioning and are swung at any time inside the belfry, the deterioration of the frame may change the way the weight of the large swinging bells is distributed in the bell tower and cause unexpected changes in load displacement in the tower. These changes may be very harmful to the condition of the tower, and in some extreme cases (such as San Michele), may begin to tear the tower apart from the inside and cause cracks by exceeding the tolerances of specific building blocks of the tower.

The first parameter that reflects the state of the bell frame is the cracks assessment of the frame. Although this is important for evaluating the bell frame, the state of the bell frame is a lot less important for evaluating the tower for instrumental monitoring, since the bell frame only shows potential cause of damage. If the damage is not present in the form of misaligned brick or cracks, the state of the bell frame is either not a major contributing factor to the deterioration of the bell tower, or perhaps the deterioration will show at a greater rate in the future. Therefore the weight for the bell frame crack parameter is 0.4, less than any of the tower shaft parameters.

The bell frame dents parameter is definitely an indicator of the health of the frame, though it is the least important parameter for the evaluation of the tower. It is given a weight of 0.2.

The final parameter to measure the healthy of the bell frame is the number of missing screws. This parameter may be very influential in distributing the load of the swinging bells if the screws are from the load bearing section of the frame, but they may not be. The forms don't provide any way of distinguishing this factor, so the weight is somewhat low, at 0.3.

The final formula:

Tower ranking = 1(avg. tower cracks) + .5(tower brick damage) + 1(tower inclination) + 1(cracks/misalignment) + 0.4(bell frame cracks) + 0.2(bell frame dents) + 0.3(bell frame missing screws).

8 Future Work

Preserving Venice's bell towers is a wonderful goal, but it would be unsettling if the only reason to do so would be to prevent them from falling down. Even though the original social reasons for the towers' importance have faded, the towers have too much potential to allow so much money and effort to go into keeping them alive for the sake of keeping them alive. The ideal world is one where the citizens of Venice genuinely want the bell towers around, and view them again with pride. We have several suggestions for ways for towers to be used that can make them valuable to the Venetian people once again.

One idea is the installation of weather stations on the tops of towers. As the bell towers are the tallest structures in Venice, it makes them ideal for monitoring the atmosphere. However, not only would meteorologists benefit, but some weather stations can emit different colors of light depending on the forecast, clearly visible to people on the ground. Something like this gives immediate and daily value to the people around it, like a clock does. However, though most people have watches nowadays, few people have portable weather forecasters on their person. Even accessing a weather program on a cell phone is less convenient than just looking up.

Another interesting way of using towers would be placing video cameras on certain towers. These could be used in numerous ways. If they were used as webcams and pointed at popular, beautiful campos, or at St. Mark's Square, then the entire world could look at Venice and see life going on in real time. Some could be used as security cameras for the police force or local government, and pointed at relatively high crime areas. The ability to see Venice on high has many different uses.

Some citizens have reported that when large boats travel near their houses, sizeable vibrations rock them, in some cases rattling windows to an alarming volume. Towers could help alleviate this problem by using cameras to track boat routes and compare them to areas where reports are highest to see how the routes could possibly be changed. In addition, accelerometers could be set up in this nearby tower to detect the vibrations and determine how much force they actually contain, as well as seeing how they are potentially negatively affecting bell towers.

The bell tower of San Giorgio Maggiore and the bell tower of San Marco make money allowing the public to enter and see the view. Very few bell towers are set up to handle this. San Giorgio Maggiore and San Marco both have the advantage of having elevators installed, and most bell towers are not constructed in such a way that installing an elevator is even possible. However, allowing the public to walk up a bell tower would not be implausible if a tower were fully monitored and its integrity known. Such an analysis would require a great deal of work and would need to focus heavily on many specific aspects of the tower, such as the stairs and landings. We suggest San

Francesco de la Vigna as a starting point for this idea, as it is one of the few towers whose height is comparable to San Giorgio Maggiore and San Marco, and its stairwells are solid brick and in excellent condition.

The preservation of bell towers is about more than simply maintaining their structural integrity. It's about preserving their spirit and niche in Venetian society. The towers' height and isolation give them the ability to provide unique services and value to everyone from nearby residents to people all over the world. If the notion of bell towers as retired and outdated could be abandoned, and people convinced to experiment with using them in new ways, the true preservation and exaltation of Venetian bell towers can begin.

9 Works Cited

Beall Tool Company. http://www.bealltoolcom/inclo.htm/. *The Inclinometer*. 2 May 2004

Binda, L. and A. Saisi. http://www.arcchip.cz/w11/w11_binda.pdf. *State of the Art of Research on Historic Structures in Italy*. 26 April 2004.

Carlson, D., Prince, R.., Roosa, S. *Computerized Catalog of Venetian Bells and Bell Towers*, WPI IQP, July 1995.

Levy, Matthys and Mario Salvadori. 1992. *Why Buildings Fall Down*. New York: W.W. Norton & Company.

Morillo, E. and Rosas, S. *A Method for the Evaluation of Venetian Bells and Bell Towers*, WPI IQP, July 1994.

Omega Engineering Inc. http://www.omega.com/literature/transactions/volume3/strain.html. *The Strain Gage*. 2 May 2004

Ruskin, John. 1885. *The Stones of Venice*. New York: John W. Lovell company.

Rutter, Richard. http://www.clagnut.com/photos/holidays/venice2003/71/. *Venice 2003. Clagnut/ Photos*. 22 April 2004.

Spina, Dan. http://savethebays.com/Pics/DSC00937I.jpg. *Save the Bays*. 2 May 2004.

Subramanian, M. http://www.svce.ac.in/~msubbu/FM-WebBook/Unit-I/Piezometer.htm. *Piezometer*. 2 May 2004.

Richard Paul Russell Limited. http://www.r-p-r.co.uk/anemometer.htm. *Anemometer - Kesrel 1000 Pocket Anemometer*. 2 May 2004.

Vericom Computers, Inc. http://www.vericomcomputers.com/Support/HowItWorks.htm . *How it Works*. 2 May 2004.

Vernier Software and Technology. http://www.vernier.com/probes/probes.html?acc-group&template=acc.html. *Accelerometers*. 2 May 2004.

Appendix A Annotated Bibliography

Armer, G. S. T. 2001. *Monitoring and assessment of structures.* London: Spon Press.

This book reviews the current technologies for monitoring and assessing structures. It also reviews older, but widely accepted, methods and discusses when each method is applicable and some basic guidelines on how to apply the method. Each chapter has a list of references at the end which may prove useful. There are also two extensive chapters devoted to photography which will be of great use when determining how to record the cracks in the walls of the towers.

Beall Tool Company. http://www.bealltoolcom/inclo.htm/. *The Inclinometer*. 2 May 2004.

This website did not have much factual information, but from it, we found a picture of an inclinometer.

Bergamo. 1987. *Monitoring of large structures and assessment of their safety*. Zurich: International Association for Bridge and Structural Engineering.

This was very specific to bridges, and did not have that much information that was relevant to towers and our project.

Binda, L. and A. Saisi. http://www.arcchip.cz/w11/w11_binda.pdf. *State of the Art of Research on Historic Structures in Italy*. 26 April 2004.

This website has a lot of wonderful pictures showing bell towers in their states of disrepair.

Burland, John, Michele Jamiolkowski and Carlo Vigginai. 2002. Preserving Pisa's Treasure. *Civil Engineering—ASCE*. Vol. 72, No. 3, March: 42-49.

Discusses some of the history of Pisa as well as the modern day struggles to keep the tower stable and upright. The techniques used are potentially too drastic for the leaning towers in Venice but some of the monitoring that was put in place – such as those to determine the rate of declination – may be applicable to our problems in Venice. A good overview and introduction into ideas for monitoring towers.

Carlson, D., Prince, R.., Roosa, S. *Computerized Catalog of Venetian Bells and Bell Towers*, WPI IQP, July 1995.

This past IQP continued the measurements that the 1994 project used, on several new towers. They analyzed all of the towers by their physical attributes, produced a regression analysis, and ranked the towers by need of restoration.

Collacott, Ralph Albert. 1985. *Structural integrity monitoring*. New York: Chapman and Hall.

Discusses methods for monitoring the structural integrity of structures and buildings. The discussions are somewhat technical in nature, and in some parts may be too much so, but the ideas contained within would appear to be applicable to our problem. Since this is a modern treatise on structural issues it focuses mostly on integrity issues concerning metal rather than stone and brick but the information may nonetheless be useful for considering the issues with the bell frames.

De Min, Maurizia and Caterina Tonolo. 1993. *Twenty years of restoration in Venice*. Venice: Il Cardo.

Revoked – not specific enough

Fang, Hsai-Yang. 1991. *Foundation engineering handbook*. New York: Van Nostrand Reinhold.

Potential reference but too in depth for non engineering majors

Feld, J., Carper, K. 1997. Construction Failure. New York: John Wiley and Sons, Inc.

Discusses issues that cause structural failure including natural and those caused by man. For each issue the book shows what signs one can look at to determine the health of the structure. Has a single section devoted to masonry structures although none of the examples are about historic structures. Different kinds of masonry structures are examined as well; reinforced versus non reinforced, hydraulic mortars, etc.

Fitch, James Marston. 1981. Conceptual Parameters of Historic Preservation. *Historic Preservation of Engineering Works*: 37-47.

This article was very advanced. It was hard for us to understand the points the author was trying to get across, since we don't know too much about the subject to begin with.

Fitch, James Martson. 1982. *Historic Preservation.* McGraw-Hill.

Once we know what problems bell towers experience, this will be a valuable reference for information on structural materials and symptoms. I found this by looking through past IQP projects, which referenced and recommended it.

Frost, Marsh and Pook. 1974. *Metal Fatigue*. Oxford: Clarendon Press.

This book was extremely informative on all of the aspects of the fatigue of metals, components and structures. It goes into extreme detail about the effects of temperature, environment and other possibilities that might have some relation to the fatigue of a structure. Most of the emphasis of the book is placed on cracks: the effect of stress concentrations, cracks on fatigue strength and possible reasons for the cracks, the growth of fatigue cracks and factors affecting crack growth. Also, which should be very helpful for the design portion of our project, the book defines several experiments that could be used to test strain amplitude on a structure. This book will be very helpful for our project, but before we can read it and truly understand it, we will need something aimed towards a beginner audience that will explain it in more simplistic terms so we can have a basic understanding of metal fatigue.

GangaRao, Hota V. S. 1995. *Nondestructive testing methods for civil infrastructure*. New York: The Society.

Revoked – not specific enough

Glasgow. 1992. *Monitoring building structures*. New York: Van Nostrand Reinhold.

This article had a lot of information that became useful to us in understanding monitoring techniques. Some of it was above our heads, but what we did understand we learned a lot from.

J.P. Schaffer. A. Saxena, S.D. Antolvich, T.H. Sanders, and S. Warner. 1998. *The Science and Design of Engineering Materials*. McGraw-Hill.

Once we know what problems bell towers experience, this will be a valuable reference for information on structural materials and symptoms. We found this by looking through past IQP projects, which referenced and recommended it.

Lauritzen, Peter. 1986. *Venice preserved*. London: Michael Joseph.

Discusses historic buildings throughout Venice and what steps have been taken in the past to ensure their survival.

Levy, Matthys and Mario Salvadori. 1992. *Why Buildings Fall Down*. New York: W.W. Norton&Company.

This is a fairly well explanation of the causes of building collapse. This book mentions many cases that are similar to the towers of Venice. In particular one tower collapse is examined in detail and an explanation for the collapse is proposed. The civic tower of Pavia collapsed due to many reasons some being bell vibrations and a volatile chemical reaction between the original and new mortar used to repair it.

Mandara, Alberto and Domenico Scognamiglio. *Prediction of Collapse Behavior of Confined Masonry Members with ABAQUS*. http://www.hks.com/reference/bibliography/search-ucp/world/pdf2003/Mandara.pdf. 24 April 2004.

This is a paper that discusses masonry members in great detail, and in a very scientific manner. There were a lot of good images in this paper, and very helpful citations.

Morillo, E. and Rosas, S. *A Method for the Evaluation of Venetian Bells and Bell Towers*, WPI IQP, July 1994.

This was one of the first IQPs completed in Venice that related to bell towers. The focus of the project was to collect various information about bell towers throughout the city. Most of the data they were able to collect was relatively simplistic, physical characteristics of the towers, since they were not able to go inside many of the towers. They created a database will all of their observations.

Omega Engineering Inc. http://www.omega.com/literature/transactions/volume3/strain.html. *The Strain Gage*. 2 May 2004.

This website had a lot of helpful information specifically related to the strain gage. Several pictures shown in our proposal were found on this site.

Smith, Ian. 1998. *Artificial intelligence in structural engineering: information technology for design, collaboration, maintenance, and monitoring*. Berlin: Springer.

Unknown – not available at Gordon library. However, the idea of using AI to assist with the assessment of structural integrity not only sounds like a plausible option but a *good* option.

There have been multiple papers written on this topic but this sounded like the best. It will be requested on inter-library loan

Richard Paul Russell Limited. http://www.r-p-r.co.uk/anemometer.htm. *Anemometer - Kesrel 1000 Pocket Anemometer.* 2 May 2004.

We found a very useful photograph of an anemometer from this website.

Ruskin, John. 1885. *The Stones of Venice*. New York: John W. Lovell company.

This book talks about the origins of towers in Venice. It also talks about the history and some components. It also talks of the importance of noble towers. It compares medieval towers with Venetian towers. We feel this book is some what useful in finding background info on Venetian towers.

Rutter, Richard. http://www.clagnut.com/photos/holidays/venice2003/71/. *Venice 2003. Clagnut/ Photos.* 22 April 2004.

This website has many good photographs of Venetian buildings. The photograph of San Marco that we have included was found at this website.

Spina, Dan. http://savethebays.com/Pics/DSC00937I.jpg. *Save the Bays.* 2 May 2004.

We copied a photograph of a tide gage from this website.

Subramanian, M. http://www.svce.ac.in/~msubbu/FM-WebBook/Unit-I/Piezometer.htm. *Piezometer*. 2 May 2004.

This website provided us with a very interesting picture of how a piezometer works.

Tung, Anthony Max. 2002. *Preserving the world's great cities*. New York: Random House Inc.

Revoked – not specific enough.

Vericom Computers, Inc. http://www.vericomcomputers.com/Support/HowItWorks.htm . *How it Works.* 2 May 2004.

We found this website to be particularly useful in explaining how many of the monitoring tools we are interested in work and what they measure specifically.

Vernier Software and Technology. http://www.vernier.com/probes/probes.html?acc-group&template=acc.html. *Accelerometers.* 2 May 2004.

We found a very useful photograph of an accelerometer from this website.

Appendix B   Table of Bell Towers and Monitoring Years

Codice	Formal Name	Local Name	Sestieri	'92	'95	'96	'97	'01	'04
ALVI	Chiesa di S. Alvise	S. Alvise	Cannaregio	0	0	1	0	1	0
ANDR	Chiesa di S. Andrea Apostolo	La Zirada	S. Croce	0	0	0	0	0	0
ANGE	Chiesa di S. Maria degli Angeli	S. Maria degli Angeli	Murano	0	0	0	0	0	0
ANGM	Chiesa di S. Angelo	S. Angelo	Mazzorbo	0	0	1	0	0	0
ANTN	Chiesa di S. Antonino	S. Antonin	Castello	0	0	0	0	0	0
ANTP	Sant'Antonio	Sant'Antonio		0	0	0	0	0	0
APON	Chiesa di S. Aponallinare	S. Aponal	San Polo	0	0	0	0	0	0
APOS	Chiesa di S. Apostoli	I Santi Apostoli	Cannaregio	0	0	1	0	1	0
ASSG	Chiesa di S. Maria Assunta dei Gesuiti	I Gesuiti	Cannaregio	1	0	0	1	1	0
ASSM	Chiesa di S. Maria dell'Assunzione	S. Maria dell'Assunzione	Lido	0	1	0	1	0	0
ASST	Chiesa di S. Maria Assunta di Torcello	S. Maria Assunta	Torcello	0	0	0	1	0	0
BARN	Chiesa di S. Barnaba	S. Barnaba	Dorsoduro	0	0	0	0	0	0
BART	Chiesa di S. Bartolomeo	S. Bartolomeo	San Marco	0	0	0	0	0	1
BASI	Basilica di S. Marco	S. Marco	San Marco	0	0	0	0	0	0
BENE	Chiesa di S. Benedetto	S. Benedetto	San Marco	0	0	0	0	0	0
BOLD	S. Boldo	S. Boldo	San Polo	0	0	0	0	0	0
CANC	Chiesa di S. Canciano	San Canciano	Cannaregio	0	0	1	0	1	0
CARM	Chiesa di S. Maria Assunta del Carmelo	I Carmini	Dorsoduro	0	0	0	0	0	1
CASS	Chiesa di S. Cassiano	S. Cassian	San Polo	0	0	0	1	0	0
CATM	Chiesa di S. Caterina di Mazzorbo	S. Caterina	Mazzorbo	1	1	0	0	0	0
COSM	Chiesa di Cosma e Damiamo	S. Cosmo	Giudecca	0	0	0	0	0	0
CROA	Chiesa di S. Croce	S. Croce	San Marco	0	0	0	0	0	0
DONA	Chiesa di S. Donato	S. Donato	Murano	0	0	1	1	0	0
ELEM	Chiesa di S. Giovanni Elemosinario	S. Giovanni Elemosinario	San Polo	0	0	0	0	0	0
ELEN	Chiesa di S. Elena	S. Elena	Castello	0	0	0	1	0	0
ELIS	Chiesa di S. Maria Elisabetta	S. Maria Elisabetta	Lido	0	0	1	0	0	0
ERAS	Sant'Erasmo	Sant'Erasmo		0	0	0	0	0	0
EROS	Sant'Erosia	Sant'Erosia		0	0	0	0	0	0
EVAN	Chiesa di S. Giovanni Evangelista	S. Giovanni Evangeli	San Polo	0	0	0	0	0	0
FAVA	Chiesa di S. Maria della Consolazione	La Fava	Castello	0	0	0	0	0	0
FELI	Chiesa di S. Felice	S. Felice	Cannaregio	0	1	0	1	1	0
FORM	Chiesa di S. Maria Formosa	S. Maria Formosa	Castello	0	1	0	0	0	0
FOSC	Chiesa di S. Fosca	S. Fosca	Cannaregio	0	0	1	0	1	0
FRAR	Chiesa di Santa Maria Gloriosa dei Frari	I Frari	San Polo	0	0	1	0	0	0
GERE	Chiesa di S. Geremia e Lucia	S. Geremia	Cannaregio	1	1	0	1	1	0
GESU	Chiesa di S. Maria del Rosario	I Gesuati	Dorsoduro	0	0	0	0	0	0

GIMA	Ciesa di S. Giorgio Maggiore in Isola	S. Giorgio	Giudecca	0	0	0	0	0	1
GIOB	Chiesa di S. Giobbe e Barnardino	S. Giobbe	Cannaregio	0	0	1	0	1	0
GREC	Chiesa S. Giorgio dei Greci	I Greci	Castello	0	0	0	0	0	0
GRIS	Chiesa di S. Giovanni Grisostomo	S. Giovanni Grisosto	Cannaregio	0	0	1	0	1	0
ISEP	Chiesa di S. Isepo	S. Giuseppe	Castello	0	0	0	0	0	0
LAZZ	Chiesa di S. Lazzaro dei Mendicanti	I Mendicanti	Castello	0	0	0	0	0	0
LUCA	Chiesa di S. Luca	S. Luca	San Marco	0	0	0	0	0	0
MAGG	Chiesa di S. Maria Maggiore	S. Maria Maggiore	S. Croce	0	0	0	0	0	0
MANT	Chiesa delle Suore Mantellate	Suore Mantellate	Castello	0	0	0	0	0	0
MARB	Chiesa di S. Martino di Burano	S. Martino	Burano	0	1	1	1	0	0
MARC	Chiesa di Santi Ermagora e Fortunato	S. Marcuola	Cannaregio	0	0	1	0	0	0
MARG	Chiesa di S. Margherita	S. Margherita	Dorsoduro	0	0	0	0	0	0
MART	Chiesa di S. Martino di Castello	S. Martino	Castello	0	0	0	0	0	0
MARZ	Chiesa di S. Marcilliano	S. Marziale	Cannaregio	0	0	1	0	0	0
MATE	Chiesa di Maria Mater Domini	Maria Mater Domini	S.Croce	0	0	0	0	0	0
MEND	Chiesa di S. Nicolo dei Mendicoli	S. Nicolo dei Mendicoli	Castello	0	1	0	1	0	0
MICH	San Michele	S. Michele		0	0	0	0	0	1
MIRA	Chiesa di S. Maria dei Miracoli	I Miracoli	Cannaregio	0	0	0	0	0	1
MOIS	Chiesa di S. Moisè Profeta	S. Moisè	San Marco	0	0	0	0	0	0
NICO	Chiesa di S. Nicolò del Lido	S. Nicolò	Lido	0	0	0	1	0	0
OGNI	Chiesa di Ognisanti	Ognisanti	Dorsoduro	0	0	0	0	0	0
OGNP	Ognissanti di Pellestrina	Ognissanti di Pellestrina		0	0	0	0	0	0
ORIO	Chiesa di S. Giacomo dell'Orio	S. Giacomo dell'Orio	S. Croce	0	0	0	1	0	0
ORTO	Chiesa di S. Cristoforo	La Madonna dell'Orto	Cannaregio	0	1	0	0	1	0
PANT	Chiesa di San Pantaleone	S. Pantalon	Dorsoduro	0	0	0	0	0	0
PAUL	Chiesa di S. Francesco di Paula	S. Francesco di Paula	Castello	0	0	0	0	0	0
PIAP	Chiesa di S. Pietro Apostolo	S. Pietro		0	0	0	0	0	0
PIEM	Chiesa di S. Pietro Martire	S. Pietro Martire	Murano	0	0	0	0	0	0
PIET	Chiesa di S. Pietro Apostolo	S. Pietro di Castello	Castello	0	0	0	0	0	0
PIVI	Chiesa La Pietà S. Maria della Visitazione	La Pietà	Castello	0	0	0	0	0	0
POLO	Chiesa di S. Paolo Apostolo	S. Polo	San Polo	0	0	0	0	0	0
RAFF	Chiesa de S. Angelo Raffaele	L'Anzolo Rafael	Dorsoduro	0	0	0	0	0	0
REDE	Chiesa del SS. Redentore	I Redentore	Giudecca	0	0	0	0	0	0
RINA	Chiesa di S. Caterina	S. Caterina	Cannaregio	0	0	1	0	0	0
ROCC	Chiesa di S. Rocco	S. Rocco	San Polo	0	1	0	1	0	0
ROMI	Chiesa delle Eremitane	Le Romite	Dorsoduro	0	0	0	0	0	0
SALU	Chiesa di Santa Maria della Salute	La Salute	Dorsoduro	0	0	0	0	0	0

SALV	Chiesa di Ss. Salvatore	S. Salvador	San Marco	0	0	0	0	0	1
SAMU	Chiesa di S. Samuele Profeta	S. Samuele	San Marco	0	0	0	0	0	0
SCAL	Chiesa di S. Maria di Nazareth	Gli Scalzi	Cannaregio	0	0	1	0	1	1
SEBA	Chiesa di S. Sebastiano	S. Sebastiano	Dorsoduro	0	0	0	0	0	0
SILV	Chiesa di S. Silvestro	S. Silvestro	San Polo	0	0	0	1	0	0
SIMG	Chiesa di S. Simeone Profeta	S. Simeon Grando	S. Croce	0	0	0	0	0	0
SIMP	Chiesa di S. Simeone e Giuda	S. Simeon Piccolo	Santa Croce	0	0	0	0	0	0
SLIO	Chiesa di S. Leone IX pp.	S. Lio	Castello	0	0	0	0	0	0
SOFI	Chiesa di S. Sofia	S. Sofia	Cannaregio	0	1	0	1	1	0
STAE	Chiesa di S. Eustachio	S. Stae	S. Croce	0	0	0	0	0	1
STEF	Chiesa di S. Stefano Profeta	S. Stefano	San Marco	0	0	1	0	0	0
STEM	S. Stefano di Murano	S. Stefano di Murano	Murano	0	0	0	0	0	0
TERE	Chiesa di S. Teresa	Le Teresa	Dorsoduro	0	0	0	0	0	0
TOLE	Chiesa di S. Nicola da Tolentino	I Tolentini	S. Croce	0	0	0	0	0	0
TRIN	Chiesa della SS. Trinità	S. Trinità	Giudecca	0	0	0	0	0	0
TROV	Chiesa di S. Gervasio e Protasio	S. Trovaso	Dorsoduro	0	0	0	0	0	0
VALV	Chiesa di S. Maria di Val Verde	La Misericordia	Cannaregio	0	0	1	0	0	0
VIDA	Chiesa di S. Vitale	S. Vidal	San Marco	0	0	0	0	0	0
VIGN	Chiesa S. Francesco de la Vigna	La Vigna	Castello	0	0	0	0	0	1
VISI	Chiesa di S. Maria della Visitazione	S. Maria della Visitazione	Dorsoduro	0	0	0	0	0	0
ZACC	Chiesa di S. Zaccaria	S. Zaccaria	Castello	0	0	0	0	0	0
ZAND	Chiesa di S. Giovanni Decollato	S. Zandegola	S. Croce	0	0	0	0	0	0
ZANI	Chiesa di S. Giovanni Novo	S. Zaninovo	Castello	0	0	0	0	0	0
ZITE	Chiesa di S. Maria della Presentazione	Le Zitelle	Giudecca	0	0	0	0	0	0
ZULI	Chiesa di S. Giuliano	S. Zulian	San Marco	0	0	0	0	0	0

Appendix C LabVIEW and Virtual Instruments

In our monitoring of San Giorgio, we constructed software device drivers for our accelerometers and strain gages. These are called "virtual instruments" and can be made and used with a software program/language called LabVIEW. LabVIEW is an extremely powerful visual programming language, perhaps as powerful as a mainstream textual language such as C++. Virtual instruments (VIs) are needed because the accelerometers and strain gages we used end in bare wires. These transmit only voltage levels, and not any intrinsically useful data. Our VIs translated these voltage levels into useful data, as well as a host of other things to facilitate our project. We made six virtual instruments for our project, two main VIs and four "subVIs" (VIs used as components inside other VIs).

Section 1 Virtual Instruments

Every VI has a front interface, with knobs and buttons to interact with, and a backend, where the actual code and computation structure is laid out. A picture of both parts for our two main VIs and pictures of the backends for the four subVIs are shown below. This appendix will not serve as a full technical software documentation, but as a general description of the function and flow of each VI. A more full documentation can be found in "Bell Towers LabVIEW Doc.txt", included with our project report. All VI files created are their name followed by the file extension ".vi", and are included with our report.

To actually use these virtual instruments to read real data, you need to have the instrument properly hooked up to your computer. We used a data acquisition (DAQ) kit, which includes a circuit board for the wires of each instrument to hook into, and a PCMCIA card to be installed into a computer. The circuit board connects into the PCMCIA card, and feeds the data from the instruments into that card. LabVIEW reads incoming data from the PCMCIA card, which LabVIEW programmers can then manipulate. If you do not have any instruments hooked up, just having the PCMCIA card in the slot will still constantly give a stream of "junk" or "ghost" data coming in to LabVIEW that you can use to test the instruments out.

Section 2 Main Virtual Instrument

Our main VI is Bell Towers Recording ("Bell Towers Recording.vi"). Figure 40 shows the front interface, and Figure 41 shows the backend. This VI uses 4 other VIs within it, which will each be covered in detail later. The purpose of Bell Towers Recording is to:

- act as a control center interface for us to interact with
- provide the general program structure
- manage timing of subprograms, including reading from instruments

To read from an instrument, you need to select the device number and channel, but these can generally be left to the defaults of 1 and 0, respectively. Select the device you are using (Accelerometer 25G, Accelerometer 50G, or Strain Gage) from the pull-down menu to the right of the device and channels boxes. "No. of scans" is how many times it will poll the instrument for data, and "scan rate" is how often it will make a scan, in scans per second. Together it determines the duration and density of the data scanned in.

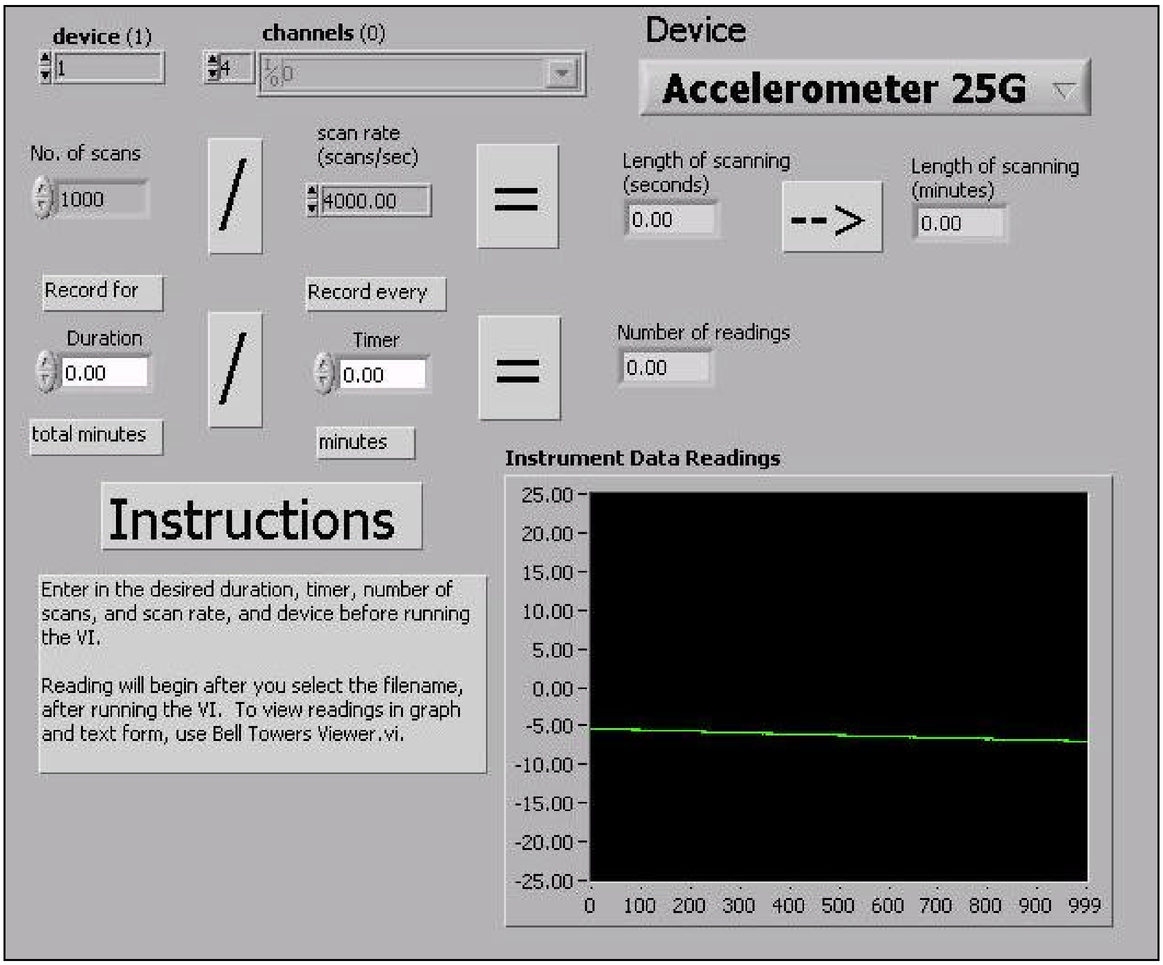


Figure 40- Front interface of the main VI

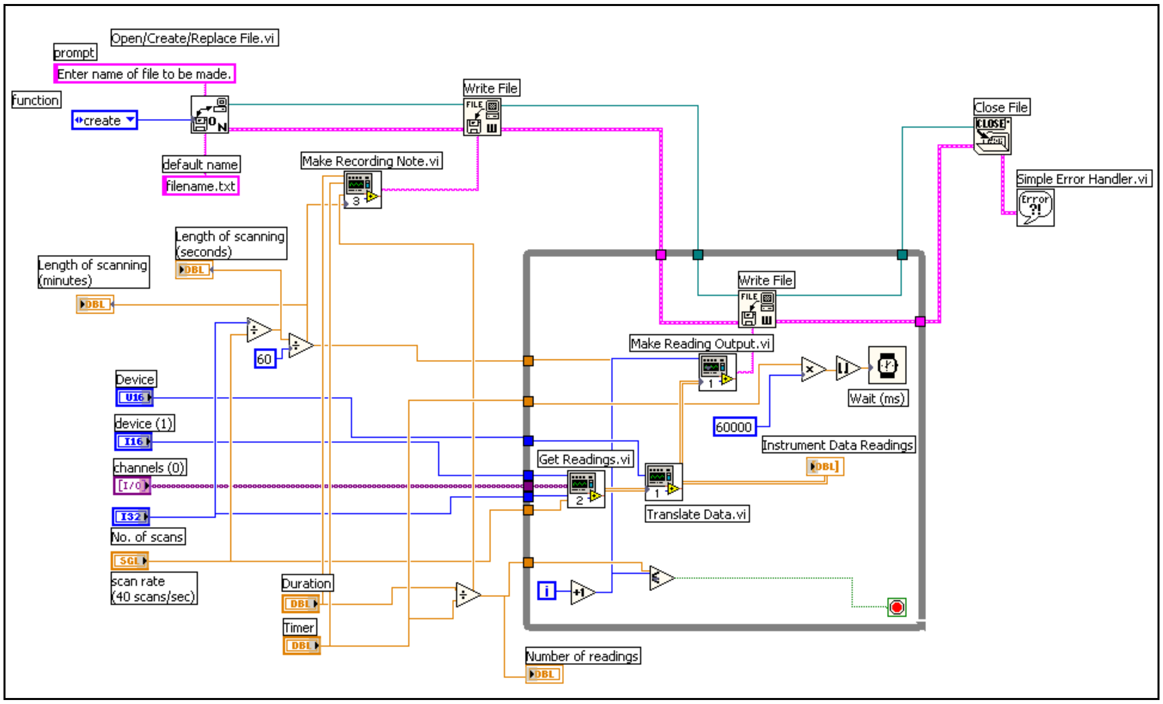


Figure 41- Backend of main VI

For example, if you want to read in data for 10 minutes (600 seconds) you would want the no. of scans to be 600 times more than the scan rate. In whatever ratio you choose, the higher the no. of scans, the denser and more comprehensive the data will be for that time span. However, this also means that the data storage cost is higher. When the VI is run, the duration is reported in the boxes labeled "Length of scanning", in both seconds and minutes.

This can be set to record at set intervals, controlled by the "Duration" and "Timer" boxes. The timer specifies how often recordings are started, and the duration is the total number of minutes the entire VI should run. The duration divided by the timer is how many readings will be done in total, and this will be reported in the "Number of readings" box when the VI is run. The duration should be evenly divisible by the timer.

Finally, run the VI in LabVIEW and it will prompt you to enter a filename for the file data will be recorded to. When that is done, it will begin recording data according to the parameters chosen, and writing it to the named file.

Section 3 Get Readings

The acquisition of data is managed by Get Readings.vi, a subVI used in Bell Towers Recording. The back end is shown in Figure 42.

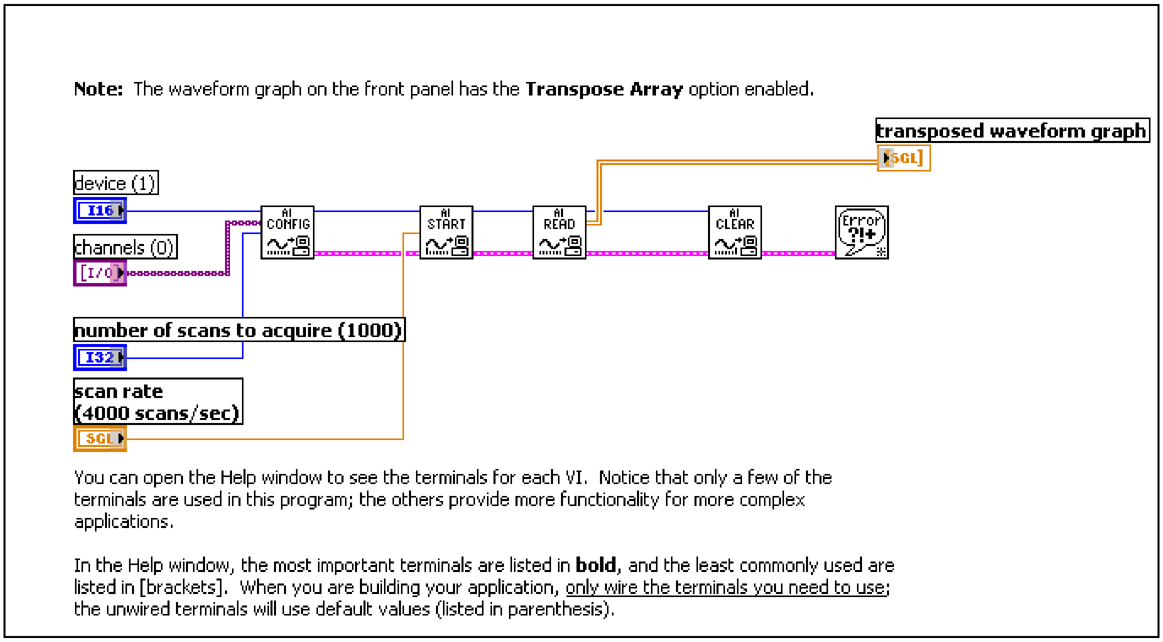


Figure 42- Backend of GetReadings.vi

This is the only VI used which is entirely taken from examples provided with LabVIEW. Nothing original has been added to it by us (though we renamed it), we are just using it as a component in a larger program, as it is meant to be used. Given the inputs of device and channel number, the number of scans, and the scan rate, it uses many subVIs of its own to interact with the hardware and get readings of data, which are output to a graph, whose data can be used in a larger program. This obtains only raw data (in the case of accelerometers and strain gages, voltage readings).

Section 4 Translate Data

Translate Data.vi will take in the voltage readings and transform them into useful data. The backend is shown in Figure 43.

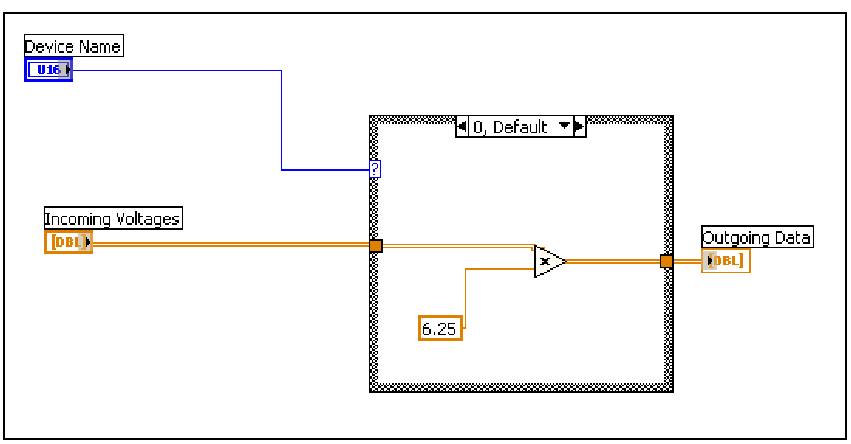


Figure 43- Backend of TranslateData.vi

The transformation process happens inside the grey box, and is very simple. The contents of the grey box will differ depending on the device name chosen on the Bell Towers Recording interface. The picture above shows the process for the 25G Accelerometer, which is simply to multiply the voltages by 6.25. It outputs the adjusted data, which can be used in a larger program.

Section 5 Make Recording Note

The data file writing is handled by two subVIs, Make Recording Note.vi and Make Reading Output.vi.

Make Recording Note is run only once while the VI runs, right at the beginning. It writes a note to the beginning of the file which describes the parameters selected when the VI was run, as well as the date and time the instrument reading session began. Make Recording Note's backend is shown in Figure 44.

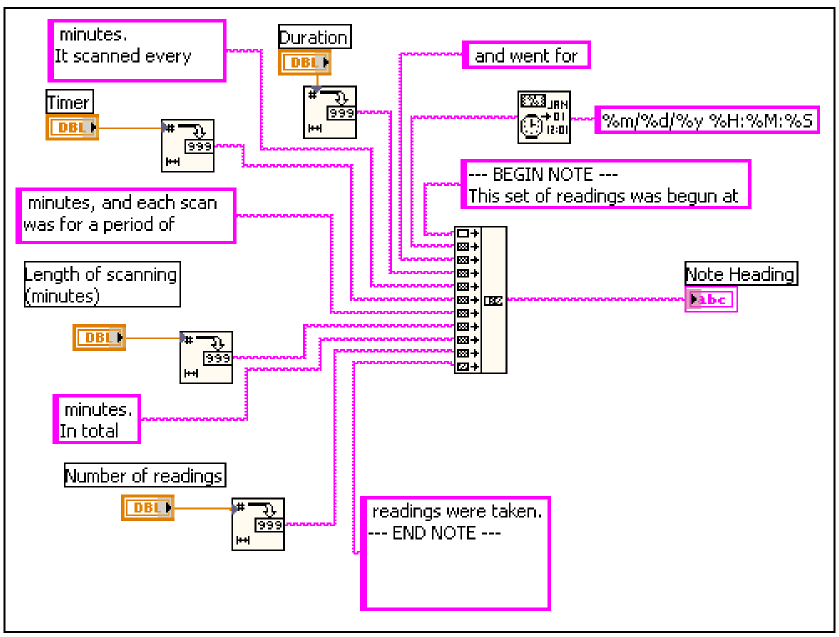


Figure 44- Backend of MakeRecordingNote

It simply takes certain parameters from the front interface as inputs, and uses them to construct a block of information which is output. The text is actually written to the file in Bell Towers Recording. The format is as follows (the numbers themselves may differ, of course):

--- BEGIN NOTE ---
This set of readings was begun at 06/21/04 10:40:59 and went for 10 minutes.
It scanned every 2 minutes, and each scan was for a period of 1 minutes.
In total 5 readings were taken.
--- END NOTE ---

Section 6 Make Reading Output

Make Reading Output.vi, shown in Figure 45, runs once every time data is read from the instrument. It takes the data from Translate Data.vi and constructs a block of information to be written to the data file.

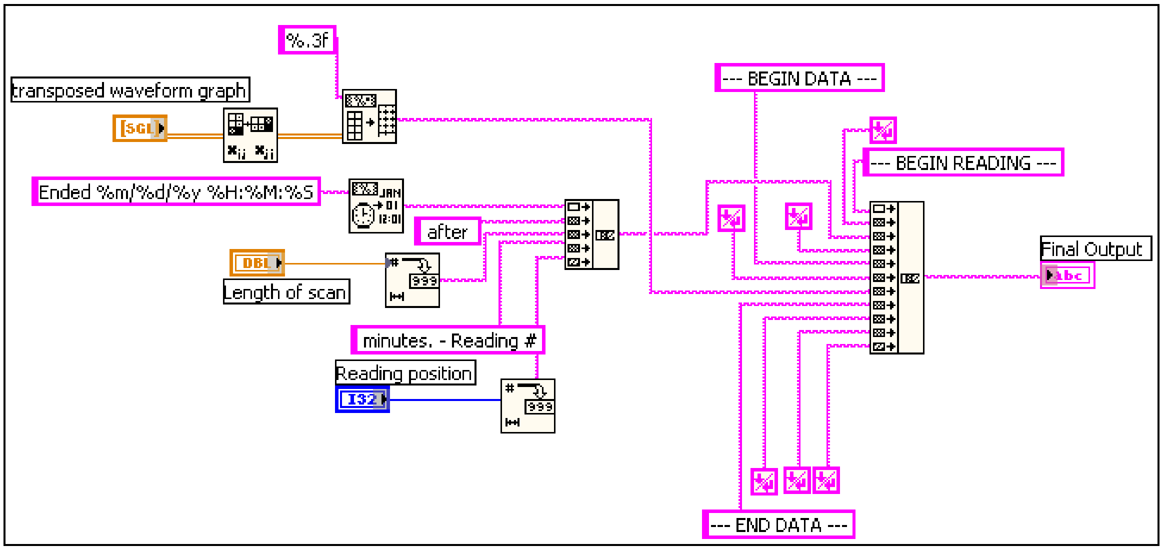


Figure 45- Backend of MakeReadingOutput.vi

It takes in the data read, along with the duration of the scan, and the position of the reading (1st, 2nd, 3rd, etc.) and constructs a block of text, of the format:

--- BEGIN READING ---
Ended 06/21/04 10:41:02 after 0 minutes. - Reading #1
--- BEGIN DATA ---
37.018 37.018 36.987 36.987 36.957
--- END DATA ---

Numbers would be different, and data would generally be longer than 5 reads. All data is stored on one line, an array of numbers which are the data values read for that period of time.

Section 7 Bell Towers Viewer

The other main VI we built is Bell Towers Viewer.vi. This is not used during the recording of data, but rather a helpful tool for viewing the data we have recorded Figure 46 is a picture of the interface and Figure 47 back end.

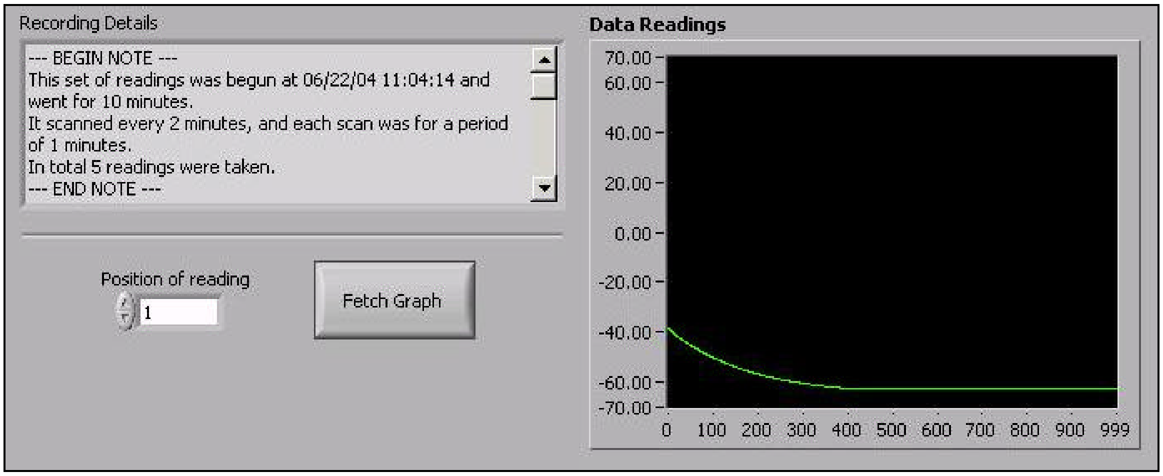


Figure 46- User Interface of BellTowersViewer.vi

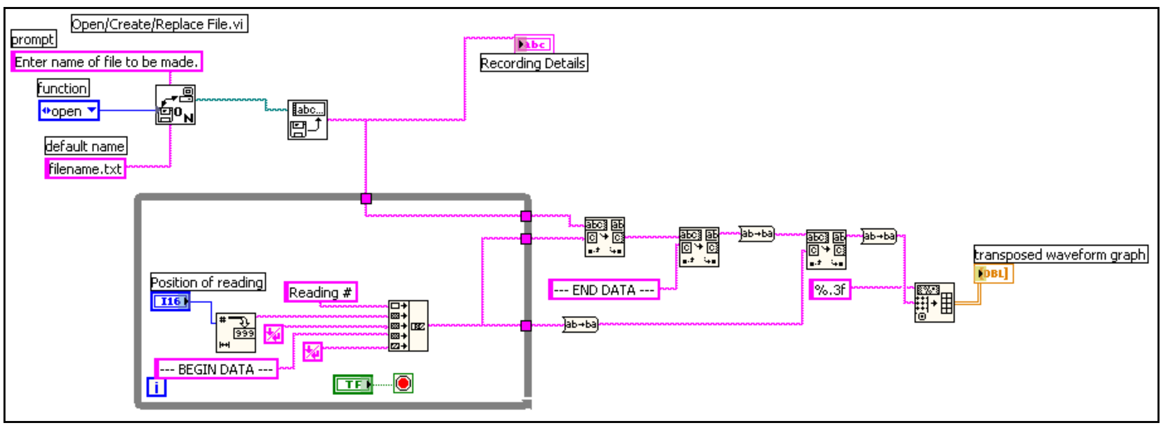


Figure 47- Backend of BellTowersViewer.vi

When the VI is run, it prompts the user for the file name to open. When the file is selected, the text of the file is loaded into the textbox named "Recording Details". The note for the recording should be displayed at the top, which the user can use to help him choose which reading he wants. After it is determined what reading is wanted, the number of the reading should be entered into the "Position of Reading" box. Lastly, click "Fetch Graph" and a graph of the data will be displayed in the "Data Readings" graph.

Appendix D Modified Field Forms

The following set of forms iis meant to also be used as a stand alone guide that should be printed out on its own and carried by any group to any bell tower that they are visually monitoring. It is in a separate file titled “Bell_Tower_Forms_E04.doc”.

Appendix E Guide to Cataloging the Venetian Bell Tower

This appendix is meant to also be used as a stand alone guide that can be printed out on its own and carried by any group going to catalog a bell tower. For this reason, we have printed and bound it as its own document. It is stored in a separate file titled "Bell_Tower_Guide_E04.doc".