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Preserving Venetian Bell Towers Through Virtual Experiences

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Preserving Venetian Bell Towers Through Virtual Experiences

Documenting the Bells and Bell Towers 'de Ultra'

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Abstract

This project aimed to aid in the preservation of Venetian bell towers by updating Venice Project Center bell tower databases through documenting their state and creating virtual experiences. It was achieved by collecting extensive written, visual, and audio data of the towers and bells. A rotating camera was then used to create 3D virtual tours of the 17 bell towers and 71 bells documented in the sestieri of Dorsoduro, San Polo, and Santa Croce. Most towers and bells were in fair to good condition, with only three towers needing major repairs and two needing bell repairs. The resulting data was added to bells.veniceprojectcenter.org. Concurrently, a mobile data collection application was created to assist future groups and campanologists in recording consistent and comprehensive data.

Executive Summary

Scattered throughout the many islands of Venice lie 136 bell towers, known by the locals as *campanili*. These towers rise above the classic buildings of the city, forming a distinguishable skyline, and are physical representations of its rich history and religious heritage. For hundreds of years, they played a major role in the city by calling people to worship, alerting the citizens in times of danger, and ringing to indicate the time. However, with the advent and widespread usage of more modern technologies such as the radio, watches, and later, smartphones, the towers are no longer needed for the same purposes as they were centuries before. This reality, along with dropping church attendance in Venice and across Italy that affects donations, means that the towers and their bells are becoming decrepit and stricken by disrepair. Over time, this has compromised the towers' structure, restricted their accessibility, and made them more prone to collapse, in addition to gradually degrading the bells' sound.

In order to combat these issues, Worcester Polytechnic Institute's (WPI) Venice Project Center (VPC) has been working with the Curia Patriarcale of the Archdiocese of Venice to ascend towers since 1992, recording information and assessing their conditions. As of 2014, according to Venipedia.org, the seven bells teams were able to visit and document the states of about 50% of the total towers out of the 136 total in Venice and the surrounding islands. These past teams completed tasks such as collecting and analyzing data on the interiors of towers, exteriors of towers, and the bells, as well as creating Venipedia pages for each tower and an online database at bells.veniceprojectcenter.com where all the information is stored and presented. Our project aimed to continue previous efforts and add to the databases, focusing on towers in the sestiere of Dorsoduro, Santa Croce, and San Polo, shown in Figure i.

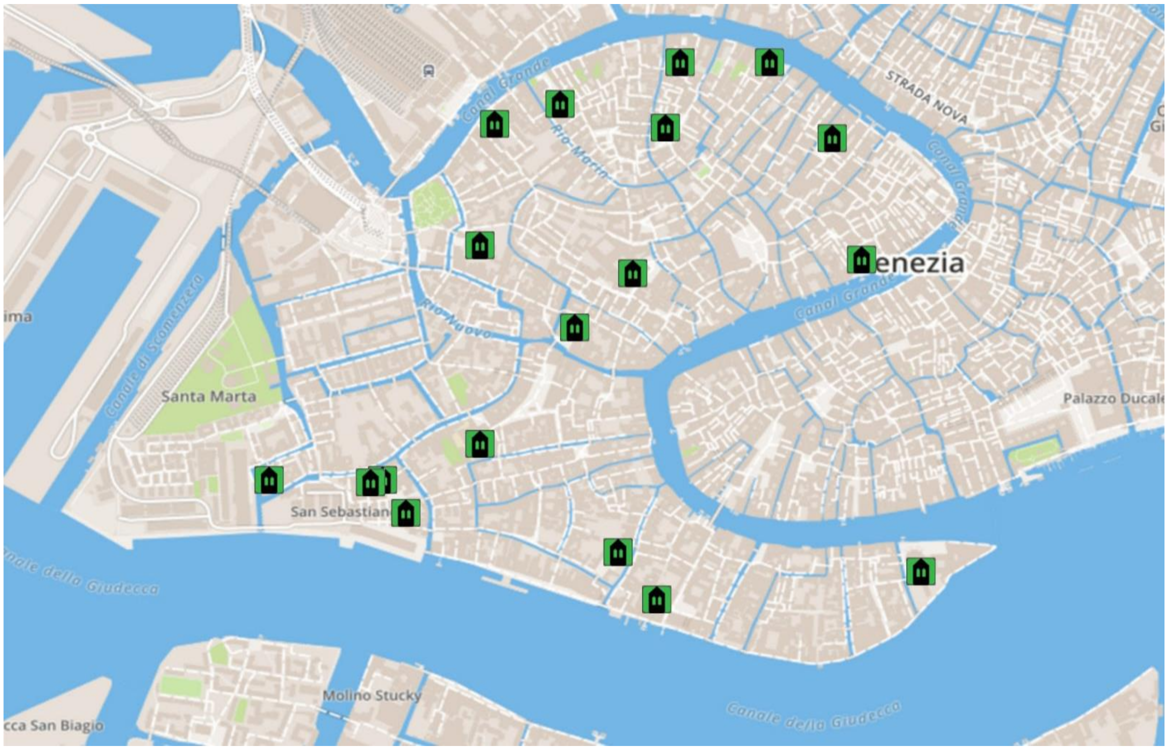

Figure i - Illustration of bell towers visited for this project.

To assist in the raw data collection, we set out to actually improve the data collection process by creating a web app that connects directly to the already existing database, cutting out the need to manually enter already-collected data. Additionally, we added to the knowledge base of the towers by creating 3D virtual tours of each one we visited, tours which can be interacted with and can also be used in an educational and informative way. We were able to accomplish this thanks to Matterport loaning us one of their 3D Pro Camera, which allowed us to open up a whole new dimension to the project that wasn't previously possible.

At the start of our project, we had three main objectives that we hoped to complete over the entirety of the seven week term. These objectives were to increase public awareness about the condition of the bells and bell towers by publishing virtual tours of them, to collect data and update the appropriate databases on the Venetian bell towers in the sestieri of San Polo, Santa Croce, and Dorsoduro, and to create a mobile application to collect the data about bell towers. For objective one, we utilized the Matterport 3D camera mentioned in the above paragraph. A picture of the Matterport can be found below in Figure ii.

Figure ii - The Matterport Pro 3D Camera

The Matterport used 6 normal camera lenses and 3 infrared lenses to scan its surroundings while taking pictures, it then was able to stitch each photo together by itself to form a complete virtual tour, providing depth to objects with the IR lenses. The tours were made available to view on Matterport's own website and then embedded into bells.veniceprojectcenter.org. To view all of the Matterport tours our group created visit https://sites.google.com/site/ve16bell/virtual-tours-3.

For objective two, we visited 16 churches and 17 bell towers. While at each, we recorded comprehensive information about the interiors and exteriors of each tower, as well as information about each individual bell. The interiors of the towers are made up of the interior shaft and belfry. Some major examples of data recorded in the interiors were measurements of each landing by length, width, and height, starting from the ground floor and up to the belfry, measurements of each window, observing and recording the number of cracks that were present in the walls, counting the stairs, and determining stair and landing stability and cleanliness in order to give each tower an accessibility and safety rating. When we ascended to the belfry, the dimensions of every accessible bell were measured, and we also made observations and ratings of the bells' conditions. Additionally, we took recordings of every bell that we could reach to rate their sound quality to determine their conditions. On the outside, measurements were made of any exterior doors, as well as exterior blocks on the base. Additionally, by observing tower traits such as the finial, or the decoration on the top of the tower shown in Figure iii below, the roof style, and the number of different brick colors, it is possible to discern how many times the tower had been restored in the past as well as the actual architectural style.

Figure iii - Example of a finial

In order to assist and streamline the process for data collection and submission into the databases, a web application was created for objective 3. The web app connects directly to the bells.veniceprojectcenter database. The advantage of developing it as a web application rather than an app specific to Android or Apple, for example, was that it can be accessed and used with a smartphone or a desktop computer, improving its versatility.

We were able to create 3D virtual tours of every single bell tower we ascended, regardless of their physical condition. Of the 17 virtual tours, 6 included not only bell towers, but the churches that the bell towers belonged to. These churches were San Nicolo dei Mendicoli, San Pantalon, San Cassiano, Santa Maria del Carmini, San Trovaso, and San Giacomo dall'Orio. A dollhouse view of Carmini can be seen below in Figure iv.

Figure iv - Scan of Santa Maria del Carmini

Every tour was then uploaded to the Matterport website, made public, and then embedded into bells.veniceprojectcenter.com. Additionally, we were able to develop a comprehensive math-based method to evaluate the safety and accessibility of each tower. This method utilized numbers and conditions that were recorded over the course of the term, such as landing condition rankings, stair stability rankings, and vibrational data to assign numerical values to the towers. Rankings were based on values assigned to the interior, exterior, and bells, which were then compiled to create an overall tower ranking for each. The visual results of the tower ranking process can be found in Figure v below.

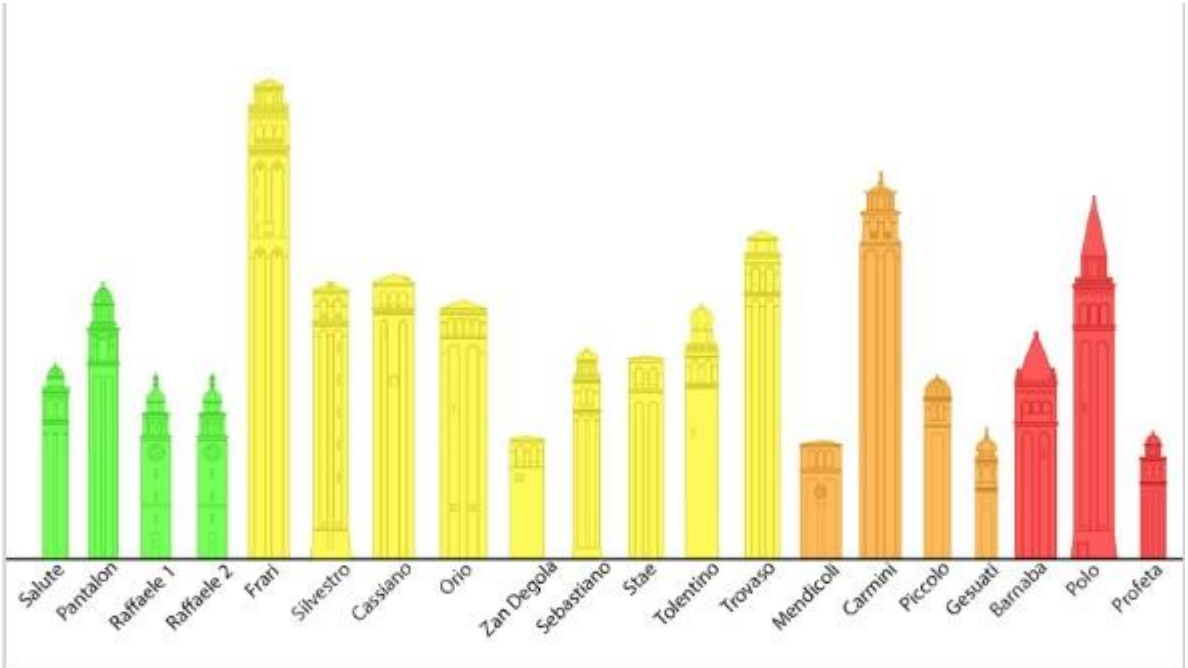

Figure v - Order of Bell Towers Ranked from Best (Left) to Worst (Right)

All of the raw data and analysis was then loaded into the bells.veniceprojectcenter website and Venipedia, and given to the Curia as well.

After we finish our projects, we hope that our hard work can do a great service for not only future bells teams, but for the Curia as well. After completing our tower rankings, we provided specific near term and long term future recommendations for the restoration of the bell towers of San Nicolo dei Mendicoli, Santa Maria del Carmini, San Simeon Piccolo, and Santa Maria del Rosario dei Gesuati. Ideally, future teams will be able to use our app to continue in the documentation and preservation of all of the bell towers across Venice, while adding new features that could be helpful, such as detailed diagrams of the conditions of each tower and a donate button on each tower page that allows any visitor to donate directly to the church of the tower that needs restoration. This will help the Curia use the information we collected in order to raise awareness of the conditions of the bells and bell towers through the use of data and pictures and to drive fundraising for conservation. By providing the tower database to the public, we believe that the towers can be preserved for years to come.

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Authorship

Fritz Brokaw	Wrote: Sections 2.2, 4.9, and Appendix F. Edited: Methodology. Created all graphics and the Final Presentation.
Rachel Huntley	Wrote: Abstract, sections 2.3, 3.1, 3.2, 3.3, 4.1, 4.3, 4.4, 4.5, 4.7, 4.8. Edited: Introduction, Background, Methods and Results and Analysis, and Recommendations.
Ricky Metters	Wrote: Executive Summary, Acknowledgements, sections 2.1, 2.3, 3.1, 3.2, 4.6, and 5. Edited: Introduction, Background, Methods, and Results.
Oba Seward-Evans	Created the data collection app. Updated bells.veniceprojectcenter website. Wrote: sections 3.3, 4.1, 4.2, and Appendix A-E. Edited: Executive Summary, Results, and Background.

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Finally, we'd like to thank Laura Robinson at the WPI Gordon Library for assisting us in the research process when we were writing our proposal for ID2050 and Jonathan Taggart for coming to the first tower, San Sebastiano, with us, and granting us some of his knowledge of bronze and the history of bells. Last but not least, we'd like to extend our gratitude towards Sibyl Chen and the rest of the Matterport team, for generously loaning us their 3D Pro Camera to create our tower virtual tours. Without the aforementioned individuals and organizations, the project could not have been completed at the caliber that we’ve been able to achieve.

1. - Introduction

Originating in their modern form in China during the 11th Century B.C., bells have played a significant role in the customs of ancient civilizations (Rombouts, 2014). The Chinese regarded them as hierarchical symbols that were considered “the vessel in which the human encountered the divine” (Rombouts, 2014, p.19). In 530 A.D., the art of bell casting quickly entered the traditions of Christianity in Italy, and the bells were first placed in campanili, or bell towers (Rombouts, 2014). As Charlemagne spread Christianity throughout Europe, the bell soon “became the sound of unified Europe” (Rombouts, 2014, p.29). Since bells are intrinsically linked to the extensive histories of Europe and the ancient dynasties of China, as well as the religions of Christianity and Buddhism, there have been extensive efforts in preserving them. Preservation attempts have been undertaken by both secular and religious institutions, including the development of preservation guides and the opening of a Smithsonian exhibit to display the artistry of bells from Bronze Age China. (“The Conservation and Repair of Bells and Bellframes”, 2007; Wilson et al., n.d.).

Within the boundaries of Venice lie 136 bell towers that hold an estimated 576 bells (Carrera, 2016). The bells and their towers are major pieces of the deep architectural and artistic histories of the Venetian Republic (Cotton, 2016a). Additionally, the towers are among the most prominent parts of the city, as they rise up above the city’s skyline and act as landmarks. Their prominence is also emphasized by the sheer number of them across the city, as every island that makes up the centro storico, or historic center of Venice, was once its own community with its own church and bell tower (Carrera, 1996). While in the present they have lost many of their practical uses due to constant improvements in technology, they are still a strong reminder of the city's deep cultural heritage, and need to be recorded so their meaning and importance are not lost to history.

Over the past two decades, Worcester Polytechnic Institute (WPI) Interactive Qualifying Project (IQP) teams have been building a catalogue of all of the bells and towers with the Curia Patriarcale, the governing body of the Catholic Church in Venice and the project sponsor, in order to educate the public about the bell towers' conditions, help document and preserve these bells, and to ensure that in the event of a tower collapse due to deteriorating conditions, there would be enough information to rebuild. Previous groups have recorded information ranging from the condition of the tower to the sound of the bells. The majority of the work to date has been on the San Marco side of the Grand Canal, where 22 of the most heavily documented towers are located. Currently, 45% of those 22 towers are in poor or very poor condition (Venice Project Center, 2015). As a way to increase awareness of the towers history and state of deterioration, the teams have shared their information on several websites including Venipedia and the bells website, bells.veniceprojectcenter.org.

While the information available for the bell towers on the San Marco side is relatively detailed and plentiful, that is not the case for the towers 'de Ultra,' or on the opposite side of the Grand Canal from San Marco. The sestieri (districts) of Dorsoduro, Santa Croce, and San Polo (highlighted below in Figure 1) have only two towers with audio recordings of their bells, only three have panoramic views from their belfries, and very few have photographs of the tower's interior. -Without this information, neither the public nor the Curia have a way to understand the deteriorating condition of the towers and the importance of preserving them, knowledge that's needed in order to determine the towers that need the most repairs. If one of these towers were to fall down, the fragmentary photos might not be enough to help reconstruct it or allow future generations to experience the towers in an engaging way.

Figure 1 - The sestieri 'de Ultra': Santa Croce, San Polo, and Dorsoduro

As a way to facilitate future documentation and allow for a more interactive view of the towers, this project created a mobile application for data collection on bells and towers, and produced virtual tours of the towers. The data collection app drew from the methods of previous projects in order to design an easy to follow process for documenting the exterior and interior of the bell towers and the bells themselves. The app updated several websites and databases with information for many of the towers in the three sestieri mentioned above, allowing for more efficient documentation. We also created interactive, virtual experiences of the belfries as a way to allow the public to see not only the views from the towers, but also the disrepair the towers have fallen into over the years. All of these tasks will preserve the knowledge of the bells and bell towers for years to come, identify which bells and towers are in need of the most restoration, and keep the history alive should the sites be lost.

2. - Background

Bells were first brought to Italy and the Christian Church from Asia in the 6th Century and soon spread across the entirety of Europe (Rombouts, 2014; Sheffield, 1903; Tyack, 1898). They have a rich history of signalling the end of a work day, calling parishioners to mass, and celebrating occasions of joy. In Venice, bell towers have become landmarks throughout the city, since almost every church has its own bell tower. However, as the city is growing older, they are starting to decay and fall into disrepair, prompting organizations like Preservenice, Venice in Peril, WPI's Venice Project Center, and Save Venice to step in to archive, preserve, and protect the city for the future.

This chapter will explore the relationship between the influence of the Catholic Church and the preservation of the buildings, as well as the function and structure of bell towers and bells in order to explain the concepts about them that we need to understand in order to contribute to their preservation in a meaningful way.

2.1 - The Church's Relationship to Bell Preservation

There are 139 churches across the central city's 118 islands and the exterior islands, see below in Figure 2 (Carrera, n.d.). Of those 139 churches, 96%, are of the Roman Catholic denomination (Carrera, n.d.), while the others include Greek Orthodox, Armenian Catholic, Evangelical Lutheran, and Methodist (Cotton, 2016b). Every Roman Catholic Church within Venice is owned by the Venetian Archdiocese, or Patriarchate, and church issues are decided on by the Curia Patriarcale. (Cheney, 2015). The Curia is responsible for running the churches, including but not limited to preservation strategies, archiving church history, handling the financial needs of the district.

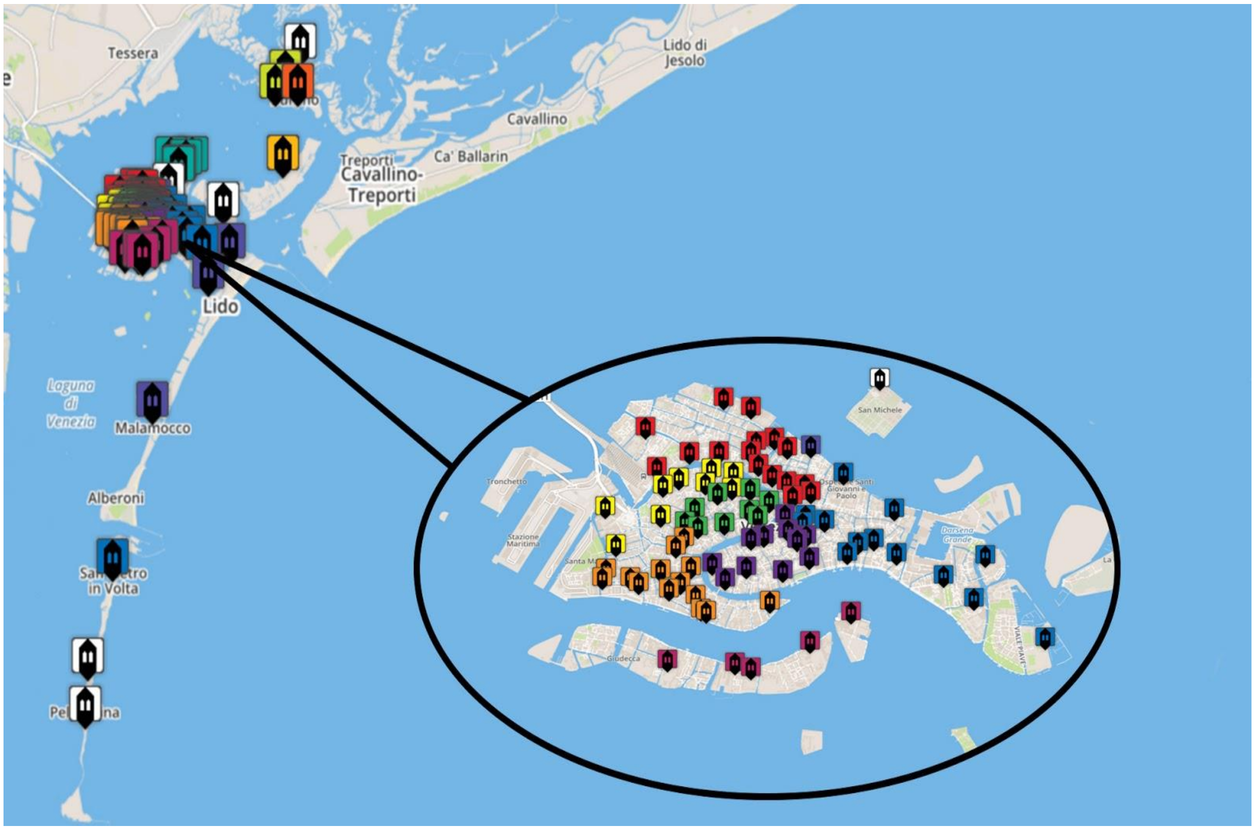

Figure 2 - Map of all of the bell towers in the Venetian Lagoon

2.1.1 - The Church in Modern Venice

Of all of the countries in Europe, Italy still has one of the highest percentages (81.2%) of Catholics in Western Europe(Pew Research, 2011). The Vatican is centered within Rome and Italy has a long history of Catholicism. The Catholic church has influence not only in the government, but also in the form of Catholic education (Roe, 2012; Sansonetti, 2009). Despite this, the Church has seen its influence decrease greatly within the past three decades. In a study done by the Critica Liberale Foundation, it was found that the rates of confirmation, communion, and concordat marriages fell 3, 2, and nearly 16 percent respectively between 1991 and 2004 (Sansonetti, 2009).

These trends are indicative of the increasing secularization of the country, especially among younger generations, which is linked to declining weekly mass attendance. In Venice, for example, it was thought that at least 30% of people attended church regularly, but a study by the Curia found that the number was closer to 15% (White, 2010). As church attendance drops, donations to individual parishes dwindle, making it much more difficult for them to conduct regular upkeep on all of their buildings and provide services that would attract more people to mass (White, 2010) ("The Catholic Spirit", 2014; "FAQs About Tithing", n.d.). As churches are nonprofit organizations, they rely on their donations to function. Since there are more bell towers than active congregations in Venice, the already declining weekly donations are being spread thinly across multiple churches and putting many towers in jeopardy of sliding into dereliction.

2.2 - Bell Tower Structures in Venice

In past centuries the churches of Venice were run by the state powers, leaving each parish with very little control over its operation. The only aspect the church itself could control was the architectural style of the building and attached bell towers, which has led to many unique ecclesiastical buildings within Venice (Carrera, 1996). In some churches that are not a part of a monastic order, meaning an organized group of monks living under specific religious rules (i.e Dominican or Franciscan), rich and noble families sponsored exceptionally beautiful churches. In others they would be used as "Trojan horses" to test new architectural styles, meaning that the new styles were effectively infiltrating into the city among the old in a subtle way (Carrera, 1996). The incredible architecture extends to the many styles and structures of the bell towers.

2.2.1 - Standard and Roman Bell Towers

Bell towers in Venice were built in two styles, Roman and Standard Style. The Roman style bell towers, or gables, shown in Figure 3, are less common in Venice than the Standard style tower. The bells are hung in exposed arches on top of a small wall like structure which is erected on top of the church. This style is typically chosen by churches due to a lack of funds to construct a more elaborate tower (Parker, 1850). Only a handful of towers have this style in Venice.

Figure 3 - Example of a Roman Style tower in Venice

The other style, the Standard style, is much more common in Venice. Every standard tower has the same major components: base, shaft, belfry, and spire, as seen in Figure 4 (Ruskin, 1850). The base is at the very bottom of the tower and supports the rest of the structure. Above the base is the largest part of the tower, or the shaft. It contains the stairs and landings that lead to the belfry. The belfry sits above the shaft and houses the bells. It is the most ornate aspect of the tower and is very open to allow the bell chimes to escape. Along with the belfry, the spire reflects the architectural style of the tower. The spire includes the attic and the roof. The attic typically holds the bell ringing mechanism and occasionally a clock if desired. The roof then covers the tower and protects everything inside (Ruskin, 1850).

Figure 4 - Saint Mark's Tower with major section divisions

2.2.2 - Causes of the Deterioration of Venetian Bell Towers

Over their existence, several major factors contribute to the deterioration of bell towers. Some of the most damaging factors to the Venetian structures are the humidity and the rising sea. Most of the towers in Venice are constructed from brick, and the most destructive phenomenon that brick buildings can experience is capillary rise, which occurs as liquids like water flow in narrow spaces without any external force such as gravity ("Capillary Action of Water", n.d.). This is a particular threat in Venice due to the city's tendency to flood during the winter months, allowing the water of the Adriatic to contact any tower regardless of where it is on its island. This capillary rise occurs because at a microscopic level, bricks are like sponges, with narrow channels between the rocks where saltwater can slowly creep up, brick by brick. When the water evaporates, the salt remains and crystallizes, taking up volume and causing bricks to fracture and break as they expand. Venetians originally combated this process by using a layer of Istrian stones, which served as a barrier for capillary rise ("Istrian stone", n.d.). Unfortunately, as sea levels have risen, the tides infiltrate the stones above the Istrian layers leaving behind salt that weakens the structural integrity of brick in the towers ("Istrian stone", n.d.).

Some solutions to prevent salt penetrating bricks have been avoiding plastering the lower part of buildings, and instead, replacing the normal plaster with a waterproof membrane, as well as adding resin between all of the bricks (Zugno, n.d.). As the seas continue to rise, the need to fortify Venice's bell towers will rise accordingly to protect their structural integrities.

Additionally, bell towers can be damaged due to the ringing process of the bells. Since bells are so massive, some weighing in excess of 1000 kg, the horizontal forces created by their motion when they are rung can cause incredible stress to the structural integrity of the towers (Smith et al., n.d.). The vibrations of the biggest bells can cause significant damage if their frequencies are the same as the resonance of their tower. When these two factors are combined within towers that house multiple enormous bells, cracks can easily form in the walls of the building (Smith et al., n.d.). Having a record of the sizes of this resulting cracks over time, can facilitate the repair before the bells destroy the tower.

Finally, bells and bell towers can simply deteriorate over time just like any old building or structure. Since some bell towers are several hundred years old they require maintenance in order to remain safe and structurally sound. For instance wood (such as stairs) may rot over time and require replacement. If this continual maintenance is not performed then the bell tower may gradually decay and become unsafe.

2.3 - Overview of Bells

The main function of the bell towers is to house the church's bells, so it is important to understand the structural supports that hold the bells within the towers as well as how these bells look and sound. If their physical characteristics are not well understood, it makes the task of preserving them much more difficult, as each bell is deliberately cast to project its own specific note across the city. Luckily, since the process for making bells hasn't changed much in the past few centuries, there are still expert bell founders alive who have the knowledge not only to cast a bell, but to tune them, repair them, and recast them precisely so that centuries-old bells can regain their form and function in the event of deterioration (Cebulak et al., 2010).

2.3.1 - The Structural Supports of Bells

There are two main types of structural supports that hold the bells and allow the bells to ring in the towers. The first, most popular type is the H-frame. In an H-frame support, the bell is hung from the middle cross of the letter 'H', as seen in Figure 5. The cross frame is usually made of cast iron or any similar metal. The second type of support is the A-Frame. In this case, the bell is hung from the top of an A-shaped support that is attached to the floor and can be seen below in Figure 6. Although the A-Frame is less common, it is more structurally sound than the H-frame because it relieves stresses caused by the bell. (Heywood et al, 1914).

Figure 5 - H Frame in the tower of Madonna dell'Orto

Figure 6 - A-frame bell support in San Nicolo dei Mendicoli

2.3.2 - Characteristics and Ringing of Bells

The major components of a bell are the canons, crown, shoulder, inscription band and inscription, waist, soundbow, and clapper, as seen Figure 7. The canons are the pieces that attach the bell to the headstock which supports the bell in the tower. The canons can be plain or highly decorative; every bell is different. The top part of the bell includes the crown and shoulder, and transitions into the inscription band. The inscription band is located near the top of the vertical sides of the bell and is the location of some writing that is on the bell. The middle section of the bell between the soundbow and the inscription band is the waist of the bell. The soundbow can be found at the thickest part of the bell and is where the clapper, located inside of the bell, hits to make the bell ring. (Frost, 2006; Rech, 2014)

Figure 7 - A bell in San Geremia Tower labelled with the parts of the bell.

A bell can be rung in several different ways; two major ways are the swinging method and the hammer method. For the swinging method, the clapper is forced to hit the sound bow on the inside of the bell to ring the bell. In the hammer method, a hammer is positioned outside of the bell and strikes it from the outside (Rech, 2014).

The many decorations found on bells can vary between bells and founder. Some of the most common decorations include crosses, flowers, and ornate borders around the lip (Sheffield, 1903; Tyack, 1898). There is also a range of word engravings that can be found on the bells. The most common of these would be the name of the church's patron saint, phrases of important prayers, and the initials of the bell's founder (Sheffield, 1903). It is also not uncommon for names of the people that funded the bell be engraved on it. The donors that gave the most money would have the honor of having their whole name added, while modest donors would only have their initials (Tyack, 1898).

It is nearly impossible to date many of the oldest bells in Europe because it was not until the fifteenth century when the practice of engraving the date on the bell became common (Tyack, 1898). Sometimes the engraved shields (inscriptions describing the bell foundry that made the bell) and markings of founders can be used to date bells, but that leads to problems when generations of the same family use the same markings, making, for example, the grandson's bells indistinguishable from his grandfather's, which further complicates the dating process (Sheffield, 1903).

Although bells come in various sizes, every bell is tuned to have the same five principal tones, one of which provides the bell's primary note, or sound, with the others sounding at a lower volume. The lowest is the hum tone and resonates through the waist of the bell. The prime or fundamental tone defines the note of the bell at the sound bow and is one octave above the hum tone. This means that it's a higher version of the same notes, as musical notes range from A-G and then repeat. Sounding just above the sound bow is the tierce, which is a minor third above fundamental. Quint is heard just above tierce and is a fifth above fundamental. Lastly, the nominal tone is heard at the lip of the bell and is one octave above the fundamental tone (Rech, 2014; Perrin et al, 1995). The three octaves and partials provide the bell with the full sound and timbre that is come to be known of bells.

Bell towers can hold anywhere from a single bell to over half a dozen bells of varying sizes. The most common number of bells in Venetian towers is 4 to 5. If a tower has multiple bells, each bell has its own name. The bell with the highest pitch is called the treble, and the lowest pitch is called the tenor bell. The bigger the bell, the lower the pitch, as pitch is determined by vibration frequency and the larger an object is, the lower its frequency is. The remaining bells are numbered from highest pitch to lowest pitch between the treble to the tenor bells (Frost, 2006). Aside from names based on pitch, bells can also have real names. For instance, in St. Mark's tower the five bells are name Marangona, Trottiera, Nona, Mezza Terza, and Renghiera, each of which had a significant meaning when rung (The bells, 2016).

2.3.3 - Deterioration of Bells

Bells, like the towers that hold them, are susceptible to deterioration due to age and other external factors which affect their looks, structure, and sound. One of the more damaging substances to bronze is actually pigeon droppings, which contain chemicals such as uric acid that, once in contact with the metal, can corrode and discolor the surface (Bernardi et al., 2009). The guano of pigeons also contains phosphates (compounds that contain a phosphate ion, made of phosphorus and oxygen), which can degrade copper, forming small black spots wherever phosphorus concentration is the highest (Bernardi et al, 2009). Phosphorus degradation occurs over extended periods of time, which makes the Venetian bells particularly susceptible because the majority are at least a century old (Berardi et al., 2009). This highlights the need for bird netting on the windows of belfries, so that the pigeons and seagulls can't get in and cause deterioration to the bells while making the belfries unsanitary. An additional threat that bells face is called bronze disease. Bronze disease occurs most often when the copper within the alloy is exposed to the chloride in seawater, reacting and forming copper chloride (Cupreous Metal, n.d.). Because CuCl is unstable when exposed to water and oxygen, a reaction occurs, which results in more copper chloride along with hydrochloric acid (Cupreous Metal, n.d.). The HCl then eats away at surrounding uncorroded metal, forming even more CuCl and creating a continuous feedback loop that without treatment could corrode the entire bell (Cupreous Metal, n.d.). With all of this information, it's essential that churches are able to maintain and repair their bells so that they can sing for years to come.

3. Methodology

The goal of our project was to contribute to the preservation of Venice's bells and bell towers for the future by raising awareness of their current state through interactive visualizations and virtual reality tours. The updated Venipedia pages, updated bells website databases, and virtual tours of bell towers provide insight into the condition of the towers in order to determine if any restoration work needs to be done. Since recent WPI projects have focused on the sestieri (town districts) of Cannaregio, Castello, and San Marco, this study focused solely on standard bell towers with belfries and bells found in the sestieri of San Polo, Santa Croce, and Dorsoduro. During our group's seven weeks in Venice, we aimed to complete the following objectives to fulfill our project goals.

1. To increase public awareness about the condition of the bells and bell towers by publishing virtual tours of them.
2. To collect data and update the appropriate databases on the Venetian bell towers in the sestieri of San Polo, Santa Croce, and Dorsoduro
3. To create a mobile application to collect data about bell towers.

We provided virtual tours of the bell towers as a way to allow access to some of the most deteriorated towers, and emphasize the need for restoration, as well as providing a glimpse into a piece of Venice's history that few people can currently experience. In conjunction with the virtual tours, we were able to collect information about each bell and bell tower to update our sponsor, the Curia Patriarcale's databases. This updated information also contributed to the bell data on Venipedia, the WPI wiki about Venice, and the bells website so that the data is more complete and easily accessible. Finally, the creation of the mobile web application will guide future users through a straightforward step-by-step data collection process, assisting future IQP students or campanologists in collecting consistent data on bells and bell towers.

3.1 Providing virtual access to the Venetian bell towers

The first component to our project was to create virtual tours of the bell towers so that the public could experience the towers which would otherwise be inaccessible and to raise awareness of the towers' conditions to aid in funding restorations. The virtual tours allow anyone viewing them to travel around the towers at their own pace while learning interesting facts and features about the towers along their way. We used a combination of the Matterport 3D Camera and Ricoh Theta S camera to create virtual tours.

3.1.1 - Using the Matterport 3D Camera to Create the Virtual Tours

Through extensive research of virtual tour techniques, we found the Matterport 3D Pro camera by Matterport provided the most professional looking final product. Compared to other tools that can create a virtual tour of spaces, the MatterPort software creates the entire model and tour on its own making sure it is correctly aligned and to scale. Other software provides the tools to create the tour but then leaves the actual production to the user. This leaves room for a large amount of human error and a large learning curve which further increases the possibility of errors. The quality of the images are also much greater as the MatterPort takes 30 high definition images whereas other 360 degree cameras take only one or two. The MatterPort camera also uses HDRI, or high-dynamic-range imagery, which means it can still get high quality results in a large range of lighting conditions.

The Matterport 3D Pro is a camera that sits atop a tripod and turns in a circle while capturing photos of its environment, collecting detail and depth. It can be seen below in Figure 8. It uses infrared lasers during each scan so it can generate the 3D model, locate each scan, and know if it is moving up or down stairs. This means that the operator does not have to tell it where the camera is being moved. After each scan, a floor-plan view (shown in Figure 9 below) is generated on an iPad that is used to operate the camera. When the scanning is complete the windows and mirrors are marked on the floor plan and the iPad transfers the data to the Matterport website, where the virtual tour is constructed. The tours were constructed on the Matterport site and did not require a powerful computer on our end to complete them.

Figure 8 - Matterport 3D Pro Camera

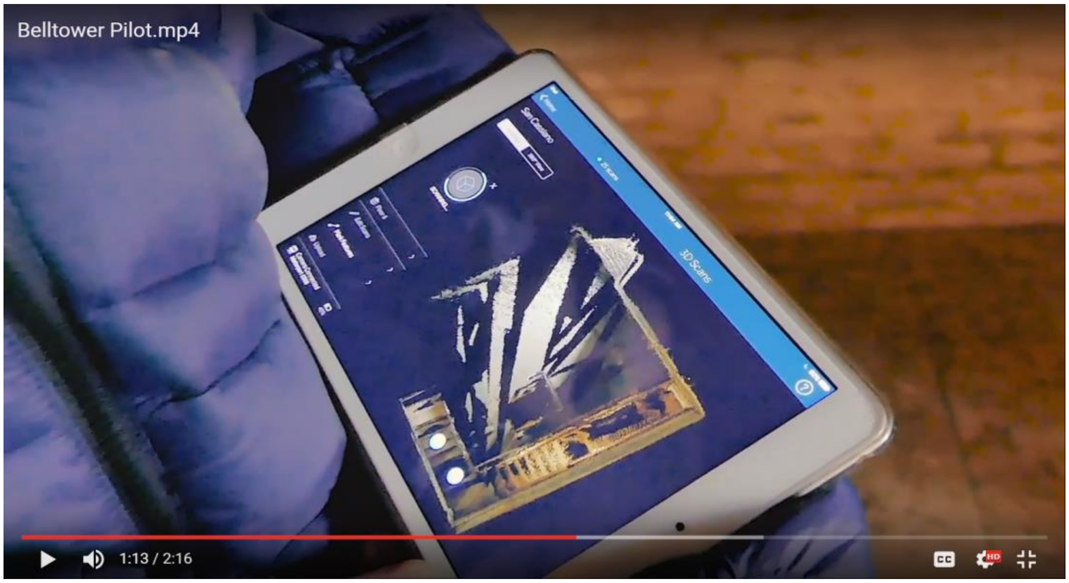

Figure 9 - Floor plan that is created on the iPad during scanning

The Matterport company generously loaned us one of their cameras for the duration of our project. Along with the camera loan, we have all of the renderings that we captured hosted on the company's website for no fee. Even though the tours are hosted on the Matterport website, we still have full access to embed and link them on our project's website.

In the bell towers, the Matterport scanning had to begin at the lowest point in the church because the camera does not easily have the ability to go down in elevation. The scans usually began just outside of the door to the bell tower. The distances between scans varied from 3 feet to 10 feet and depended on the lighting of the tower and type of walkway. Steeper staircases required more scans than flatter ones. During each scan, there could be no one in the shot or any objects that were not generally in the tower. This meant that if any of our backpacks or supplies were in the area being scanned they had to be moved and the Matterport operator had to either walk in a circle behind the Matterport cameras or go up or down a landing to be out of sight. This process continued until it reached the belfry, where the camera was placed in several locations in order to give an immersive view of the tower and also to capture the views from the tower. Every tower took between 50 and 200 scans depending on the size, and each scan takes around 4-5 minutes. It typically took around two and half to three hours to complete a tower. If there was still time, the church would also be scanned.

3.1.2 - Using the Ricoh Theta S

In addition to the Matterport virtual tours, we used the Ricoh Theta S 360 camera to provide interior visuals. The Ricoh Theta S, as seen below in Figure 10, is a small handheld or mountable camera with two fish-eye lenses that stitch together a 360 degree image or video. The camera can be controlled with an app on a mobile phone or using the shutter on the camera itself. The Theta S software renders the 360 degree photographs and videos on its own and required no special software from us to create the images. Like the Matterport, the images and videos produced by the Ricoh are hosted on the Ricoh website, and can be embedded into any of our websites.

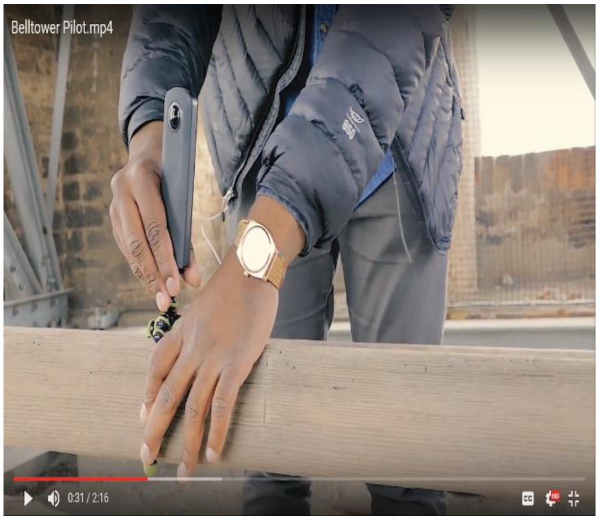

Figure 10 - Ricoh Theta S Camera

At the towers, we first took video of the ascension by mounting the Ricoh onto a selfie stick and climbing the tower. These videos were uploaded to YouTube and linked to the bells website. In addition to the ascension video, we took 360 degree images on every landing of the tower and the belfry in order to give higher quality 360 degree photographs of the specific landings than the video provides. For the images of the belfry and landings, we made sure there were no people in view in order to give an unobstructed view of the tower.

3.2 Collecting data on the bells and bell towers and updating databases

In order to update the previous catalogues of information about the bells and bell towers for both the Venice Project Center and the Curia and to locate towers in need of restoration, we visited seventeen towers throughout the seven weeks of our project. At each tower we collected measurements, observations, took pictures, audio recordings, vibration recordings, made Matterport and Ricoh tours, and recorded the overall condition of the interior and exterior of the tower and the bells. After we visited the towers, we used the data to update the Venipedia pages for each bell and bell tower and to update the bells website. While the data collection web application was still being created (see section 3.3), we used a Google Sheet to collect the data on the bells and bell towers.

Don Caputo from the Curia Patriarcale granted us permission to visit 25 towers in the sestieri ‘de Ultra’: ten towers in Dorsoduro, seven in San Polo, and nine in Santa Croce. In Figure 11 below, the towers we had permission to visit are in purple.

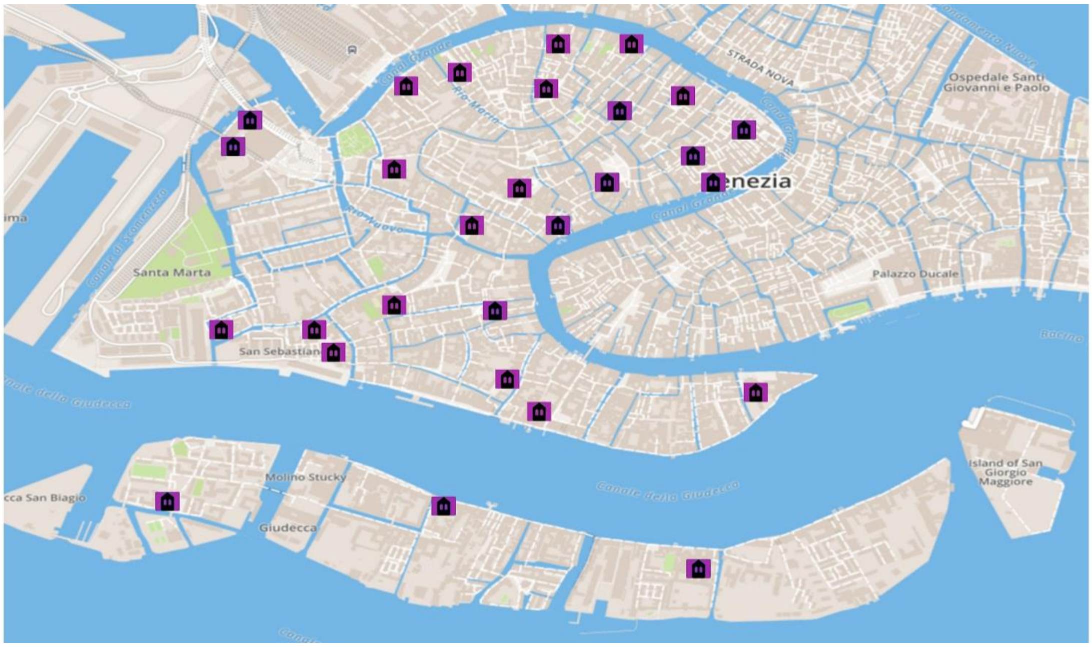

Figure 11 - Bell towers ‘de Ultra’ we had permission to visit

With the help of Sarah Puccio, who helped us schedule visits to the bell towers, from the Venice Project Center, within our first few days in Venice we were able to visit two bell towers. Visiting the towers immediately allowed us to refine our documentation process, as we quickly learned what materials we would need, like calipers to measure the bells thickness and chalk to read engravings, and what methods made the most sense while we were in the towers like how to rank the cleanliness of a landing and which team member would do which task. In total we visited 17 towers. A typical week included about four towers, beginning in the mornings and typically continuing into the early afternoon.

3.2.1 - Identifying Data to Collect

Over the past 24 years, several WPI project teams have documented and organized the data of many bell towers around Venice. Each group examined previous WPI work to determine how they would add to it, and this has resulted in many different lists of information that each team thought pertinent to collect. The most recent projects, in 2012, 2013, and 2015, have compiled much of this data into the VPC hosted database, City Knowledge (CK), and Venipedia pages. We mainly focused on the 2012 and 2015 projects' data sheets for our project, since the 2013 project mainly focused on artwork and the church itself and not the bell towers.

There are main categories that the data has been split into: bell tower exterior, bell tower interior, and bell information. We discuss in detail the different data categories in future sections below. All of the quantitative and observational fields for each category are important for the overall understanding of the bell tower. Measurements help lead to a full catalogue of the tower that can be used by campanologists, archeologists, and historians to learn more about the towers as well as in future restorations to help to determine the condition of the towers and if any work needs to be done in the near future. Data fields for the tower exterior include measurements of the exterior doors and building blocks and observations about the tower including number of cracks, ties and bands, inclinations of the tower, and parts of the tower. Data collected in the interior of the tower ranges from the number of stairs inside the shaft and the dimensions of the windows to the number of cracks on the walls and the type of frame in the belfry. Bell data includes a full set of the physical dimensions, the engravings and inscriptions on the bell, as well as observations of its discoloration, cleanliness, and overall condition. Lastly, some general church and tower information encompasses information about the location, architecture, pastors, and restorations of each.

In addition to the above written information, recording and analyzing the sounds of the bells can assist campanologists in further determining the condition of the bells and recording the vibrations of the tower when the bells are ringing can determine if the tower is at risk from its bells.

3.2.2 - Collection plan and visiting the towers

There were many different tasks that needed to be completed in order to fully document each tower successfully. The main tasks were taking audio recordings, photographing the entirety of the tower, using the Matterport to make the 3D virtual tours, using the Ricoh Theta S to take 360 degree pictures within the tower, and collecting all of the written information.

Once we visited the first few towers we learned how to get multiple tasks done at the same time by having different people focus on different tasks. The Matterport was the most time-consuming portion of the visit since it had to start at the bottom of the tower and have no people in view during the scans. To make our time the most efficient, while the Matterport was going up the shaft, all of the data collection that needed to be done in the belfry was completed, and then when the Matterport reached the belfry to complete its scan, any remaining data for the interior shaft was collected. The scans typically began at either the base of the tower or the entrance of the church to allow whoever was recording data in the shaft enough time to complete all of their fields before the Matterport reached them. A diagram of this process can be seen below in Figure 12.

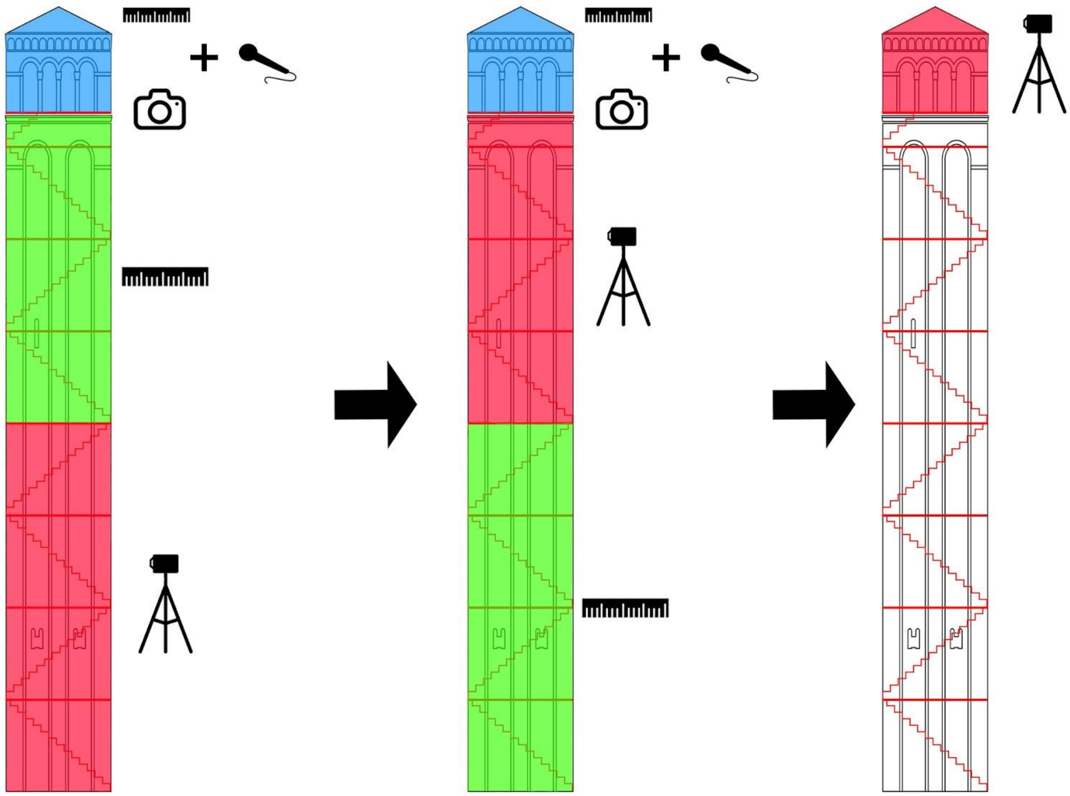

Figure 12 - Data collection process – Matterport starts at the bottom, as the Matterport moves up the tower data collection shifts

We broke up all of the work into four jobs, as seen in Figure 13, which became more concrete as the project went on and we became more efficient at doing our jobs. The first job was the Matterport operator. The next job was recording data in the shaft of the tower and assisting with exterior data collection. The following job was taking pictures of everything in the belfry, documenting the bells, and taking sound recordings of the bells. The last job was using the Ricoh to take a video of the tower ascent and pictures of the belfry and each landing.

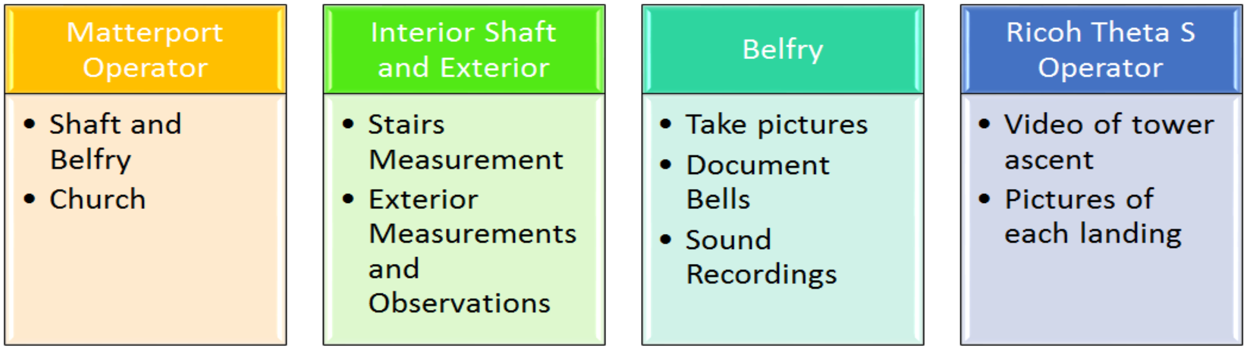

Figure 13 - Each of the four jobs during a bell tower visit

Once we returned from the towers we then compiled all of the data that was not collected in the spreadsheet, including sound recordings, videos, images, and uploaded the MatterPort scans, onto Google Drive.

3.2.3 - Exterior Data Collection

The exterior of the bell towers have many important details and decorations that need to be documented. By looking at characteristics of the exterior, one can discern how many times the tower has been restored, the age of the tower, and even the architect if any have trademark styles that are clearly visible on the tower. From the outside of the tower, we determined the tower's accessibility, restoration state, and observed any tower defects, windows, and parts of the belfry. A summary of the list of data fields can be seen below in Table 1.

Table 1: Summary of exterior data fields

Public_visibility	Number of brick colors Front/Right/Back/Left
Visibility of Front/Right/Back/Left	Number ties and bands Front/Right/Back/Left
Exterior tower notes Front/Right/Back/Left	Num blocked/meshed/barred windows per side
Tower Connected to Front/Right/Back/Left	Clock
Length attached percentage all sides	Number_lesene
Number of Plants Front/Right/Back/Left	Arches Front/Right/Back/Left
Number of art pieces Front/Right/Back/Left	Drum_type
Exterior Inscriptions	Cross/Weathervane/Lightning rod
Number crack & holes Front/Right/Back/Left	Finial type and description

When we were recording the restoration state and tower defects, we were looking for any metal supports, called ties and bands, that had been added to the structure to support it as well as if there were any new bricks. By counting the number of different colors of bricks, it is possible to gauge how many times the church has been restored since newer bricks will typically have a different shade than the originals. A picture of an example of the metal ties can be seen on the left of Figure 14 below, as well as an example of different brick colors on the right of the figure.

We took pictures of any decorations, cracks, and visible restorations. We also made sure that we took a good picture of the entire tower that could be used as the main photograph for the tower on Venipedia and the bells website.

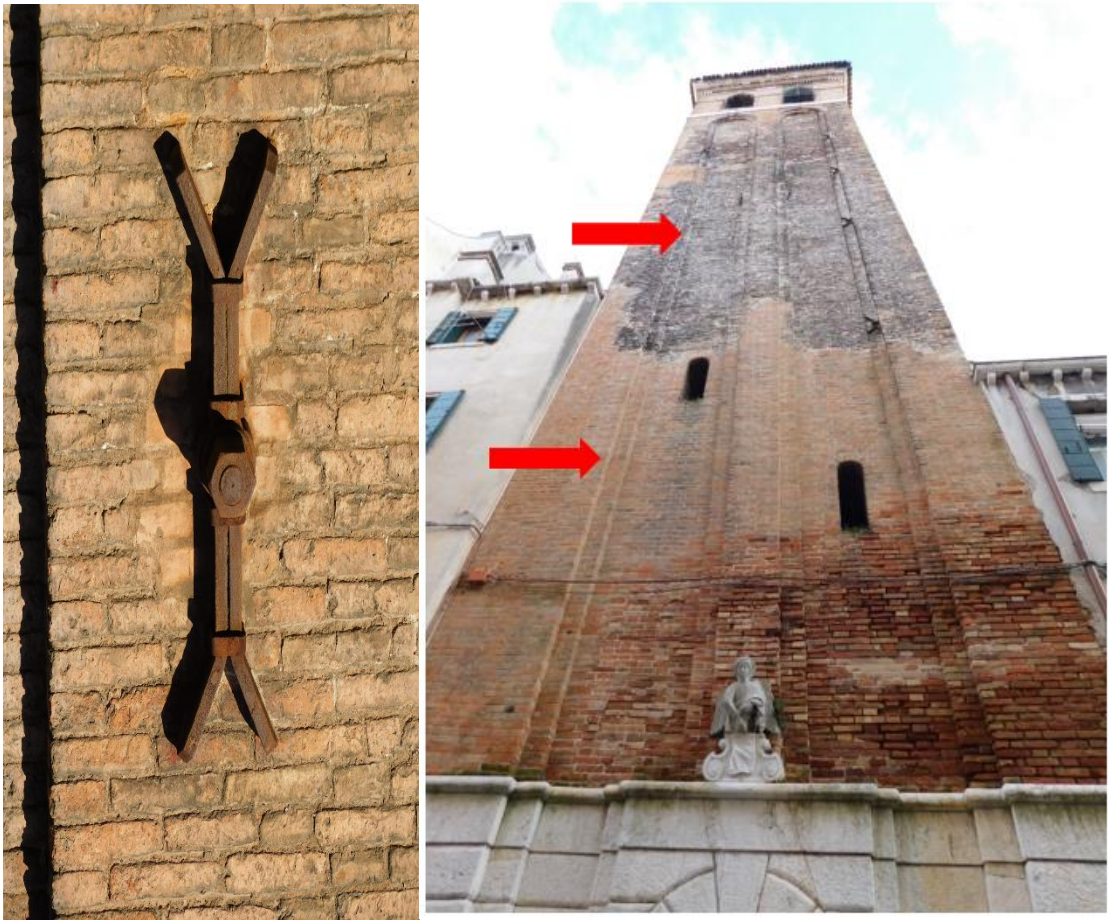

Figure 14 - Left: Example of a tie on a tower, Right: Example of two different colored bricks

We also took several measurements of the exterior of the towers. These measurements included the orientation and inclination of the tower and dimensions of the building materials and doorways.

To measure the orientation and inclination of the bell tower, we used the compass application on our smartphones. For the orientation, we would put the bottom of the phone against the front wall of the tower and read the degrees displayed. To measure the inclination of the tower, we used the level application in the compass, put the side of the phone against the tower, and recorded the degrees. These two processes are show below in Figure 15

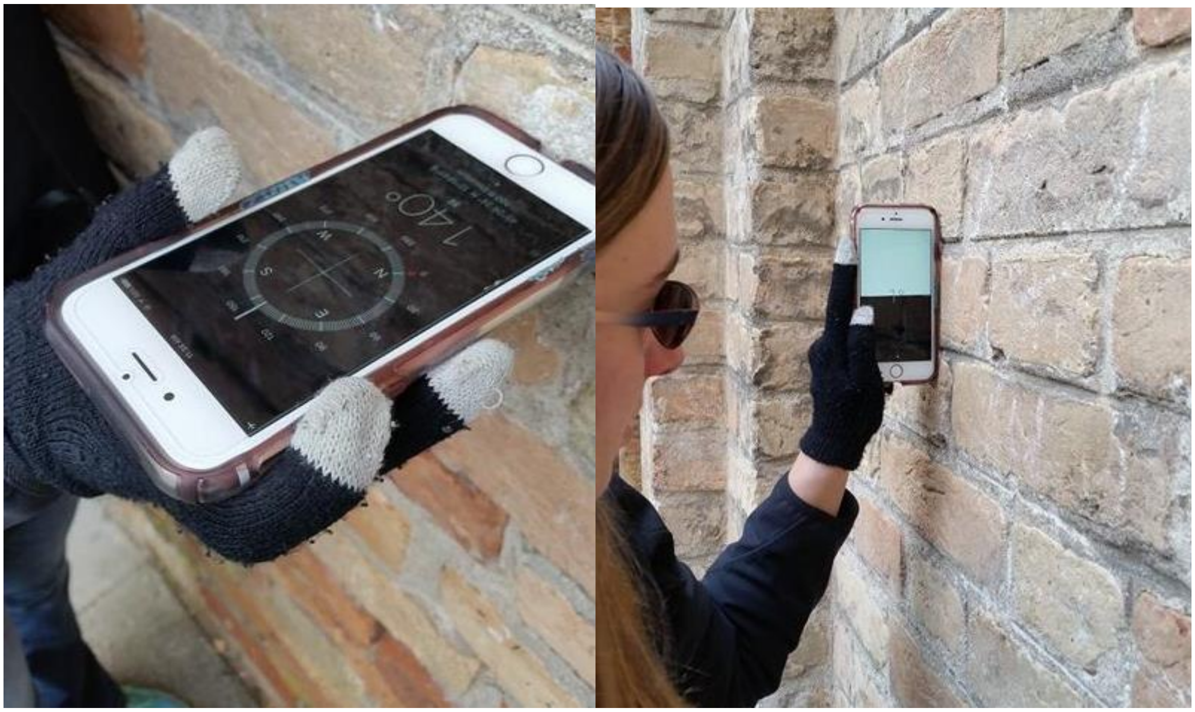

Figure 15 - Left: Measuring the Orientation of the Tower, Right: Measuring the inclination of the a tower

Most of the towers we visited had a base made out of stone and the shaft and belfry made from bricks. As can be seen Figure 16 below, we used a measuring tape to measure the height, width, and depth of a stone and brick from the base and shaft.

Figure 16 - Measuring the exterior blocks of the bell tower base

Not many towers had exterior doors, but if they did we measured their height and widths as seen below in Figure 17.

Figure 17 - Measuring a tower's exterior door

3.2.4 - Interior Data Collection

The interiors of the bell towers contain the majority of the most important pieces of data that need to be collected, most notably information about its bells and observations that help in the analysis of the tower's structural integrity. A summary of the data collected in the interior shaft of the tower is is Table 2 below.

Table 2 - Summary of interior data fields

Landing/Stair Material	Lighting_rating
Landing/Stair Sturdiness	Ramp or Stairs
Landing/Stair Cleanliness	Railing and Sturdiness
Landing/Stair Length_F_B_cm	Number of total and bad steps
Landing/Stair Width_R_L_cm	Window/Door number and dimensions
Landing height to ceiling_cm	Number of Ties and Bands
Clock_mechanism	Number of cracks and misaligned bricks
Natural/Artificial Lighting	Interior decorations and inscriptions

The stairs in the shaft are one of the main safety concerns of the tower. As we ascended the tower, the number of bad steps were logged (example below in Figure 18) as well as the cleanliness and sturdiness of them. The number of stairs for each landing was how many stairs it took to reach the next landing. The sturdiness and cleanliness rankings were on a scale from 1 to 5, with 1 being the worst and 5 being the best. An example of a 1 Ranking and 4 Ranking are shown below in Figure 19. The presence of a railing and its sturdiness were also recorded.

Figure 18 - Example of a bad step in Gesuati

Figure 19 - Top: 1 Ranking (worst possible) for Landing Cleanliness, Bottom: 4 Ranking (generally clean) for Landing Cleanliness

As we ascended the shaft, we also documented how many windows were on each side of the tower in addition to their dimensions. By recording the depth of the window, we were able to determine the thickness of the walls. Dimensions were also taken of the steps and landings. Figures 20, 21, and 22 show how windows, stairs, and landings were measured respectively.

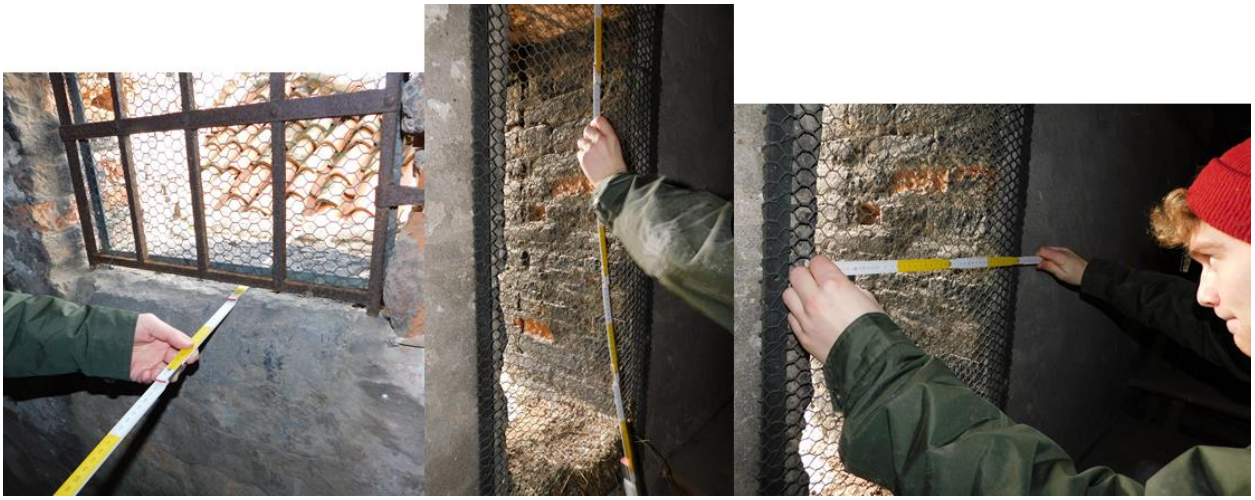

Figure 20 - Measuring interior window dimension, from left to right: depth, height, and width

Figure 21 - Measuring stairs dimensions using a laser meter, from left to right: length, width, and height

Figure 22 - Measuring landing height and length

Lastly, if there were any significant cracks in the walls, we documented their location and their size. A significant crack is a crack that goes through the middle of bricks rather than around the seams. As seen in Figure 23, the picture on the left shows an insignificant crack between the seams of the bricks and the picture on the right is a significant crack because it cuts bricks into two pieces. The benefit of documenting the size of the cracks is that it can be determined if the crack is getting worse in the future.

Figure 23 - Examples of an insignificant (left) vs. a significant (right) crack

Photographs were taken of any significant restoration or cracks in the interior and exterior walls of the shaft. The pictures along with the measurements of the cracks can now be used as a baseline of the current state of the towers.

Table 3: Summary of belfry data collection fields

Frame type	Bell_locations_side_view
Frame restoration	Bell_locations_top_view
Frame material	Frame notes
Frame missing screws or bolts	Belfry_Opening_side
Frame rust	Belfry_Width
Number_of_Frame_cracks	Belfry_Length
Frame_cleanliness	Condition_of_inside_of_roof
Frame warping or dents	Bird_net_condition Front/Right/Back/Left
Frame_Overall_condition	Drain_holes

Along with the measurements from above, belfries have additional data to be collected, a summary list can be seen above in Table 3. The belfries were often small and cramped, either due to a small amount of floor space or due to the sheer sizes of the bells and bell frames. This meant that we had to have a limited number of people in each belfry at once, or else data collection became uncomfortable and inefficient for all involved. The most essential pieces of data were the dimensions, typically measured either by the use of a tape measure or a laser distance meter, depending on the belfry size, as the tape measure we often used only measured up to 10 feet, or 300 cm. The dimensions are marked in Figure 24. The laser meter allowed for measurement of the height of the belfry, taken either from floor to ceiling or floor to the beginning of the attic. In addition to belfry height, width (left to right side) and length (front to back) were measured, and the windows were counted and then measured as well.

Figure 24 - Example of how the belfry dimensions were taken

Pictures were taken from the corners of the belfry in order to capture as much of the belfry as possible in one picture. If there was any restoration work or cracking, we took pictures in order to track changes into the future. We also took pictures of the views of the city from the windows in order to make panoramas. These all helped form a complete picture of the size of the belfries.

While in the towers, if the bells rang in a chorus, meaning that all of the bells minus the sonello rang together, we used the Vibsensor app to record the vibrations of the tower. We only recorded the vibrations if there was a whole chorus ringing because that is when the most vibrations would be produced. Before we left the belfry, we would leave the phone face up on the ground of the belfry as close to the middle as possible. In order to record only relevant data, the app has the option to delay the start of data collection and set the duration. We usually set the data acquisition time to between two and three minutes to ensure enough data without collecting too much.

3.2.5 - Bells Data Collection

The bells themselves are arguably the most important part of the towers, as they provide the towers' functions. There were usually 3-5 bells per tower, all of which belong to the same musical scale except for the sonello (see Figure 25), the smallest bell in each tower. A musical scale is a set of notes that that sound good when played with each other. Many measurements, observations, and recordings were taken of each bell in order to assess their physical state, showing whether or not they should be restored. A summary of the data fields collected of the bells can be seen below in Table 4.

Figure 25 - The sonello(L)is the smallest bell and not tuned to the scale of the rest of the peel.

Table 4 - Summary of bell data fields

Musical_Note	Frequency_Hz
Ringing_Times	Swing direction
Crown Engraving/Inscription Front/Right/Back/Left	Hammer side
Body Engraving/Inscription Front/Right/Back/Left	Ringing method
Lip Engraving/Inscription Front/Right/Back/Left	First_casting
Clapper condition	Cleanliness
Clapper Rust	Discoloration
Clapper Length	Overall condition
Belt condition	Foundry
Skidmark Sides and Length	Place of Casting
Conservation state	Thickness_mm
Safety cable	diameter_cm
Cracked side and length	Height internal and from ground_cm

For each bell, their internal height, height from ground, thickness, diameter, and clapper length were measured. All of the dimensions except the thickness was found using either the laser meter or a tape measure, like in Figure 26 and 27 below. The thickness was measured using a pair of simple calipers that were used at the thickest part of the bell, which occurs at the point the body and lip meet toward the bottom. The calipers were closed until they were unable to go any further, and then the distance between the two claws was measured with a tape measure to find the thickness as shown in Figure 28 below. Most importantly, if there were any cracks present, those were measured in order to analyze their severity to the bell structure using a string and a tape measure. Cracks can negatively affect bell sound, and increase the risk that a bell could break and fall onto the belfry floor, which could damage the tower badly given the immense weight of the bells.

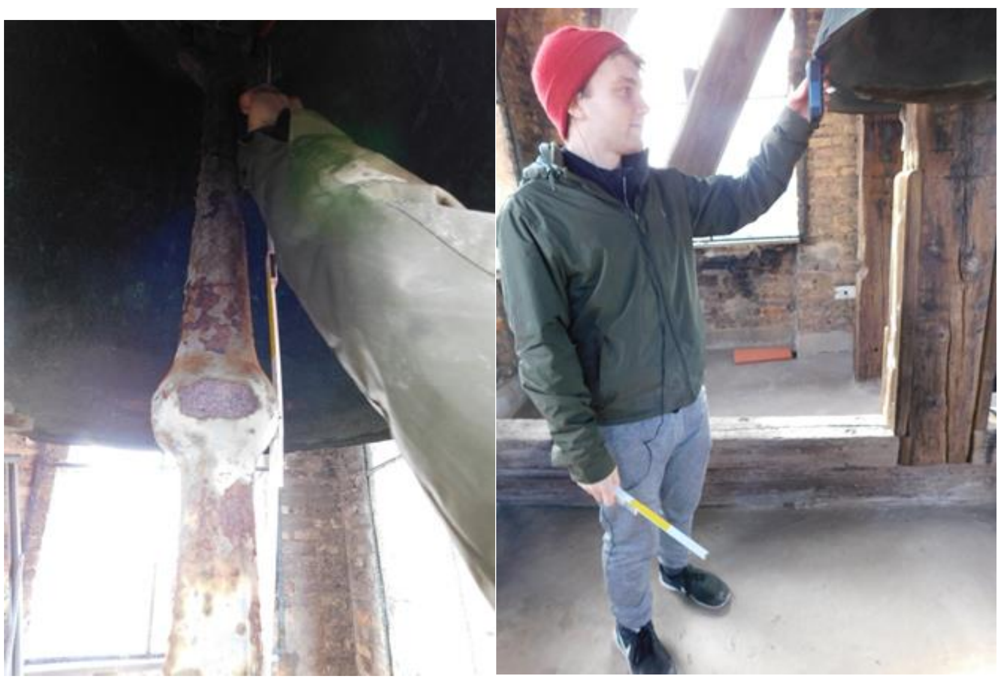

Figure 26 - Left: measuring the clapper length Right: measuring height from ground

Figure 27 - Measuring the bell diameter

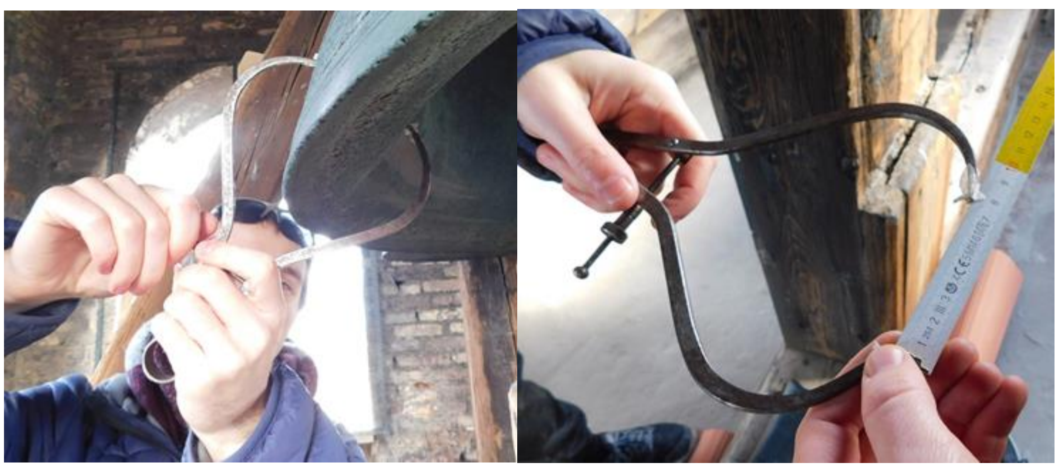

Figure 28 - Measuring the thickness of the bell using the calipers

In addition to physical measurements, the exterior surfaces of the bells were observed to document and describe all of the engravings and inscriptions, as each bell is a work of art. They typically had religious symbols and figures engraved throughout (Figure 29), which were accentuated by symmetrical, intricate patterns that added to the artistry of the bells (Figure 30). The inscriptions (Figure 31) were even more important than the engravings, however, as they almost always provided information about the place of casting, date of casting, and the foundry that cast that particular bell (Figure 32). With this information, a bell making history of the city was able to be obtained. Each particular inscription and engraving was written directly or described, and then the information for each was submitted to the bells website and Google Sheets to keep them organized.

Figure 29 - Example of a religious engraving from Bell 1 in San Cassiano

Figure 30 - Example of the ornate borders on the bells from Bell 2 in Frari

Figure 31 - Example of an inscription from San Zan Degola

Figure 32 - Example of a bell foundry inscription from Bell 7 in Frari

Recordings of each bell were done using a Tascam DR-40 handheld recorder, and an Audiotechnica AT2020 cardioid microphone attached to an iPhone via an XLR to 3.5mm conversion cable. To ensure the best sounds, each bell was rung twice in succession by hitting the clapper against the interior lip, and the microphones were placed slightly within the bell to eliminate exterior noise (See Figure 33 below), especially from the wind. Each recording was then labeled with its respective bell and uploaded to our Google Drive to keep them organized before moving them to the bells website.

Figure 33 - Recording the bell sounds

Additionally, we heavily photographed each bell. For each bell, we took pictures of each engraving and inscription, the clapper and belt, skidmarks, and full view shots from several angles. If a bell was cracked, we made sure to take extra pictures from both the exterior and interior of the bells. After we returned from the tower, we sorted the pictures by the bells and then named the bells by their sizes so they can be easily referred back to. The pictures were uploaded to Google Drive and linked to the websites.

3.2.6 - Update the databases and Venipedia Pages

After finishing our visit to each tower, we uploaded all of the pictures and sound recordings to our Google Drive and organized them by tower in order to not confuse them with other towers and make it easy for future groups to look at our work. The Matterport renderings are hosted through the company's website with access to the models from Venipedia.

After all of the data was organized, we updated the Venipedia pages that pertain to the towers. Even though there are pages that already exist for each tower, they are mainly placeholders with very little information. Our job was to update each page with the information from the bells site database. The Venipedia pages are populated by a script created by Tomaso Minelli, which pulls bell tower data from the CK database to the Venipedia pages. Tomaso will be running this script for us after the project is complete.

3.2.7 - Update the bells website

Past teams have compiled their information on the bells website (www.bells.veniceprojectcenter.org), and we aimed to create a more friendly user experience for the same website. For example, in the current website design, once a tower is chosen and the "more information" option is selected, the users are directed to a page for each respective tower, an example of which is shown in Figure 34. While it is easy to find information since the layout is very linear, with pieces of information stacked on top of one another which requires extensive scrolling to view it all, it does not use the white space as effectively as it could. This motivated us to create a new layout for the individual tower pages that is not only more visually appealing, but is better organized and uses the space more efficiently. Our goal was to fit as much information on one screen without requiring the user to scroll. The appearance overhaul will ideally attract more people to the site, which will help us make strides in raising awareness of the bell towers' significance and conditions.

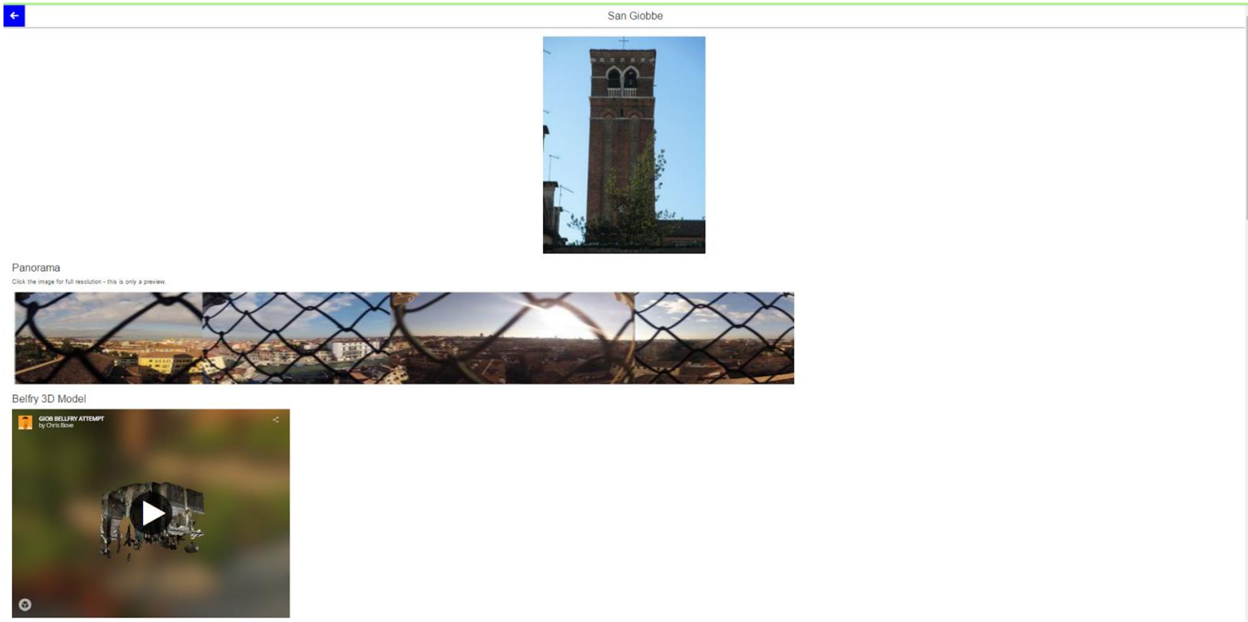

Figure 34 - Individual tower page on the current bells website

3.3 Creating the Data Collection Web App

In previous years, the documentation of Venice's bell towers have been guided by paper data sheets that included information on the exterior and interior of the towers as well as the bells themselves. As paper systems are slowly becoming outdated because they take up space and are more difficult to organize, a data collection application will help to modernize the process. We used the data collection sheets and procedures used by the most recent WPI IQP project groups, along with our experiences from the term, to create a new outline for data collection. This new process was used to create a web application that can be used by future WPI groups and campanologists throughout Italy.

3.3.1 - Organizing the data fields

The previous data fields discussed in Section 3.2 were split into four main categories: bell tower exterior, bell tower interior, bell information, and general church and tower information.

Within each of those categories, there can be upwards of 100 different pieces of information, which can be very overwhelming. The information gathered ranged from quantitative data, such as physical dimensions of the bells, to qualitative data, such as safety ratings from 1-5 of each landing. To make the collection easier and more efficient, our group organized the data fields into categorical groups. For example, within the bell section we added a subsection called “bell dimensions” with the data fields: internal bell height, thickness, diameter, and height above the ground. We did similar groupings for all of main categories to make the information easier to follow. The list of headings and categories can be seen in Table 5 below, and the full list can be found in Appendix A.

While organizing the previously recorded fields, we added a field that will require the measurement of the lengths of specific cracks in tower. We have found that the specific lengths of cracks in the walls were not measured by the 2015 group, but this data was worth gathering because it can be used by subsequent projects to see if cracks have grown over time.

Table 5: Organization of Data Collection Categories
This displays the breakdown of all of the categories of data collected.

Tower Interior		
	Ground/Landing/Belfry	
		Basic Info
		Stairs Info
		Wall Thickness and Windows
		Interior Doors
		Restoration
		Tower Defects
		Decoration and Inscriptions
		Belfry Only
Tower Exterior		
	Tower Exterior	
		Exterior General
		Orientation and Inclination of Tower
		Public Access, Accessibility, and Doors
	Base/Shaft/Belfry/Roof	
		General
		Visibility of Tower
		Notes
		How is it connected to Church
		Decorations Outside
		Tower Defects
		Windows
		Restoration
		Clock
		Belfry only
Bell Info		
	Bell	
		Bell Name/Number
		Note and Ringing Times
		Engravings and Inscriptions
		Clapper and Stock
		Ringing Method and Info
		Historic Information
		Physical Dimensions
Bell Tower Extraneous Info		
	General	
	Location	
	Fire Protection Information	

3.3.2 - Designing and creating the web application

Before we started designing the application, we thought about how we wanted it to function. We wanted a simple, easy-to-use framework that made logging the data very intuitive for the user. In order to accomplish this, we designed the web application to have four main headings that correspond to the main categories from section 3.3.1: Bell Tower Exterior, Bell Tower Interior, Bell Information, and General Bell Tower Information. Within the four main headings, there are accordions, or drop down type menus, that organize the remaining categories and data entry fields.

Along with the organization of the data fields, we also determined what input style each data field would have. Input styles include text, multiple choice, radial checkboxes, sliders, and media uploads. Data fields that require number entries and notes have text entry fields. Fields like staircase material and frame type that have specific entries have multiple choice inputs that save the user from having to repeatedly enter the same information and ensure that the entered data is consistent. For data fields that have Yes or No answers (Stairs, Ramp, ect), there is a checkbox that allows the user to select the correct answer. A slider is used for data fields that require ranking (Staircase cleanliness, Staircase Sturdiness, ect), and goes from 1 to 5. The final input style is media uploads, which gives the user the option to upload media including photographs and audio recordings.

The application is a web application, the benefit to using a web application versus a mobile phone application, is that it can be accessed from a mobile device and a desktop computer. Since there is information such as images and sound recordings that are taken using equipment other than a cell phone, having the ability to add that data once the user is back in an office with a computer is important.

In order to develop the software we needed to build two things, the front end and the back end. Front end development deals with what the user sees and interacts with, while backend development is all of the functionality that happens behind the scenes, such as logging a user in or connecting to a database.

For the front end development of the website our group used HTML, CSS, and Semantic UI. HTML and CSS are the standard languages used to create websites, and Semantic UI is a development framework that helps create beautiful, responsive website layouts. For the backend, our group used Node.JS, Express, and Firebase. The website will be hosted on Heroku web servers, which is a computer system that processes web requests and serves the web page to users' browsers.

The application is connected to and automatically populates the VPC CK database, so the data does not have to be manually entered. Not having to manually enter into the database not only saves time, but will increase accuracy because the data will only be entered once.

Additionally, we hope that the application will be able to be adapted by campanologists when they do their own research on ancient bells in Italy and across other countries. This web app, even if it isn't perfect, will ideally be a starting point for any individuals and groups that wish to participate in the preservation, documentation, and protection of bells and their towers, and will hopefully be adaptable for any future use so that it can be improved if the need arises.

4. Results and Analysis

There are 37 bell towers in the sestieri 'de Ultra' of San Polo, Santa Croce, and Dorsoduro, and two of those towers are Roman style. The locations of the 37 towers can be seen below in Figure 35

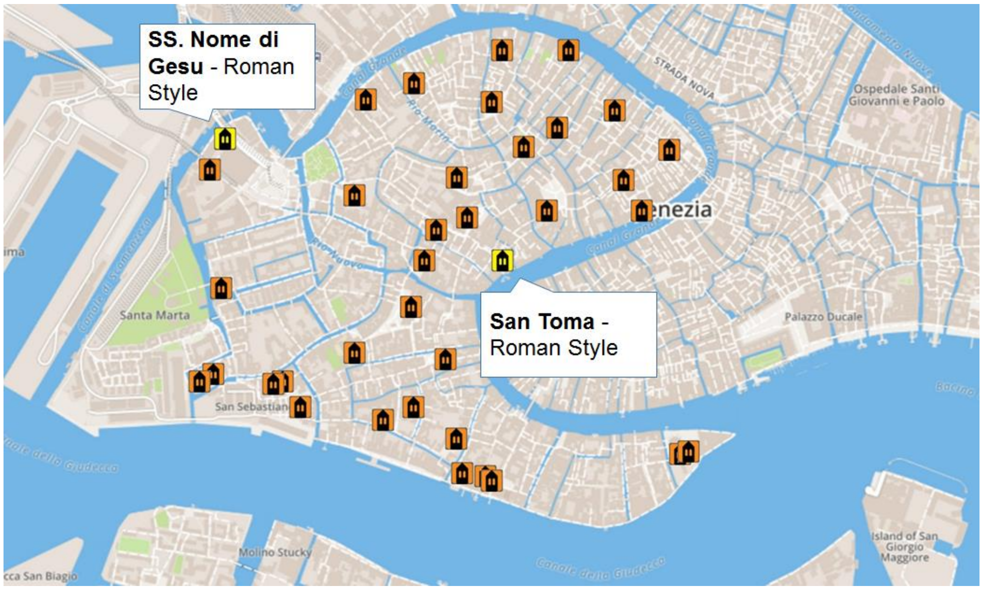

Figure 35 - Location of the 37 bell towers in San Polo, Santa Croce, and Dorsoduro

Three of those towers, San Simeon Profeta (Grande), San Barnaba, and San Polo were too unsafe for us to be able to visit due to the poor conditions of their stairs. These three towers are circled in red in Figure 36 below. We were unable to visit another eight towers because of various logistical problems. We could not ascend San Andrea de la Zirado because we did not know who the owner was to discuss getting into the tower, San Boldo because it does not have belfry, Giovanni Elemosinario because of a missing key, Santa Maria Maggiore because it is part of a prison, Santa Margherita because it is only half of a tower used for housing, Sant'Aponal becasue it is under construction, and Gesuati 2 and Salute 2 because they do not have bells for us to document. The locations of these towers can be seen in Figure 37 below.

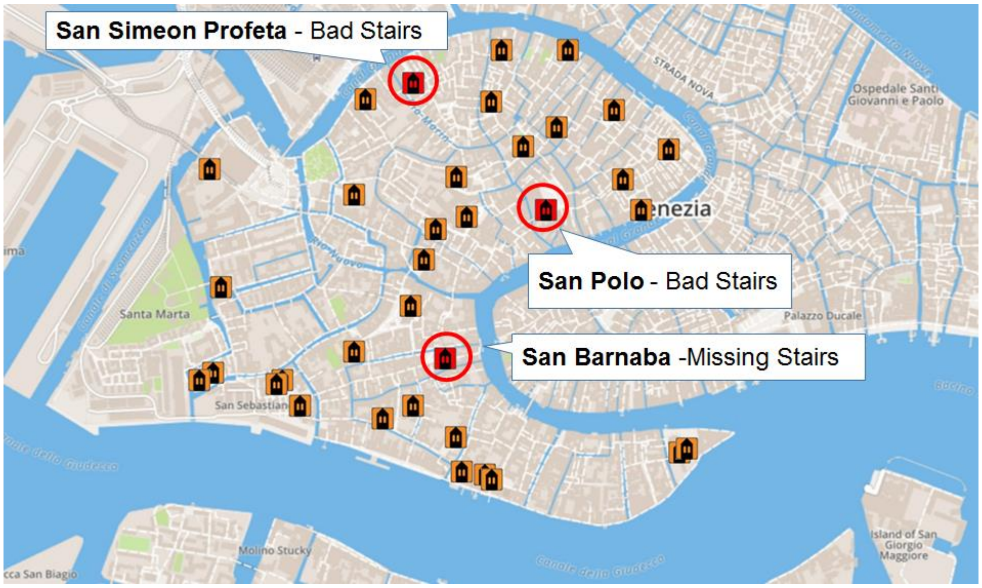

Figure 36 - The three towers that we were unable to access because of unsafe conditions

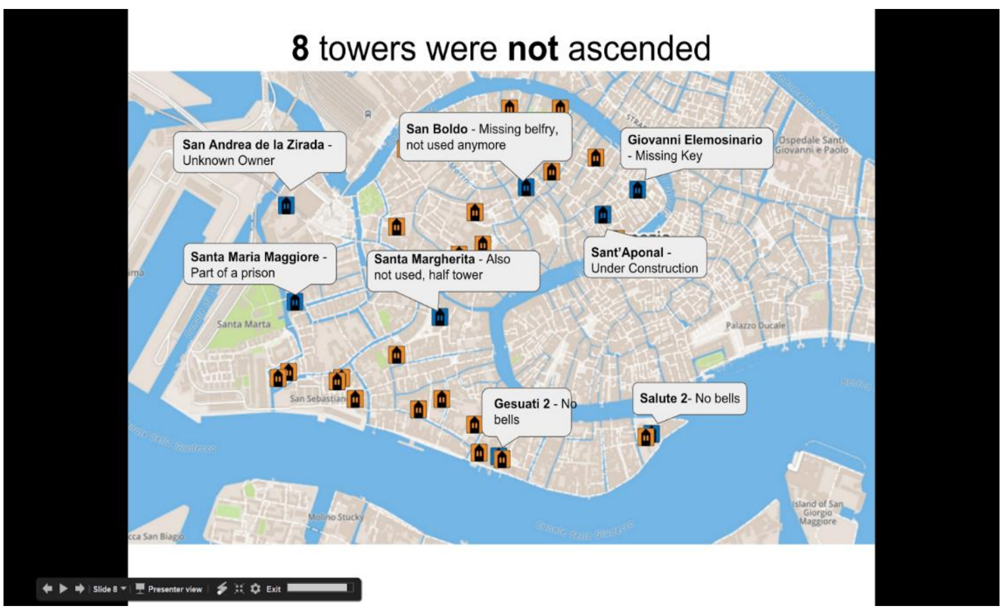

Figure 37 - Locations of the eight towers we were unable to visit because of logistical issues

Of the remaining 24 towers, we visited a total of 17 bell towers at 16 churches and documented a total of 71 bells. We went to the bell towers of Carmini, San Cassiano, Frari, Gesuati, San Nicolo dei Mendicoli, San Giacomo dell'Orio, San Pantalon, Anzolo Rafael, La Salute, San Sebastiano, San Silvestro, San Simeon Grande, San Simeon Piccolo, San Stae, Tolentini, San Trovaso, and San Zandegola. The locations of these towers can be seen in Figure 38 below.

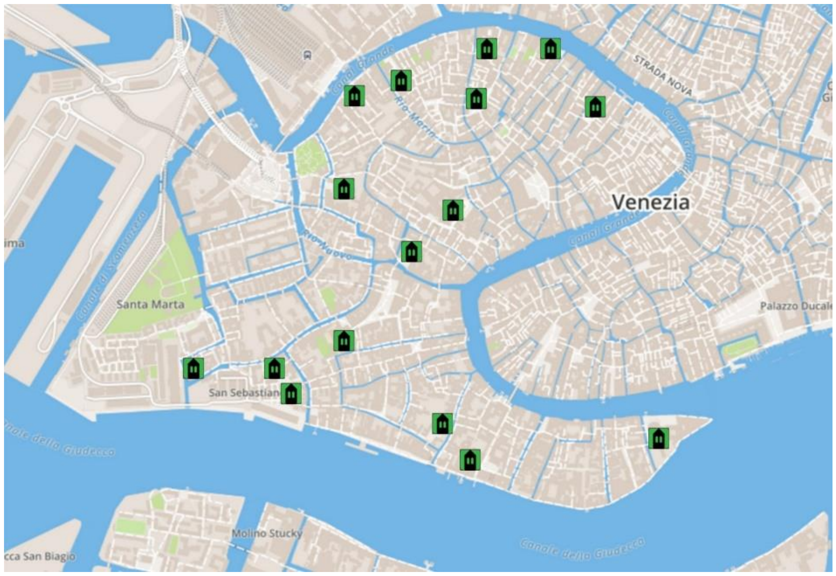

Figure 38 - Locations of the bell towers visited

For all the bell towers that we visited, comprehensive interior and exterior data was collected. Much of the information gathered and the ratings assigned to different criteria in the towers were used to assess the relative levels of safety and accessibility for each.

4.1 Data Collection Application

We created the data collection application over the course of the term so it can be used by future groups. The main page of the app, seen below in Figure 39, displays each of the bell towers found in the City Knowledge database and gives to two options to move forward. The user can either choose to 'View' the tower or 'Edit' the tower. If the user chooses to view the tower all of the data is displayed in a list like in Figure 40. If the user chooses to edit the tower, they are brought to a screen, like in Figure 41 that prompts the choice of the category to begin collecting data.

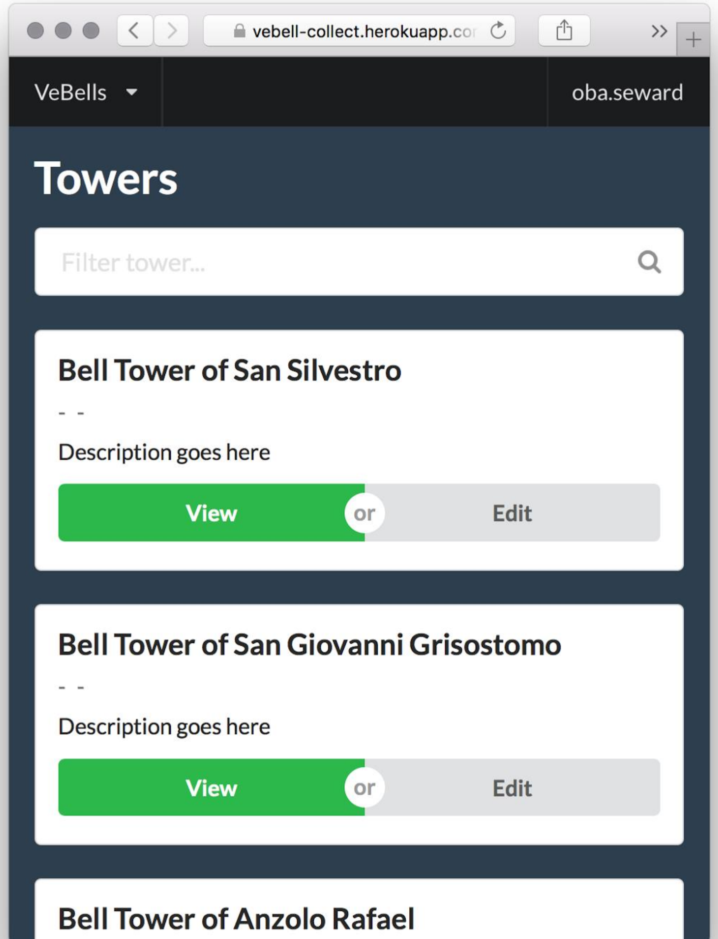

Figure 39 - Main tower page on the data collection application

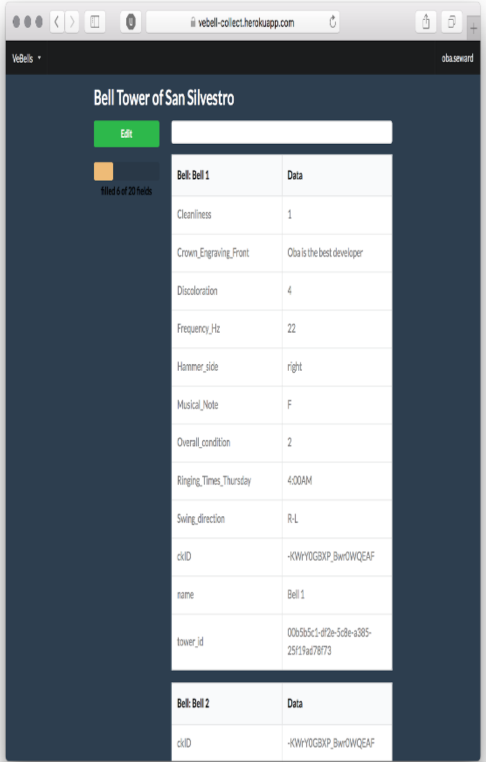

Figure 40 - Example of the 'View' page of a tower on the app

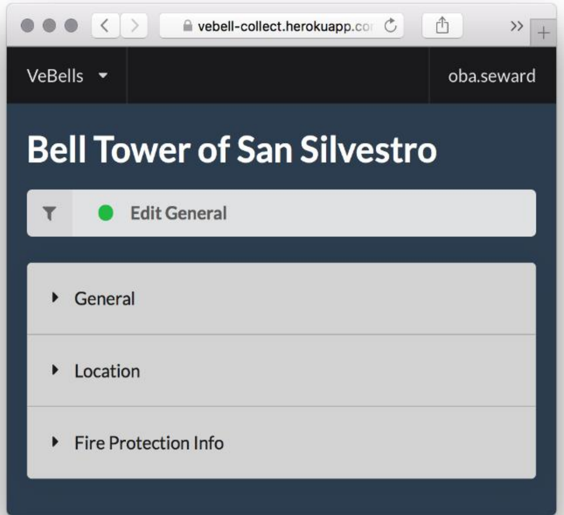

Figure 41 - Opening page of the edit tower screen on the app

When the user reaches the edit screen, they can choose from a dropdown, see Figure 42 below, to choose which category of data they will collect: General, Exterior, Interior, Bells, or Linked Media. Within the editing pages, there are four ways input the data. Each are shown below in Figure 43.

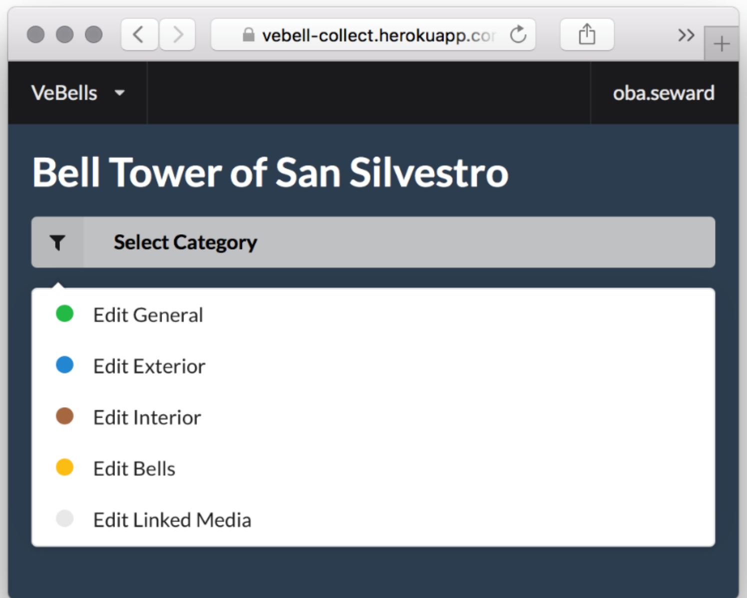

Figure 42 - Drop down menu to choose which main heading to edit

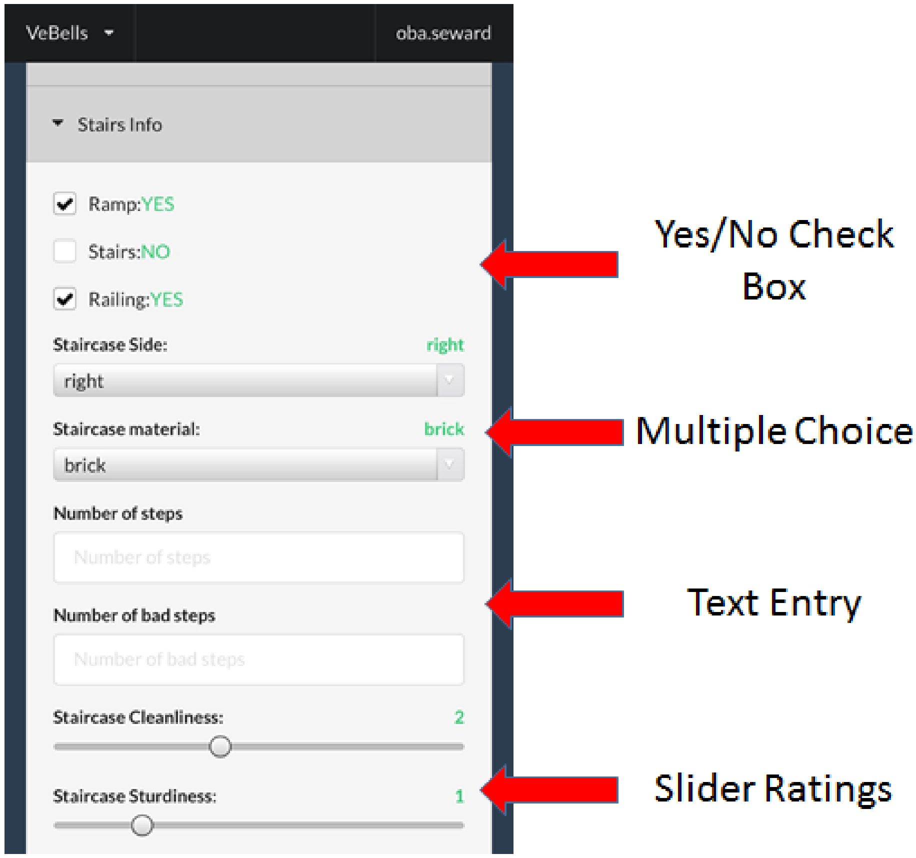

Figure 43 - Examples of Yes/No, multiple choice, text, and slider inputs

The biggest setback our group had with the application was having to restart making it halfway through the term. The first version of the app, although it showed significant promise, could only allow one user to edit it a time. Since the application us ultimately going to be used by multiple people at the same time, we had to find a new way to design it.

Another struggle we encountered was linking the application to the City Knowledge (CK) database. The separate test database that our group used to test on was set up in a way that allowed easy access between tower, bell, and landing data. Currently the CK database is not fully arranged in a way to easily link the application. Fortunately, Tomaso has agreed to make the needed arrangements on the CK database so the application can be fully implemented soon. While this is being completed, our data collection app will remain connected to the sample database.

The final version of our data collection app be found at https://vebell-collect.herokuapp.com/.

4.2 Updated Bells Website

The new design of the bells website does a great deal to improve upon the previous site. In the previous version, all of the content was displayed linearly with each chunk of information stacked on top of each other. In addition, there was no styling that adjusted the width of the content to resize to different screens which made it difficult for mobile devices to display properly. In our new version of the site, we have designed the content in a way that makes exploring the towers much more pleasant.

4.2.1 - Updating Map Page

The first page the user sees when entering the site is the map page. On this page, the user can see every single bell tower in the Venetian Lagoon. Additionally, they can use filters to change the colors of the tower icons to display the different characteristics of the tower that are listed out in the Map Legend. An example of this can be seen in Figure 44. Then, the user can also select a tower he/she wants to explore from the map page and view it on the tower page.

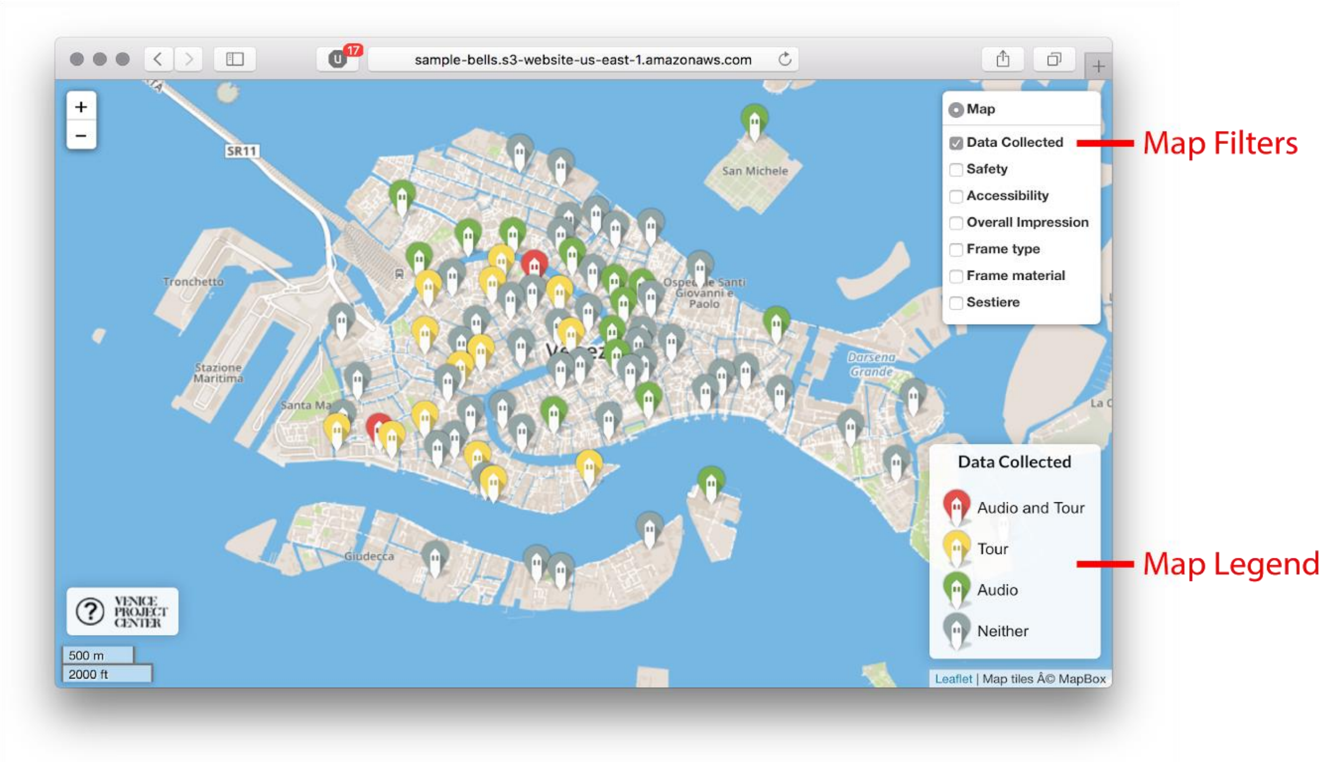

Figure 44 - Example Map Filter

The previous group did a great job implementing the map. It is very functional and allows user to easily get to the tower the user would like to view, and therefore our updates of the site's map screen were minimal. On this screen, our group changed the tower icons from the ones in Figure 45 to the ones in Figure 46. We believe that these new icons convey a more modern appearance to the page. Lastly, we added a filter to the map which highlights all of the towers that have a Matterport tour, which can be seen in Figure 47 below. This way a user can immediately find towers we've added tours to.

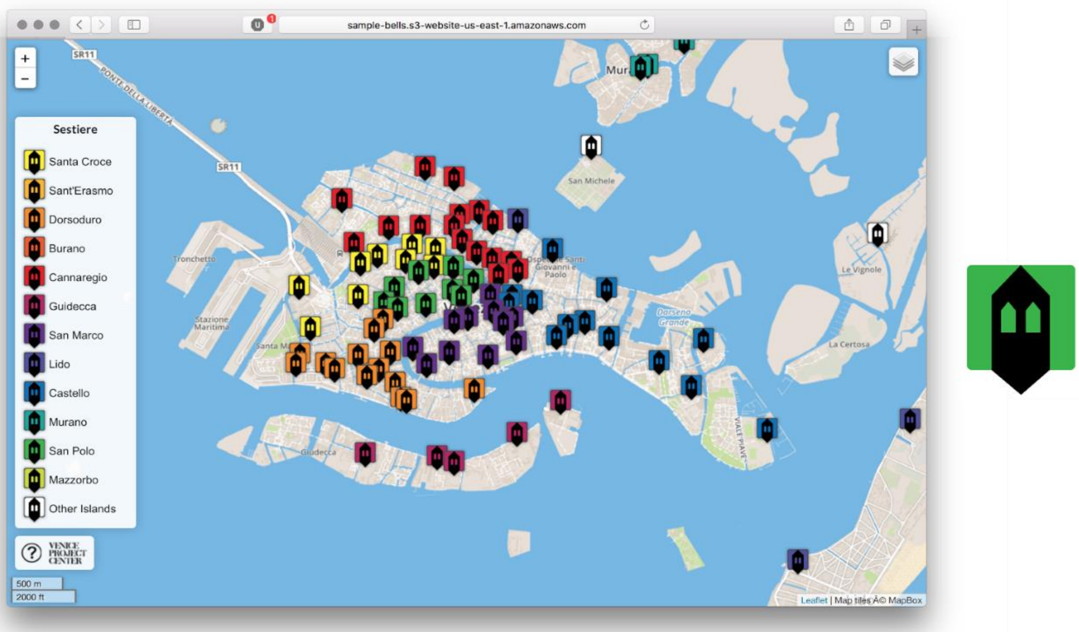

Figure 45 - Map with old icons

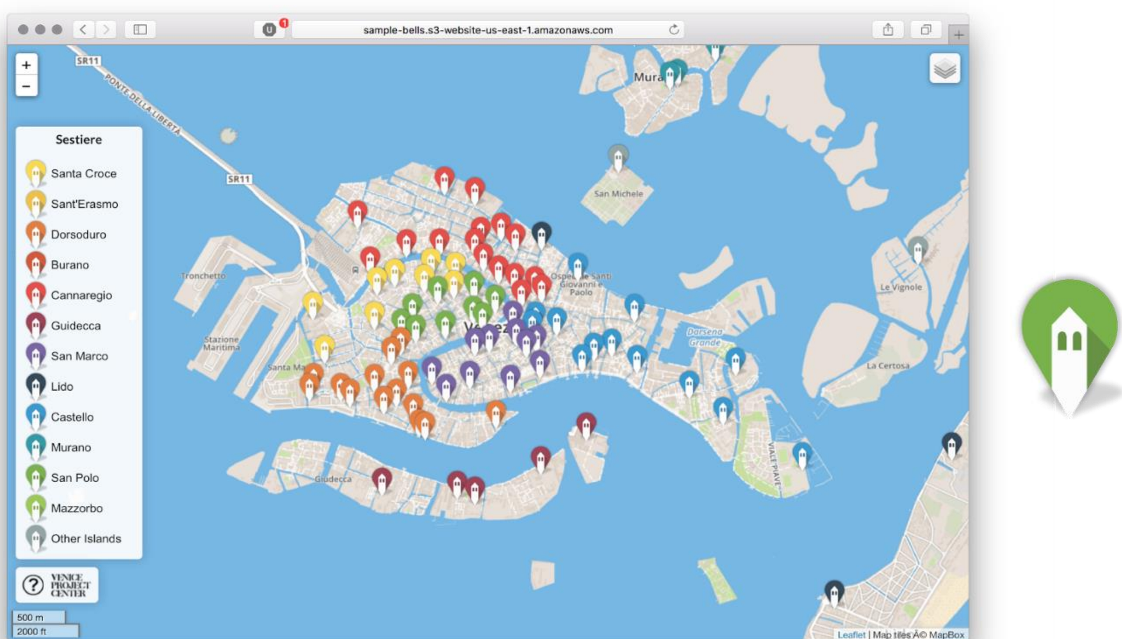

Figure 46 - Map with new icons

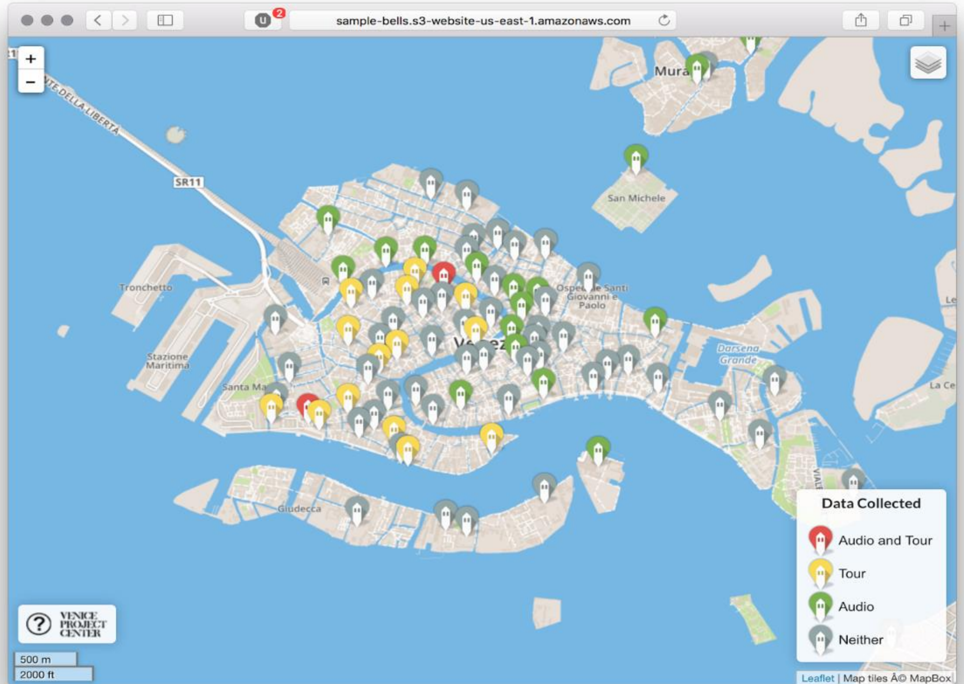

Figure 47 - Map filter highlighting towers with tours in yellow

4.2.2 - Updating Tower Pages

The tower pages are accessible by clicking any of the tower icons on the map, and display all of the data collected about each tower, as well as Matterport tour, Ricoh images, and sound recordings.

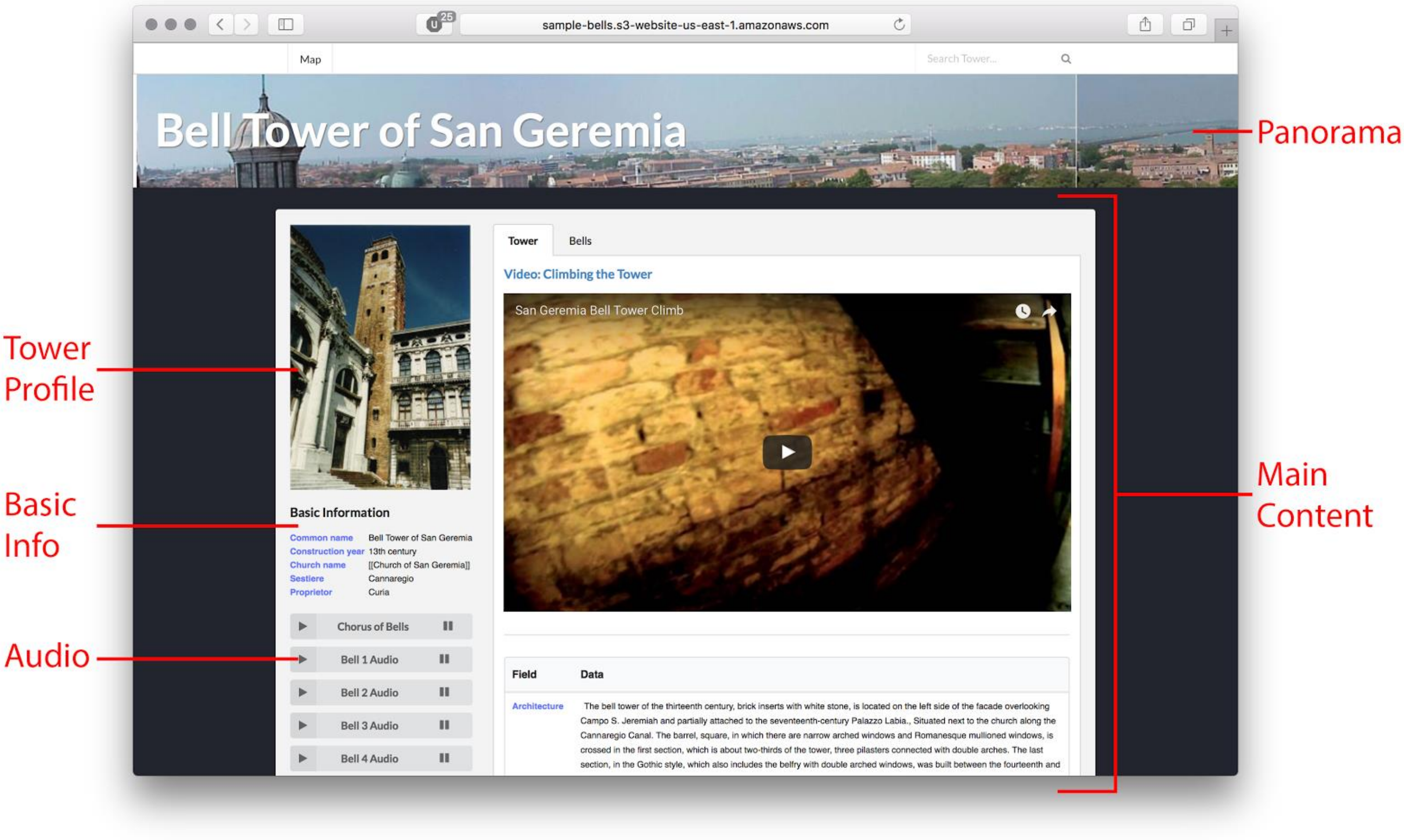

Figure 48 - Example of tower show page

As seen above in Figure 48, on the top of the page we have a section which displays the panorama of the tower's belfry view with the tower name displayed over the image. If the tower does not have a panorama of its belfry view, a generic photo of Venice is shown in its place. Below, there is side content area on the left of the window which displays the towers profile image. Under the profile image, the basic information about the bell tower such as common name, church name, and sestieri is displayed. Play buttons for every bell audio file that is connected to the tower is shown under the basic information. On the right of the side content area we display all of the main content. This includes a tab which allows users to move between content of the towers to that of the bells. In the “Tower” tab, we have a section for the Matterport tour, a Ricoh image of the belfry, the video of the ascension, and a table of data collected for that tower. An example of the “Tower” tab can be seen below in Figure 49. In the “Bell” tab, we have an area that displays all of the 3D bell models that have been collected by previous groups for that tower. An example of the “Bell” tab can be seen below in Figure 50.

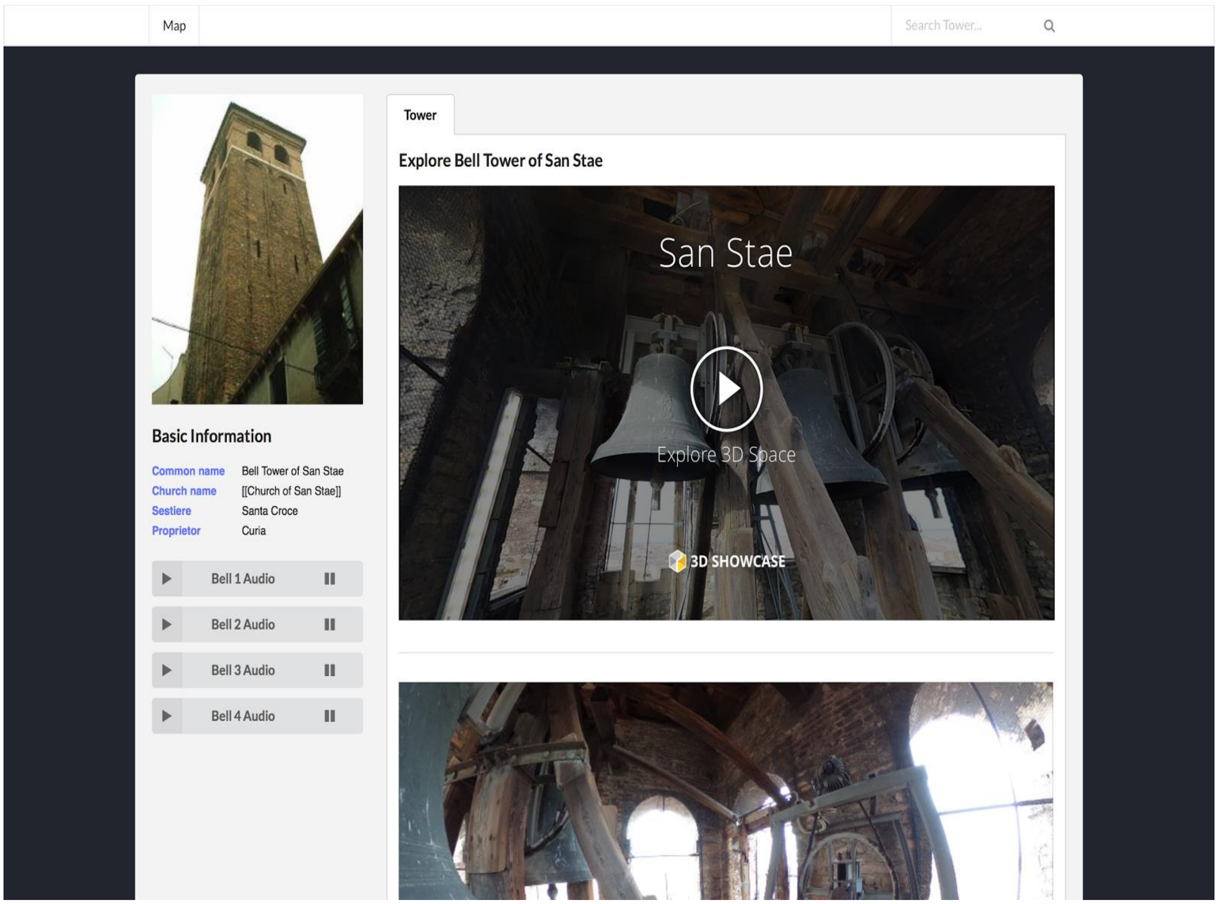

Figure 49 - Example of “Tower” tab with Matterport and Ricoh

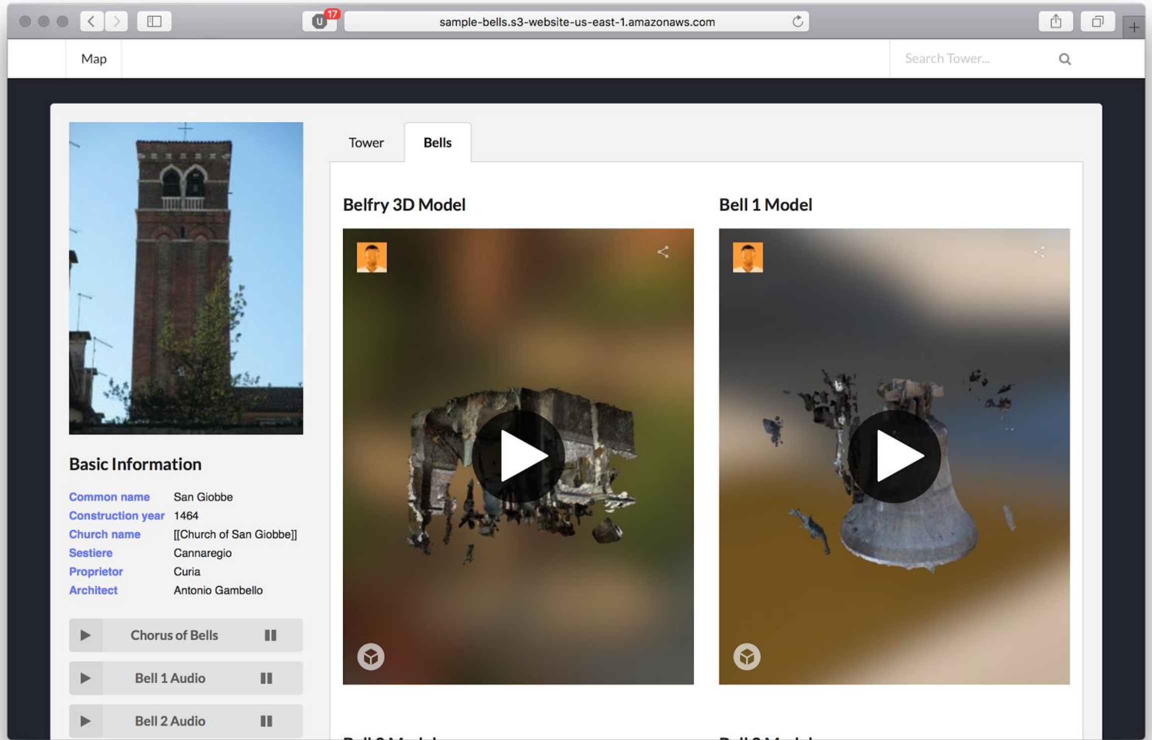

Figure 50 - Example of "Bell tab"

We believe that greatest way to engage a user in our site is by displaying the visual tour of the tower on the top of the first page that loads when a tower icon is clicked. This way the user will be able to experience the tower as if he/she were there. A tour can range from a Matterport 3D experience, a video of someone walking up the tower, or a Ricoh image of the belfry. If a tower has any of these linked media, it is displayed on top of the main content area.

If any of the content is missing from the displayed tower, that section which would display that content is hidden. For example if a tower does not have a Matterport tour, that section is not shown on the page. This allows the tower page to adapt to the different media that each tower might be connected to. Furthermore, when a user views the tower page on a mobile device all of the content is stacked on top of each other and resized to match the screens width. This was a great improvement over the lengthy single item lists found on the old design, using the space more efficiently and making the site more eye-catching and easy to navigate.

The link to our website is http://bells.veniceprojectcenter.org.

4.3 Bell Tower Exteriors

Upon arriving at the bell towers, the first notable aspect of the tower is its height. Below in Figure 51 the silhouettes of the seventeen towers we visited are ordered from tallest to shortest. The tallest tower we visited was the Basilica de Frari at 69 meters and the shortest was San Nicolo dei Mendicoli at 26 meters.

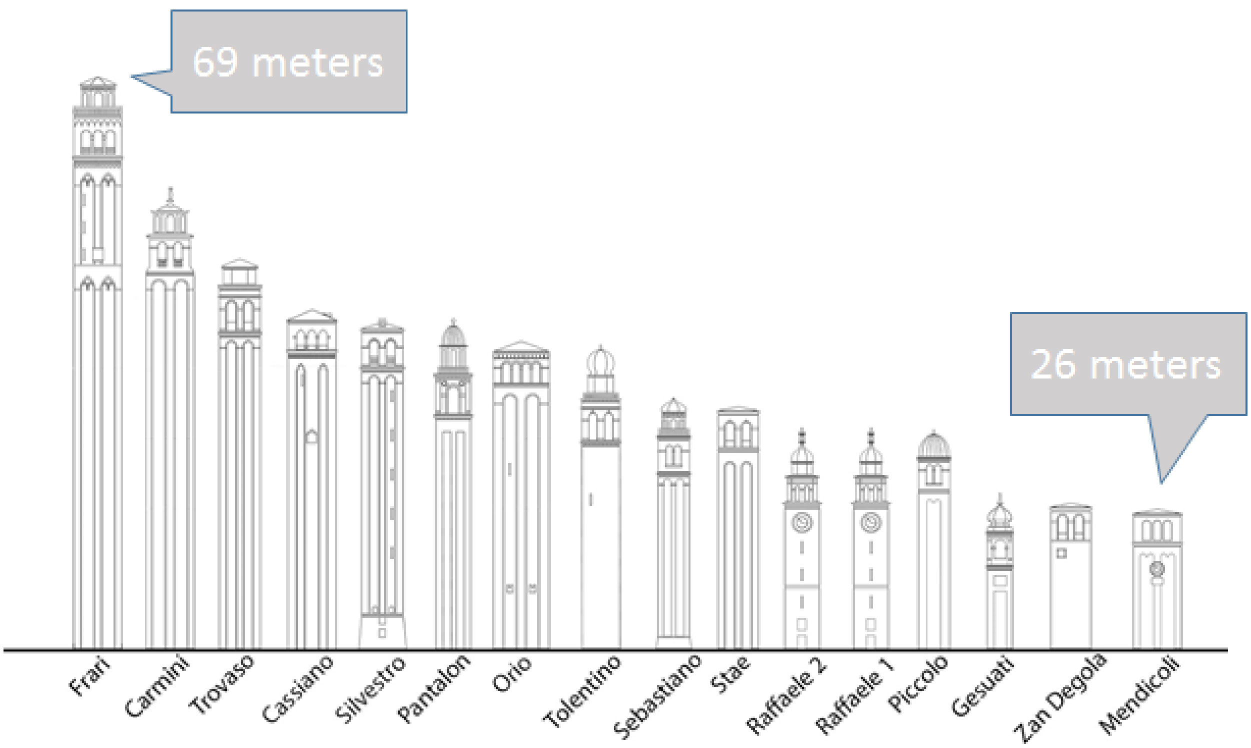

Figure 51 - The 17 towers we visited ranked from tallest to shortest.

The next two characteristics of the tower to be noted were how to access the tower and what tower itself is attached to. Fifteen of the seventeen towers required us to enter the church and walk through either back rooms or into restricted areas of the church. The remaining two towers, San Cassiano and San Silvestro, were able to be accessed from a door outside that directly enters the tower. It is better to have a tower that has its own entrance because churchgoers will not be disrupted should the tower need to be visited during a mass or repaired for an extended period of time. We also observed what types of buildings, if any, the bell towers were attached to on each side. Of the towers that had this information recorded, eight were attached in some way to the church and six were attached to apartments. Knowing what the towers are attached to is important to know because in the case of a collapse, these buildings would be in the danger zone and have the potential to be severely impacted.

One structural concern for the towers is plants growing out of the tower. As the plants grow, they force their roots into and between the bricks, which often causes cracking, decreasing the structural integrity of the towers. Three of the towers we visited had extensive plant growth in the upper section of the shaft and belfry. These towers included San Sebastiano (pictured below in Figure 52), San Giacomo dell'Orio, and Carmini.

Figure 52 - Example of the plants growing from San Sebastiano

The final, and arguably most important piece of data recorded on the exterior of the towers is the inclination the tower. The most notable inclined towers were San Trovaso and San Cassiano, both pictured below. San Travaso (Figure 53) was leaning noticeably to the back and well as the right. On the back, the belfry is actually leaning nearly a meter over the base. San Cassiano (Figure 54) leans to the right, with the belfry leaning 0.5 m over the base. While it appears that these two towers are not in any danger of falling right now, as there are more severely leaning towers in other parts of Venice, they should remain monitored in case there are any drastic changes.

Figure 53 - San Trovaso leaning to the right

Figure 54 - The leaning of San Cassiano

With the above information, we ranked the towers based on their exterior condition. The weightings of the importance of each data field can be found in Appendix D. Figure 55 below shows the order of the towers from our ranking. The tower in the best exterior condition is Salute and the worst two are San Trovaso and San Cassiano. This is because a heavy weight was put for the inclination of the towers. The towers in the right of the figure did not have enough data to complete a fair analysis as it was hard to view all sides of many towers and reach the bases in order to measure inclination.

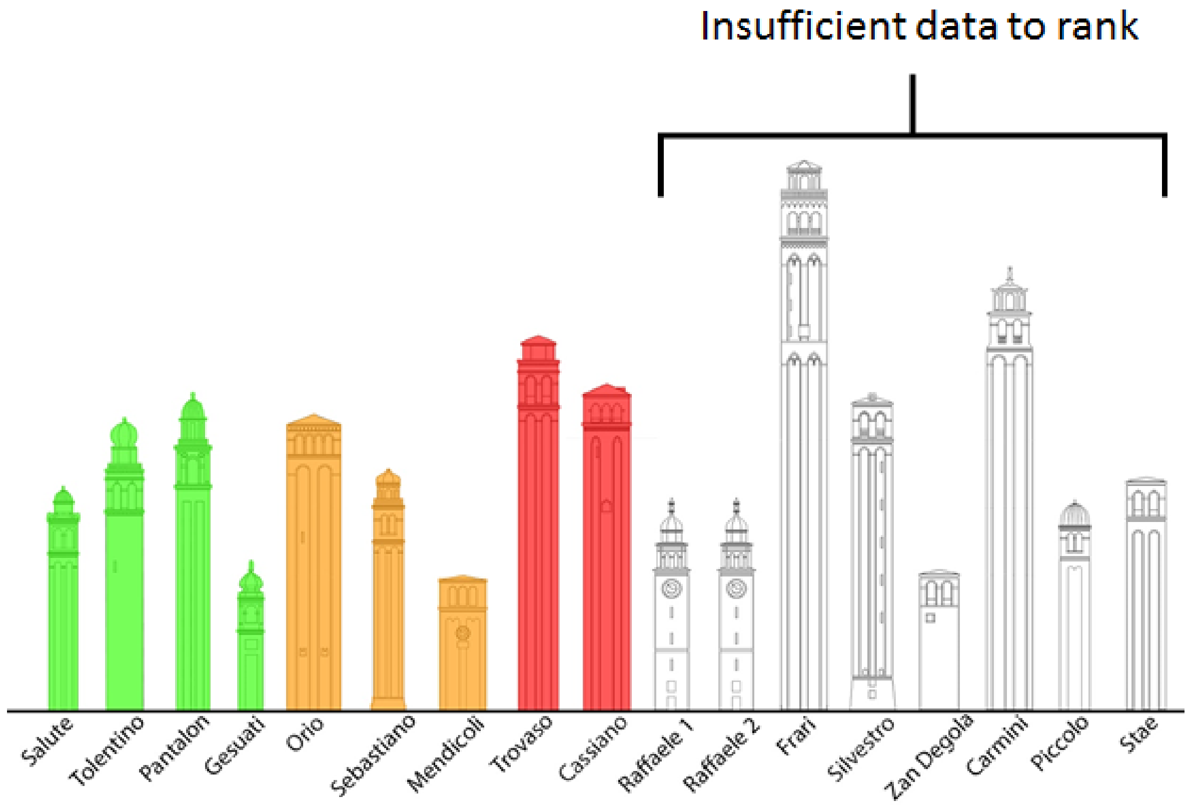

Figure 55 - Exterior tower ranking from best to worst

4.4 Bell Tower Interiors

4.4.1 Stairs and Ramps

One of the first aspects of the tower that is observed upon entering the tower is the presence of stairs or ramps. The state of the stairs or ramps is important since it is how one would reach to the tower. Of the seventeen towers that we ascended, sixteen of them had some form of staircase or ladder, and one had a ramp. Fifteen of the seventeen towers had railings to assist in the ascension, and of the towers that had the sturdiness rating recorded, the average sturdiness of the railings was 3.99 out of 5 (5 being the best). The lowest rating was in the bell tower of San Simeon

Grande, where we did not even climb the tower because the condition of the stairs was so poor. The ladder can be seen below in Figure 56.

Figure 56 - The flimsy and unstable ladder leading to the bell tower of San Simeon Grande.

The two towers that do not have railings are Frari and Salute, but both were still climbable. The bell tower of Frari is the only tower that we visited that used a ramp to ascend the tower, and because of the ramp and structure of the interior of the tower the lack of a railing does not severely impact the safety of the tower. This is also the same for the bell tower of Salute which has a spiral staircase with stone walls on either side. Images of the interiors both Frari and Salute can be seen in Figure 57 below. In comparison, Figure 58 illustrates the importance of a railing in Carmini, which we would not have been able to climb if there was no railing.

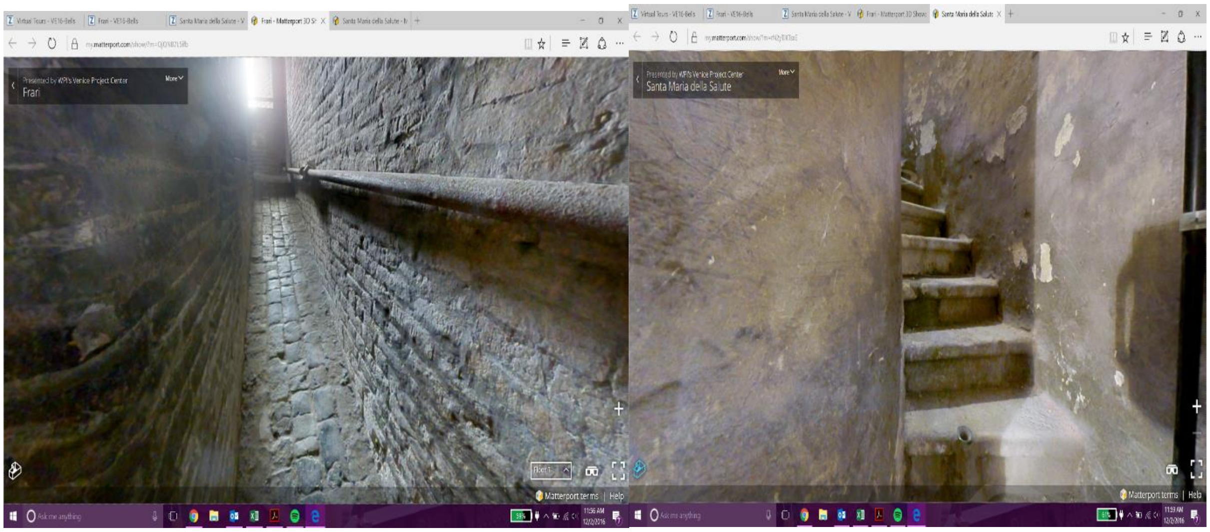

Figure 57 - Interior of Frari (left) and Salute (right) showing how safety is not compromised without a railing

Figure 58 - Interior of Carmini to illustrate why the railing is important

Another aspect of the tower that we documented was the amount of stair. The average total amount of stairs for each tower is 97.4 stairs. The tower with the most amount of stairs was Carmini with 306. Frari would probably have been similar if it did not have ramps. Within the towers, the steps are broken down by landings. The average number of landings in each tower was 4.88, and they ranged from one landing in Frari and Salute (because of their continuous ramps and spiral stairs) to nine landings in San Giacomo dell'Orio. An example of a landing can be seen below in Figure 59. The average number of steps per landing was 17.77. In addition to the amount of stairs in the tower, we also recorded the amount of bad stairs because they cause a safety concern and need to be fixed to increase the safety of the tower. The average number of bad steps per landing was 0.22, as they often were not present.

Figure 59 - Example of a landing in San Giacomo dell'Orio

Using the weighting process outlined in Appendices C and D, we determined the best and worst interiors of the towers. Some of the factors considered included landing and stair sturdiness as well as cleanliness, railing sturdiness, and amount of lighting. Figure 60 below shows the results of the weighting. The two best interiors were Salute and San Zan Degola and the worst interior was San Simeon Piccolo. San Simeon Piccolo was ranked the worst because the stairs were unsturdy, it was very dirty and covered in guano, and it was also not very well lit.

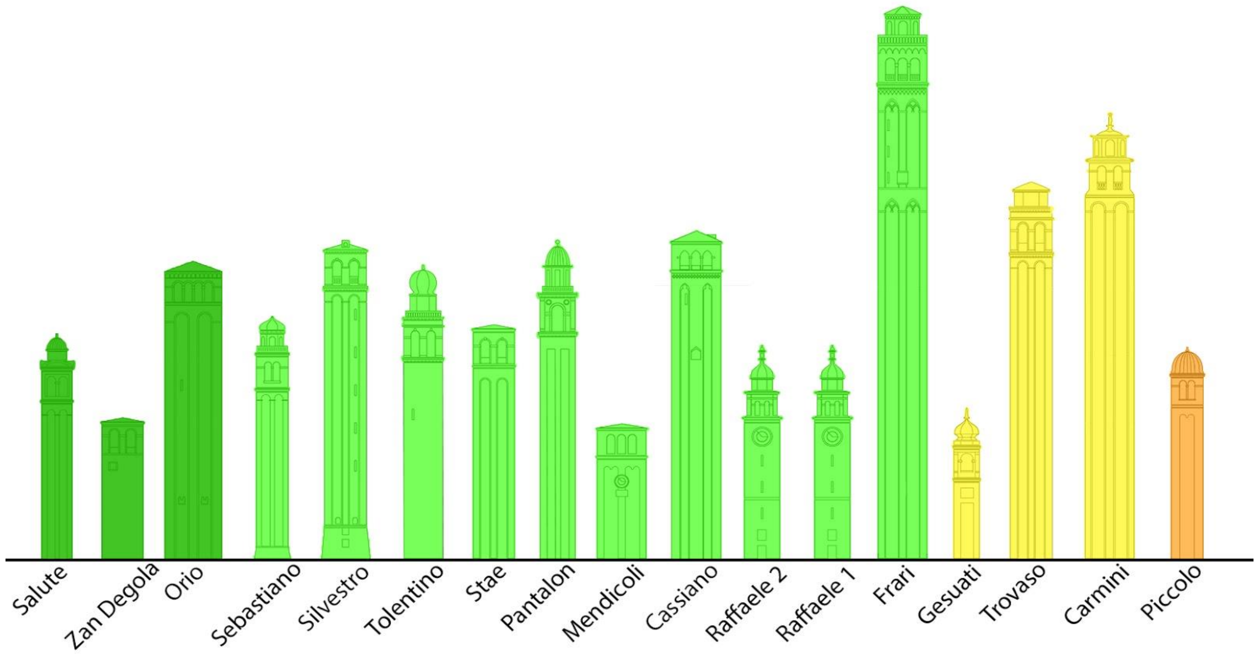

Figure 60 - Ranking of the interior of the towers from best to worst

4.4.2 Belfry

Moving up to the belfry, there are several aspects that we catalogued including, but not limited to, the type and material of the bell frame and the condition of the bird netting. We found that fifteen towers had A-frames and 3 had H-frames. All of the A-frames were made from metal, except for the frame in San Stae that was made from wood. The metal usually indicates that the frame has been restored from the original wooden structure. Among the H-frames, San Simeon Piccolo was made from wood, and San Zan Degola and Gesuati were both made from metal, where Gesuati was built for the Veronese-style of ringing. In Veronese-style ringing, the bells are spun in full 360 degree rotations, rather than rotating just enough for the clapper to fall as in the more common slancio style.

Figure 61 - Veronese style frame in Gesuati

Also in the belfry are bird nets that cover the windows. The bird nets are a major part of keeping the belfry clean, as they keep the birds from entering the tower and leaving guano on the frame and bells. All of the towers have some type of netting except Frari, San Silvestro, and Gesuati. Although they does not have netting, the belfries in both Frari and San Silvestro were very clean. Gesuati, on the other hand, did not have netting because of how the bells are hung inside the windows (as seen above in Figure 61) and the belfry was not clean. Of the rest of the towers that did have bird netting, the average bird net condition rating, on a scale of 1 to 5 with 5 being the best, was 4.07. The only towers with insufficient netting were Carmini and Zan Degola and they both were ranked 2.

Some major problems that we found were cracks around the bell frames. In Figure 62 below, the lefthand picture shows the cracks forming in the newly restored frame in San Giacomo dell'Orio, which was fixed within the past decade. These cracks are paint a poor image of the frame's condition, specifically because the frame is very new and is already causing major damage to its base. The righthand pictures shows one of the numerous cracks in the walls of Gesuati. These cracks are caused by the improper attachment of the frame to the walls of the belfry, and if the bells continue to ring the tower is in danger of collapse.

Figure 62 - Cracks from the bell frame in San Giacomo dell'Orio (left) and Gesuati (right)

Using a weighting system described in Appendices D and E, the belfries of each bell tower were ranked from best to worst, and the ranking can be seen in Figure 63. Some of the fields that were included in the ranking include landing cleanliness, frame type, and bird netting condition. The two towers that were in the best condition were the two towers of San Raffaele, and the two worst towers were Carmini and Gesuati.

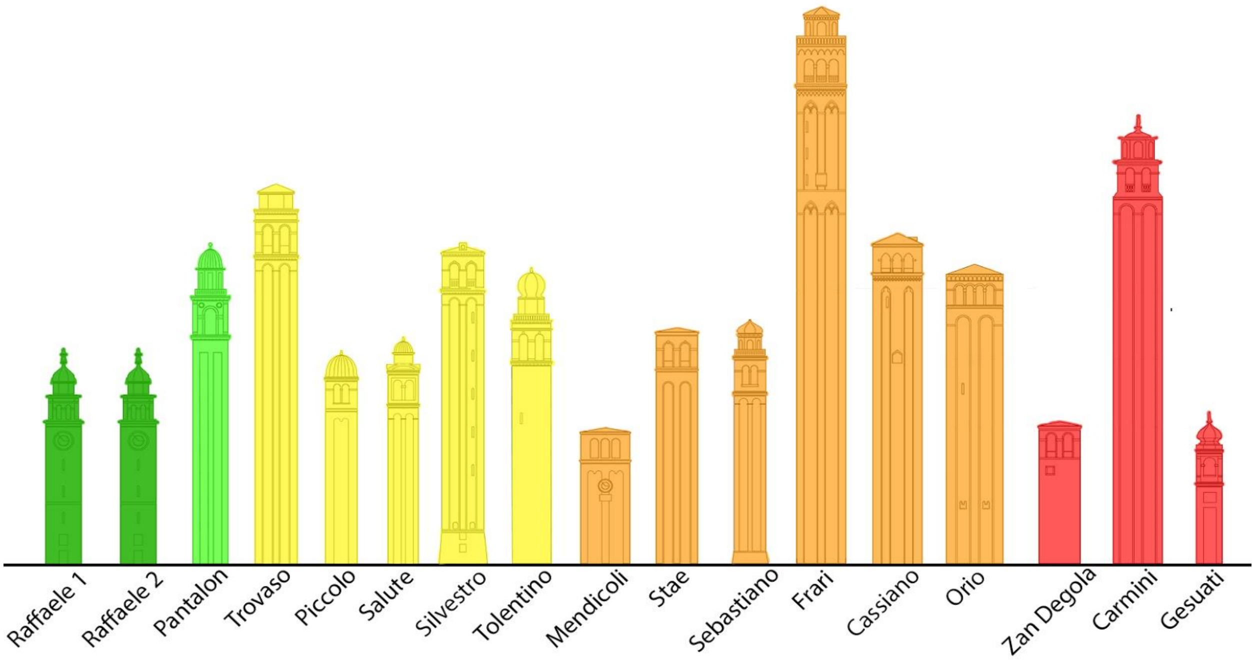

Figure 63 - Ranking of the belfries from best to worst

4.5 Vibration Recordings

Another piece of data we collected was vibrational data that can lead to conclusions about which bells should or should not be rung due to tower safety issues. Using the Vibsensor app, we were able to collect information using the accelerometer in our phones. We were only available to collect vibrational data for six different towers because we only recorded the vibrations during scheduled ringing times. The six towers were Carmini, San Raffaele, Mendicoli, Giacomo dall'Orio, Frari, and San Pantalon. Below are the vibration graphs for each tower (Figures 65, 66, 67) that show the vibrations in m/s^2 for the X, Y, and Z axis (Shown in Figure 64 below). Unfortunately, we did not make sure the phone was facing the same direction in each tower, so the X and Y axes will be different for every tower.

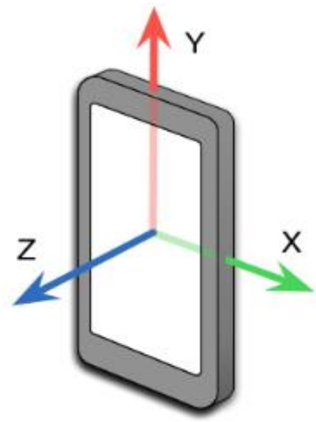

Figure 64 - Direction of X, Y, and Z axes on a phone when acquiring data in Vibsensor

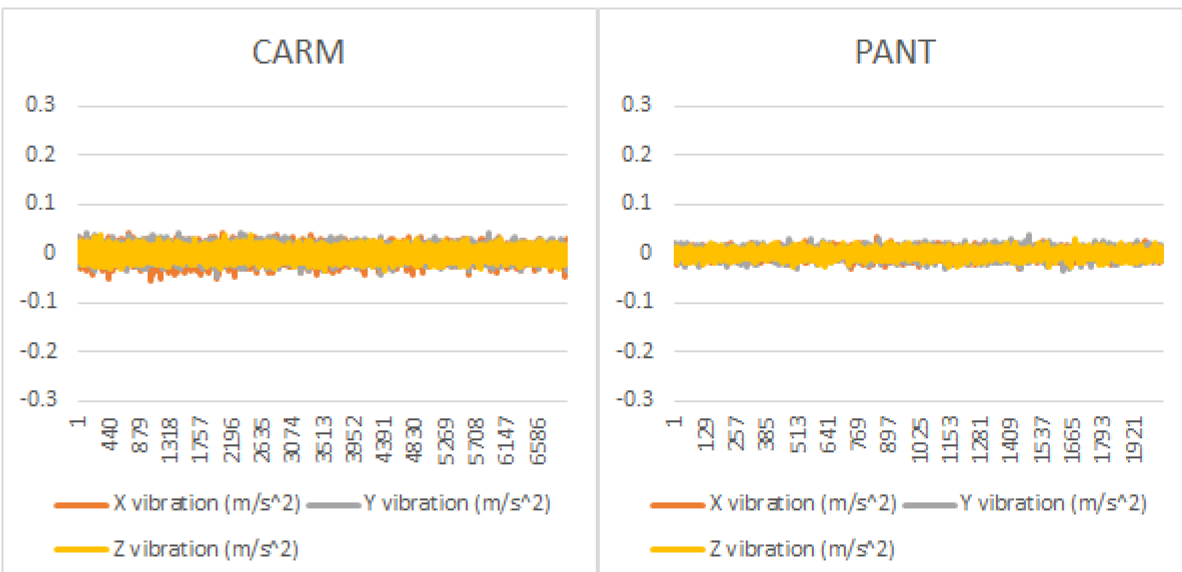

Figure 65 - Vibrational data for the towers of Carmini (left) and San Pantalon (right)

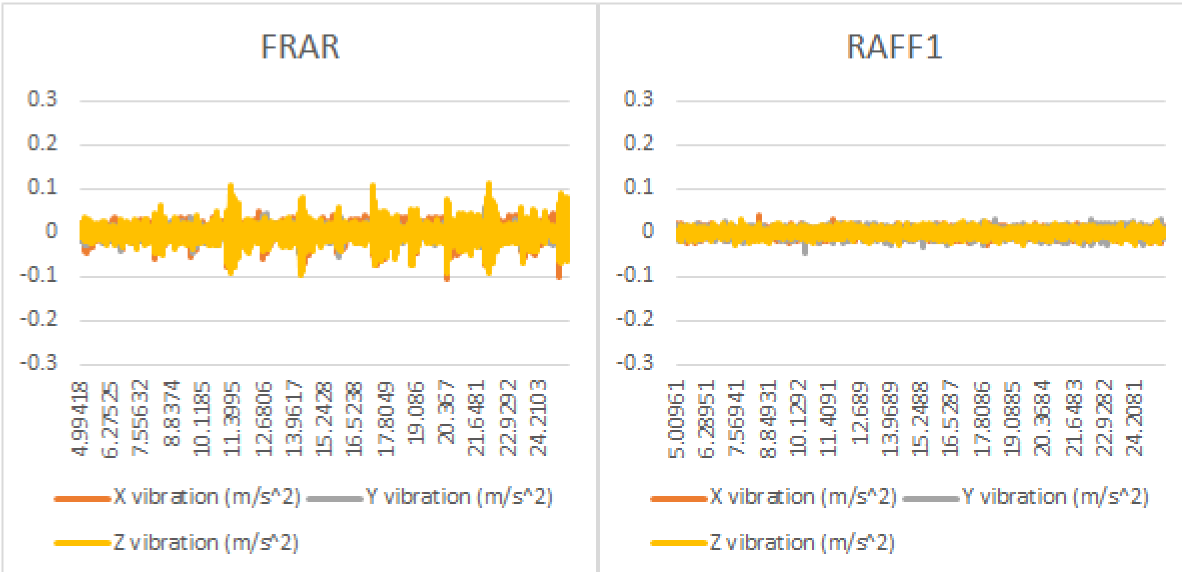

Figure 66 - Vibrational data for the towers of Frari (left) and San Raffaele 2 (right)

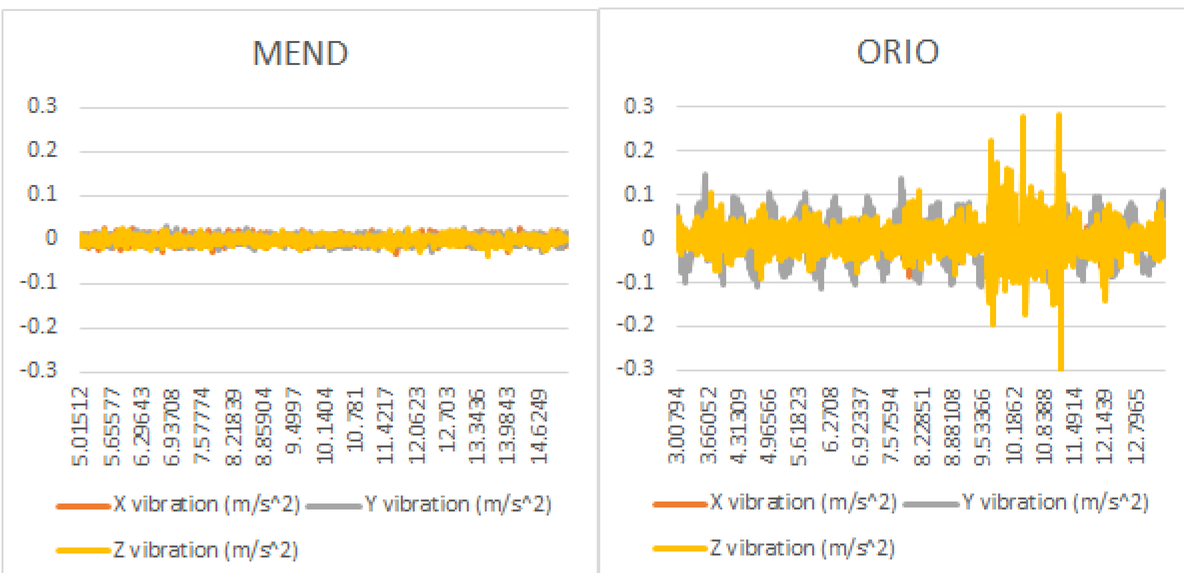

Figure 67 - Vibrational data for the towers of San Nicola dei Mendicoli (left) and San Giacomo dall'Orio (right)

Based on the figures above, we found that Frari and Giacomo dell'Orio had the most vibrations caused by the bells ringing. In fact, when we were in the tower of Giacomo dell'Orio, we could actually feel the tower shaking, we did not feel that in any of the other towers. These vibrations are most likely the cause of the damaged frame bases from Section 4.4.2. In Frari, the vibrations were not as drastic as in San Giacomo dell'Orio, but they are larger than the other four towers. This is mostly attributed to the immense height of the tower. At 69 meters tall, is was the tallest tower we visited.

4.6 Bell Measurements

Along with the tower exteriors, the bells are the most prominent and important feature of each tower, as their ringing can be heard all over the neighborhoods in which their towers are located. The bells are all very uniform in terms of their shape and their material, but vary greatly in size, in age, and in sound. As the size of the bell determines its pitch and note, its dimensions are valuable to know so that in the event a bell needed to be restored or re-tuned, there will be no mistakes making sure its principal note and its nominal tones stay consistent.

Within each belfry, the number of bells varied from a minimum of one to a maximum of seven. In order to keep each bell throughout every tower organized, they were named in a simple but consistent manner - the lower the bell number, the larger the bell. So, the largest bell was Bell 1, the 2nd largest was Bell 2, the 3rd largest was Bell 3, and so on for the remainder of the bells in each tower. The only exception to that rule was the sonello, which was always the smallest bell in each tower. It was not referred to with a number because in order to qualify as a sonello, the bell had to be in a different key than all of the rest. Across all the towers the sizes of each bell that qualified as a "Bell 1","Bell 2", etc. varied greatly, so it made the most sense to take their averages to display the changes in dimensions in relation to their assigned numbers. Shown below (Figure 68), is a bar graph displaying the average internal heights of each bell in each tower, starting from Bell 1 and finishing at the sonello. The height averages follow a logical progression downwards as the number increases, with the exception of the averages for Bell 3 and Bell 4. This is likely due to the number of occurrences of a “Bell 3” in a tower versus a “Bell 4”. This is illustrated by the histogram in Figure 69, where a Bell 3 exists in 15 out of 16 towers and a Bell 4 exists in only 7 out of 16 towers. This led to a greater variance in sizes of the 3rd largest bell in each tower, resulting in a larger standard deviation and an average that doesn’t follow the established criteria of bell naming.

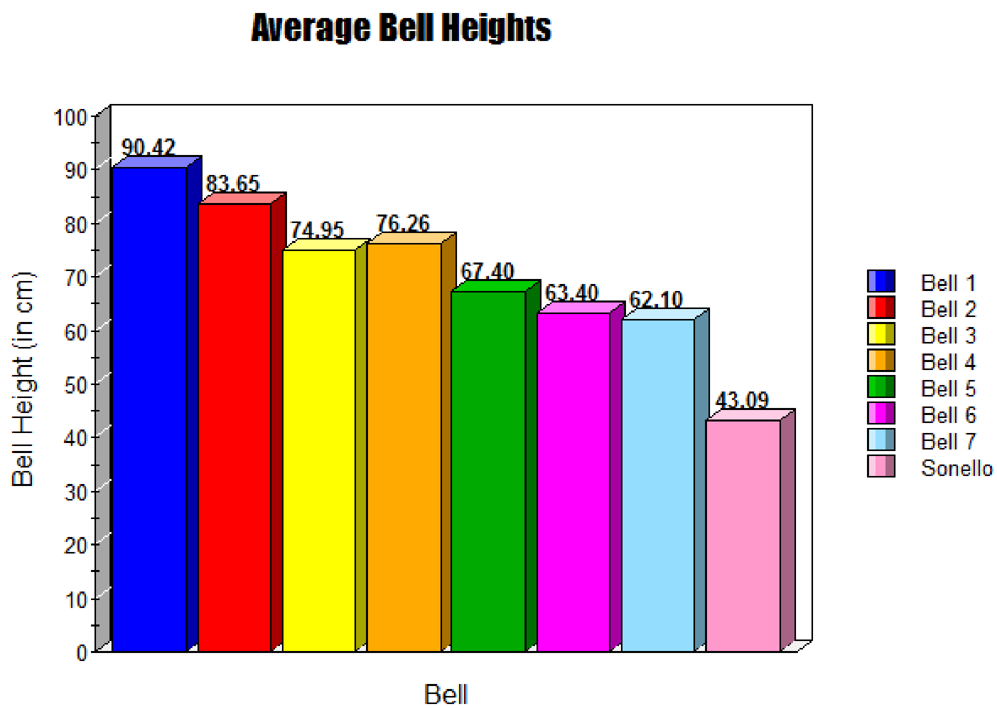

Figure 68 - Average internal bell heights in each tower

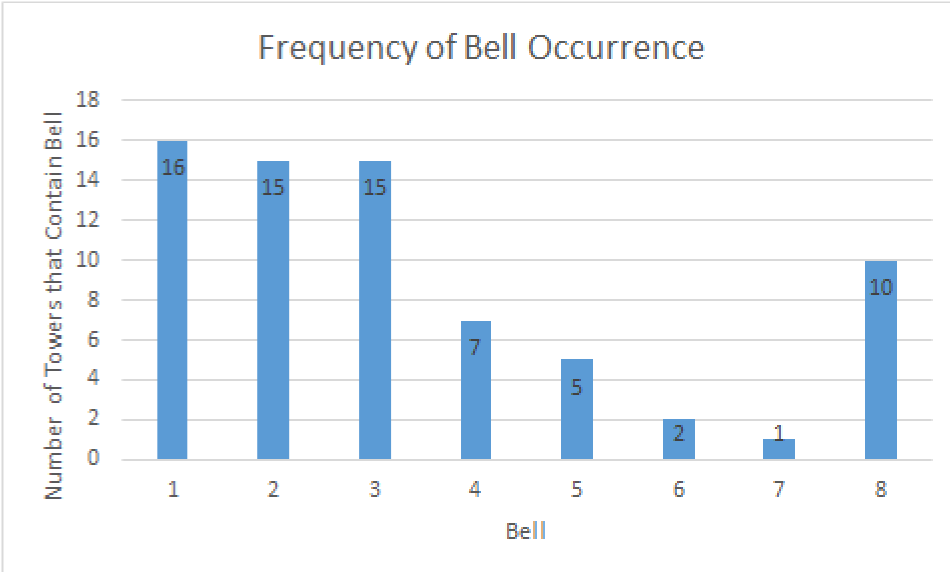

Figure 69 - Frequency of Bell Occurrence (Bell 8 is the Sonello)

Within each tower that was visited, the most common quantity of bells was 4, usually configured as 3 normal size bells and a sonello. The maximum number of bells in any tower was 7, found in the Basilica dei Frari, and the minimum was 1, found in the tiny bell tower of San Zandegola. Most of the time the belfries were cramped, as the bells took up most of the limited room and often made it difficult to stand up. The average height of the bells above the belfry floor was 165.26 centimeters so that the bells and their clappers were given room to swing freely without the risk of making contact with any parts of the frame or the ground.

Regarding the actual conditions of the bells, measurements were taken of skid marks caused by clapper impact on the insides of the bells and observations were made of both the discoloration and surface degradation of the bells, as well as whether or not any bells had cracks. Within all of the towers surveyed, there were 71 bells, 2 of which were cracked. The first was in the second tower of Sant'Anzolo Raffaele on Bell 5, and the crack was 46 cm long. It started at the top of the crown of the bell and continued to halfway down the body on the left side. The crack was also wide enough that if it was observed from the inside of the bell, light was able to clearly shine through and can be seen below in Figure 70. The second bell that had a crack was Bell 3 in the Basilica dei Frari. This crack was much less concerning than the crack in Sant'Anzolo Raffaele, as it was much more narrow, was much shorter and was located on the back side of the bell, starting at the body and ending at the bottom of the lip. It can be seen below in Figure 71. All of the bells in the Basilica are still rung, but luckily the bell in Sant'Anzolo Raffaele had ceased ringing before we went there to do our data collection. Along with the cracks, bell condition was observed through surface discoloration and degradation of engravings and inscriptions.

Figure 70 - Crack on Bell 5 in San Raffaele internal (left) and external (right)

Figure 71 - Crack in Bell 3 of Frari

As was done in previous sections, using the weightings and procedure found in Appendices C and D, we ranked the overall conditions of each tower's bells (shown below in Figure 72). Some of the factors considered for this ranking include bell discoloration, bell cleanliness, cracks, and if the clapper has a safety cable. We determined that Salute housed the best bells, and the bells in San Zan Degola, San Giacomo dell'Orio, San Stae, and San Trovaso all need attention. All of the bells need to be cleaned in order to reduce any deterioration caused by the guano, and the clappers should be restored or replaced because of their rust.

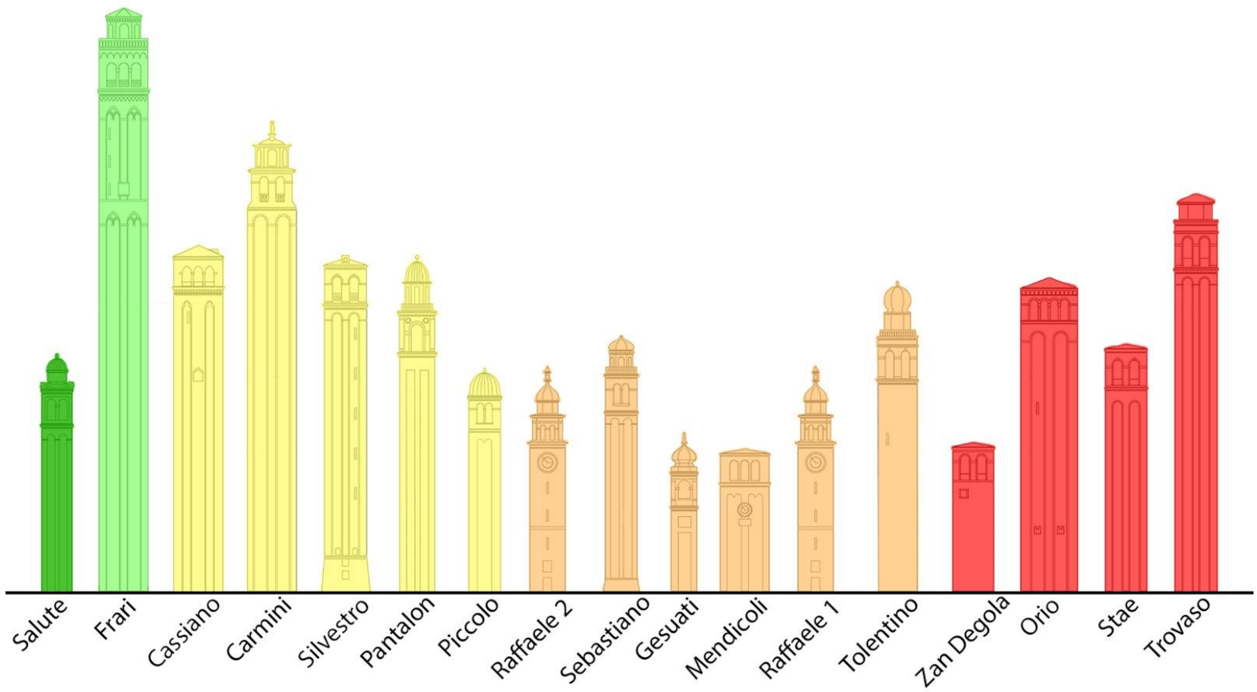

Figure 72 - Ranking of each tower's bells from best to worst

4.7 Sound Recordings

We recorded the chimes of 65 of the 71 bells. The only bells we did not record were those that were too high of the ground to be safely recorded. The towers that have missing recordings are two from San Nicola da Tolentino, two from San Pantalon, one from Santa Maria del Carmini, and one from Santa Maria del Rosario, Gesuati. In the future, these sound recordings can be analyzed using a software called Wavanal. The software finds the prime and partials of each should in order to figure out which bells are most out of tune and in need of restoration. Due to time constraints and lack of expertise, we were unable to fully analyze the recordings that we made, but an example of a Wavanal output, from Bell 1 in Carmini, can be viewed in Figure 73 below. The plot on the left displays the frequency of the sound and the right lists the notes and partials of the chime. The sound files that we make have been converted into the proper format for easy analysis.

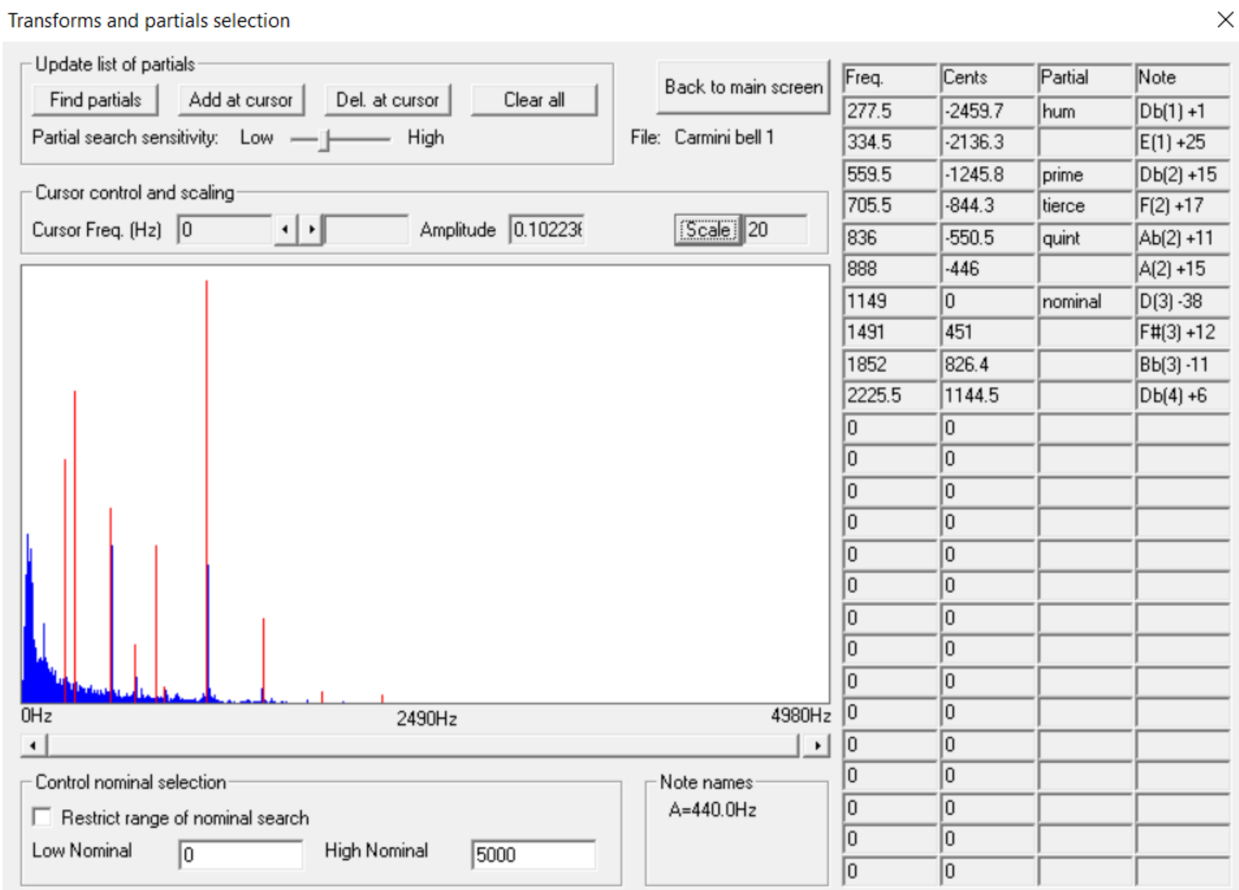

Figure 73 - Example of results produced from Wavanal

4.8 Overall Bell Tower Condition

In order to provide a complete view of each tower's overall condition, we compiled the rankings from the exterior, interior, belfry, and bells into one ranking system. There were a total of 29 fields that we chose to use in the ranking criteria, each weighted differently based on what we determined to be most important:

- Landing_Sturdiness : 2
- Landing_Cleanliness : 1
- Natural_Lighting : 0.4
- Artificial_Lighting : 0.1
- Staircase_Cleanliness : 1
- Staircase_Sturdiness : 2

- Railing_Sturdiness : 2
- Number_Misaligned_Brick_Front : 0.25
- Number_Misaligned_Brick_Right : 0.25
- Number_Misaligned_Brick_Back : 0.25
- Number_Misaligned_Brick_Left : 0.25
- Frame material : 1
- Frame_cleanliness : 1
- Frame_warping : 0.1
- Frame_Overall_condition : 2
- Condition_of_inside_of_roof : 0.5
- Drain Holes Rating : 1
- Railing : 2
- Bird_net_condition_front : 2
- Calculated_vibration : 1
- Conservation_state : 1
- Safety_cable : 1
- Cracked_side : 2
- Cleanliness : 1
- Discoloration : 0.2
- Overall_condition : 2
- Clapper_condition : 0.5
- Belt_condition : 0.5
- Inclination_rating : 1

Using the process outlined in Appendix C, each tower was given a score that determined its placement in the overall rankings. The color of each tower was determined by its resulting score: dark green for score above 90, green for score in the 80's, yellow for a score in the 70's, orange for scores in the 60's, and red for any score below 60. The complete ranking can be seen below in Figure 74.

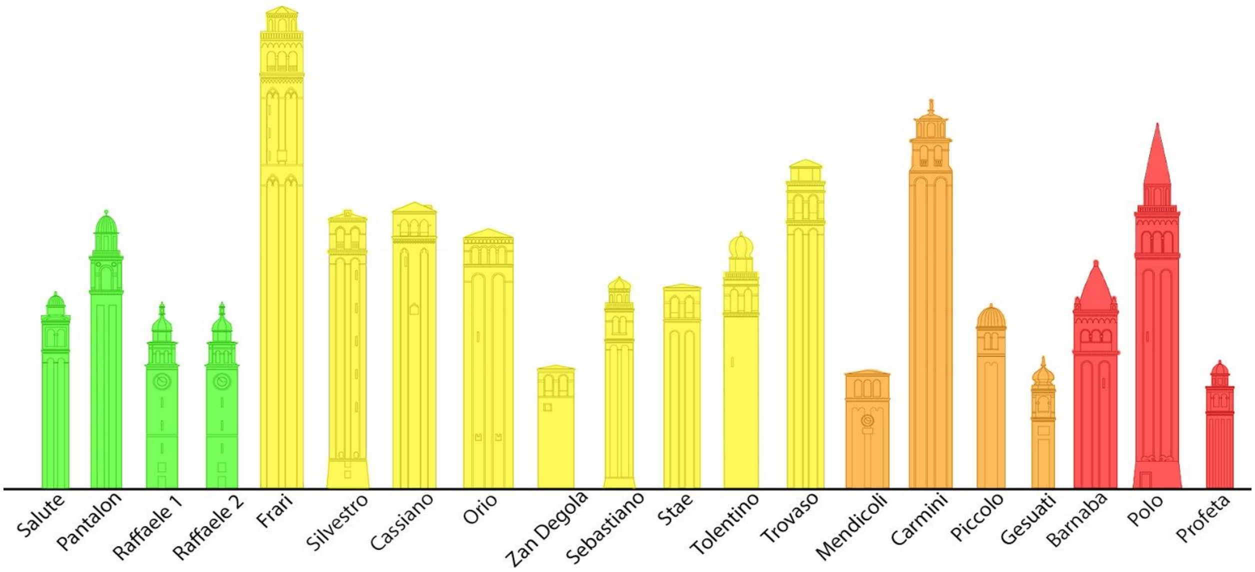

Figure 74 - Overall ranking of the tower conditions from best to worst

The four best overall towers are Salute, San Pantalon, and the two towers of San Raffaele. The bottom three towers are San Barnaba, San Polo, and San Simeon Profeta, which have been colored red because these are the towers we were unable to visit due to safety concerns. The next towers are the worst towers that we were able to visit and ascend. They include San Nicolo dei Mendicoli, Carmini, San Simeon Piccolo, and Gesuati. In Figure 75 below, the four towers are colored according to the condition of each part of the tower. Gesuati's belfry and bells were in very poor condition and the interior was fair. San Simeon Piccolo's bells and belfry were in average condition, but the interior was in poor shape. Carmini's bells and interior were in an average condition, but the belfry itself was in very poor condition. Lastly, San Nicolo dei Mendicoli had a very good interior, but the belfry and bells were only in average and poor conditions, respectively.

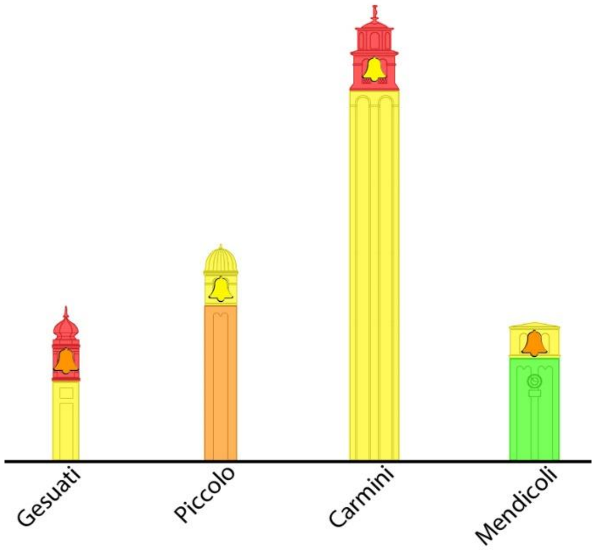

Figure 75 - The four lowest ranking towers visited colored by condition of each part of the tower

The main issues found in Gesuati were severe damage to the belfry walls from improper mounting of the bell frame, missing or bad steps in the shafts, and a dirty belfry. There were multiple steps in very poor condition, and one even broke when we were climbing it. Since the bell frame was improperly installed, there is not only guano on the floor, but also brick dust.

In San Simeon Piccolo, the major problems were related to cleanliness. Throughout each of the landings, within the belfry, and on the bells there were massive amounts of guano. The guano is not only bad for the bells themselves, but can also cause health problems to those visiting the towers. Additionally, the sonello was mounted in a window outside of the bird netting and its frame was in very poor condition. Because of the instability of the frame, the bell has a high potential of falling from the tower in the near future.

The belfry in Carmini is the largest concern of the tower. It was very dirty, including heavy amounts of guano, pieces of metal, and even a frog skeleton. The biggest problem was that there was only a bird net in one out of eight windows, and this was causing most of the mess as there was no way to prevent pigeons or gulls from entering.

Lastly, San Nicolo dei Mendicoli's two main problems were cleanliness and the clapper length of its bells. We found two recently deceased bird carcasses underneath the frame, which raises a large health concern. Regarding the clappers, the clapper in Bell 1 was too long and only had about two centimeters of clearance from the bell frame. This is a concern because if the clapper were to make contact with the frame while ringing, it could be detrimental to both the bell and the frame.

4.9 Virtual Tours

With the Matterport camera, we were able to scan all 17 towers we visited as well as 6 of the 16 churches: San Trovaso, San Giacomo dall'Orio, Santa Maria del Carmini, San Cassiano, San Pantalon, and San Nicolo dei Mendicoli. We also scanned the church Sant'Antonin in the sestieri of Castello per request from Don Caputo. He was impressed with the results of the MatterPort and asked if we could add it to our list of scans. The tours are viewable on our teams website. Most scans were completed in one visit but a few times we had to return later to finish a tower due to the church closing for a few hours in the middle of the day.

As with any new technology, the MatterPort software is not perfect. Each tour can be navigated from the ground floor up to the belfry, but there are a few places in the tour where one of the navigation points is either not visible or not selectable making it impossible to click and move forward. To bypass this problem, the user can click past to the following point and continue up the tower. The camera does not capture images directly above or below where the camera is placed so those locations cannot be viewed. This makes navigating down some stairs particularly difficult. It is typically an issue on the uppermost staircase, going from the top landing into the belfry, where the stairs are usually the steepest. When this is an issue, the user can go to the dollhouse view by clicking in the bottom left corner and selecting where they want to go. The dollhouse icon is shown in Figure 76 below.

Figure 76 - The dollhouse icon in a Matterport model

Additionally, the software sometimes has issues stitching the images together. Stitching the images is when the individual images are put together to create the 360 degree view. The ideally stitched images would be seamless and look like one fluid image, but with our models that is not always the case. Typically the images are not seamless when the camera scans objects that are less than a one foot from the camera. The objects that cause the issues are also thin like the railing in Figure 77. For more information about techniques for scanning see Appendix F.

Figure 77 - MatterPort stitching error. The railing in this scan is noticeably misaligned.

When viewing the tour online there are several different ways to look at it other than the standard view from inside the model and clicking from point to point. To see the entire model click on the button in the bottom left corner to enter the dollhouse view, Figure 78, and the model can be rotated, moved, and zoomed in on using the mouse. In dollhouse view, there is another view called the floor plan, Figure 79, that can also be selected in the bottom center of the screen. With a virtual reality, VR, headset the models can also be viewed from a first person perspective by clicking on the glasses icon in the bottom right.

Figure 78 - Dollhouse view

This view shows the entire model scanned in a 3D view

Figure 79 - Floor Plan view

This view shows the floor plan of each floor of the model

On the MatterPort website we can use the MatterPort Workshop, Figure 80, to add things to the model. The one we found to be the most useful is MatterTags shown in Figure 81. These add a blue dot in the model and when they are scrolled over they display whatever text we want to add as well as hyperlinks. In the future MatterTags could be added to all of the models to add important information about different aspects of the towers and include links to the Venipedia pages.

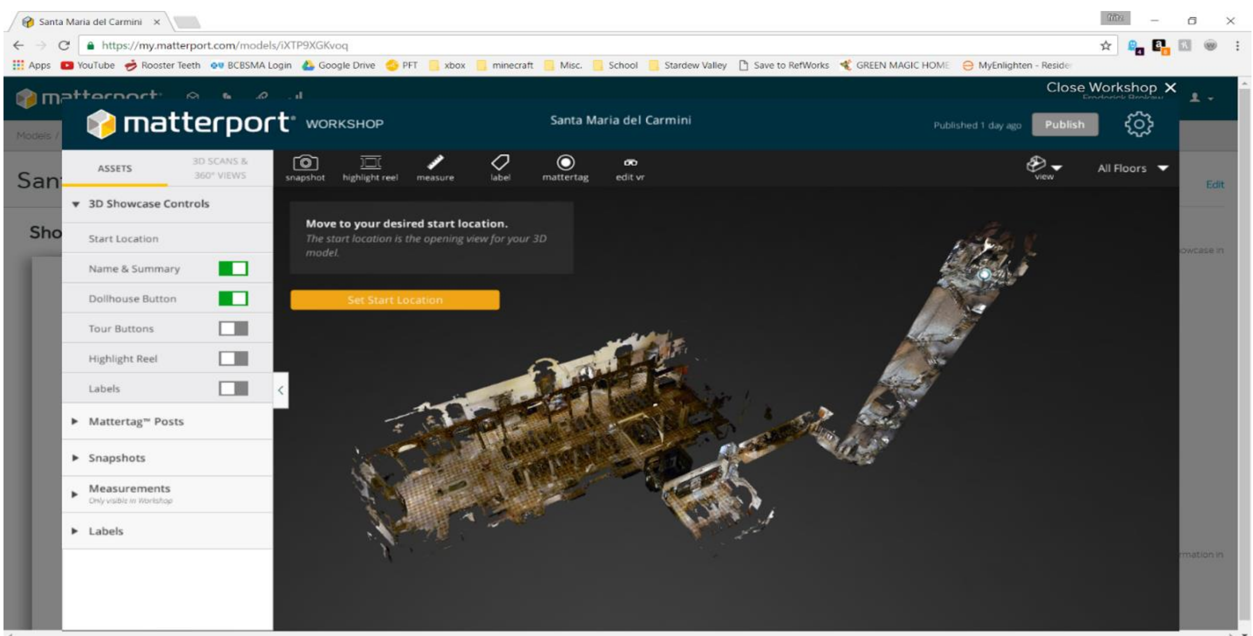

Figure 80 - MatterPort Workshop

This is accessible to the uploader of the model and allows additional information, tags, labels, and snapshots to be added to the viewable tour.

Figure 81 - MatterTag

When the blue and white circle is highlighted the text box with information and links is displayed.

5. - Conclusion and Recommendations

In the past seven weeks we have contributed in a significant way to the VPC's efforts to preserve the city of Venice for years to come. We added information for seventeen towers and 71 bells to the work WPI students have done over the past 22 years of bells projects. This information will help the Curia immensely in their preservation mission. The virtual tours will also catapult the process of historical preservation into the 21st Century, showcasing a novel way to display the towers in a modern and immersive medium. In addition to our material contribution, we have some recommendations to aid the Curia in preservation and future groups with their projects.

5.1 Recommendations for Preserving the Towers

While documenting the towers throughout the term, we encountered a number of problems, inside and out, that need to be dealt with, especially in the four worst-ranked towers of San Nicolo dei Mendicoli, Santa Maria del Carmini, San Simeon Piccolo, and Santa Maria del Rosario dei Gesuati. The main problems in San Nicolo were found up in the belfry. The belfry needs an extensive cleaning due to the bird carcasses found within and the waste that they've left. Additionally, the bells need to have their clappers replaced because they're too long. Most notably, the clapper in Bell 1 is in most urgent need of replacement, as it hangs down to only around two centimeters from the bell frame itself and is at risk of striking the frame and becoming damaged.

Carmini had similar issues in its belfry as San Nicolo, albeit more serious. The belfry is in need of extensive cleaning as animal carcasses and guano abound, and the bells should be cleaned as well. To prevent further sanitation issues, we recommend that bird netting be installed on each of the windows so that pigeons and other common birds in Venice are kept out of the belfry.

San Simeon Piccolo also had extensive issues with sanitation, but its issues were generally much more concentrated throughout the landings in the shaft than in the belfry. The entirety of the interior should be fully cleaned in order to make any future ascents more safe. Up in the belfry, each bell is in major need of cleaning as they're all covered in guano. Additionally, the frame for the sonello, which currently resides in one of the windows outside of the bird netting, needs to be either repaired or replaced to prevent the sonello from falling off within the next few years as the wood frame continues to decay.

Of all of the towers we visited, however, Gesuati needs the most work. Most of the efforts should be concentrated up in the belfry first, as the improper securing of the iron frame to the belfry walls is causing major cracks that have the potential to cause catastrophic damage to the tower. Our first recommendation is that the bells stop being rung altogether to prevent vibrations from further damaging the belfry. Once this is done, efforts should be made to either replace the bell frame or restore it in a way that is better optimized to prevent excess vibration. Moving down into the shaft, there are several bad stairs that should be replaced in order to make ascent safer, and multiple wood boards in the landings should be reinforced or replaced.

While the top four towers are in need of the most work, that doesn't mean the remaining thirteen towers are exempt from improvement or restoration. The towers at the Basilica dei Frari and San Silvestro are in need of bird netting that should be installed as soon as possible to prevent damage to the bells. Additionally, the bells in San Trovaso should probably cease ringing, at least temporarily, so that the severity of the tower's inclination can be assessed and possibly fixed.

5.2 Methods Recommendations

While our methods in each tower improved greatly over the course of the term as we quickly learned what techniques worked best, there are still multiple recommendations we'd like to make for any future teams. First, in order to improve the sound recording process, future teams should acquire a "Deadcat" furry microphone wind screen, as the intense wind at the top of the towers can interfere with the bell's sounds. This makes it more difficult to perform a an accurate Wavanal sound analysis, so it's important that the Deadcat or something similar is used to negate the effects of wind on the recordings. Additionally, because the bells are so loud, it's important to use microphones that can handle intense sound amplitude as well as frequency so the bell's partials can be fully captured and not distorted. Our Audiotechnica AT2020 worked fairly well, but still had minor problems with distortion, so in the future we'd suggest an investment in a more powerful condenser mic. One thing to note, however, is that any mic that is used cannot require phantom power, the process of transmitting DC power (usually 48V) through microphone cables to mics that contain electric circuitry, or else it won't be portable. The other alternative is if the microphone can use batteries to power itself, negating the need for an external preamp.

Next, when measuring the dimensions of bells, we realized towards the end of the term that we should have been measuring total clapper length, but also clapper length from the top to the ball. An example of a clapper ball is shown below in Figure 82.

Figure 82 - Example of a clapper ball

It’s important to have this measurement because the ball is the part of the clapper that strikes the soundbow to create the bell’s sound. If the clapper is too long or too short so that the ball strikes either above or below the soundbow, the structure of the bell can be negatively affected.

Finally, in order to improve the methods used to record vibrations using Vibsensor, it’s important that an X-axis and a Y-axis are established prior to recording so that the directions can be properly identified later. The X-axis for Vibsensor comes out of the side of the phone, and the Y axis comes out of the front of the phone. A visual representation of this can be found in section 4.5. Because of this, in order to establish the axis directions, the phone needs to be placed down deliberately. For example, if you place the phone with the top facing the front of the tower, that means that the Front-Back axis will become the Y-axis, and the Right-Left axis will become the X-axis. Being precise in this way allows for a more detailed analysis of the vibrations, as when the recordings are collected and put on the graphs, the X-axis and Y-axis vibrations will be identifiable.

5.3 Recommendations for Future Projects

Going forward, we have multiple recommendations for tasks that future projects could undertake. We believe that the vibration analysis should be emphasized more strongly than it was for our own project, as the vibrations for many of the towers are still unrecorded, and we've seen in towers like San Giacomo dell'Orio how much damage those vibrations can cause. In order to analyze results more effectively, we believe it will be worth getting professional vibration analysis gear which will allow for more comprehensive numbers, as well as hopefully providing a path for mitigating damage done by vibration, which is not knowledge we currently have.

Additionally, it may be worth making a project one year to focus more heavily on the programming side, rather than doing so much data collection at towers. This would include improving and adding features to bells.veniceprojectcenter.org and the data collection app, and perhaps creating something entirely new. When it comes to improvements to the the website, we have some suggestions. One new feature that would be extremely helpful would be a donate button on each tower's page. In theory, this donation button would allow the public to send money to the Curia so that they can raise the funds to begin further restoration projects. This could ideally be accompanied by a section on the site that describes the tower's condition both verbally and visually, while estimating potential restoration prices, allowing people to know exactly what their money will be going toward when they click to donate. Additionally, a useful feature would be a way to compare the features of two towers side by side, similar to how websites compare things like smartphones so that people can make a more informed decision on what they're buying. A visual example of this can be found in Figure 83- below.

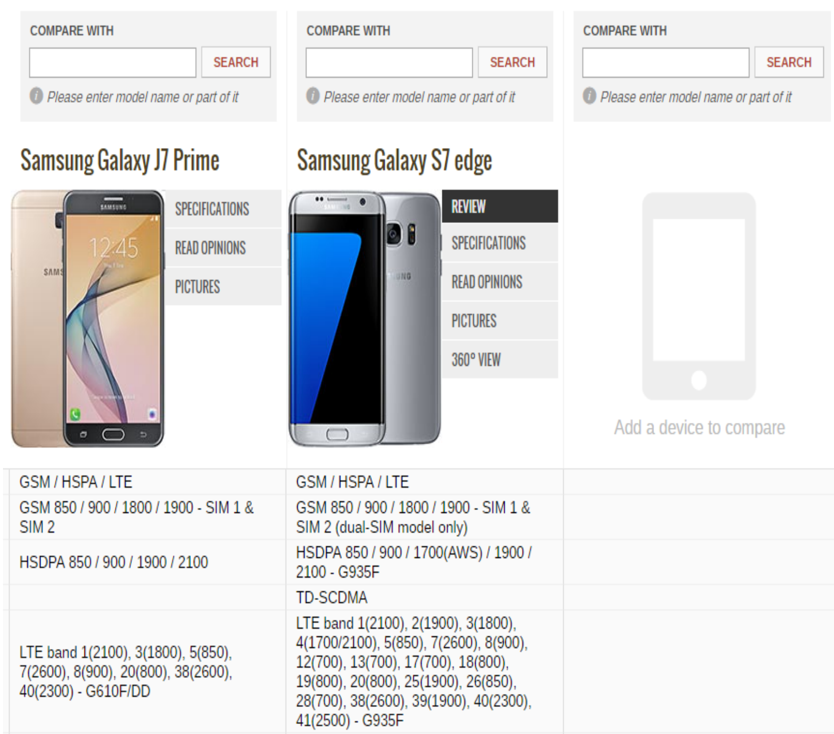

Figure 83 - Example of a side-by-side comparison feature (GSM Arena, 2016)

This could theoretically allow for a side-by-side comparison of tower conditions, which could help people decide which to donate to because the comparisons will put condition in perspective, especially when a good tower like Salute is compared to a poor one like Gesuati. Additionally, this could make analyzing tower rankings easier. The final feature that we'd recommend being implemented comes from a plugin called Image Map Pro (IMP), which is a powerful program that makes it possible to create detailed infographics and pictures that can be interacted with. With IMP, teams could create even more detailed, interactive silhouettes of the bell towers that allow for exploration of the various features of the towers by clicking on a part of it, such as the belfry. Because all three of these tasks would require extensive time to complete, it makes more sense for them to be done separately from a project that involves visiting more towers.

We hope our recommendations will not only help to guide the restoration of Venetian bell towers, but also propel future projects forward while helping improve consistency between projects.

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Appendix A - Data Fields

Sections Missing
Belfry block depth_cm
Belfry block height_cm
Belfry block width_cm
Belfry landing length_cm
Belfry landing material
Belfry landing width_cm
Belfry window depth_cm
Belfry window height_cm
Belfry window width_cm
Internal landing material
Internal transcription
Internal wall material
Intro Blurb
Photos_Link
Rating_Accessibility
Rating_Condition
Rating_Overal
Rating_Safety

Tower_Interior
Ground_/_Landing_X_/_Belfry
Basic Info
name
Landing_Material :select(wood, brick, stone, concrete, marble, tile, other)
Landing_Sturdiness :rating(1, 2, 3, 4, 5)
Landing_Cleanliness :rating(1, 2, 3, 4, 5)
Landing_Length_F_B_cm
Landing_Width_R_L_cmLanding height to ceiling_cm

Clock_mechanism :bool
Natural_Lighting :bool
Artificial_Lighting :bool
Lighting_raiting :rating(1, 2, 3, 4, 5)
Basic_Info_Notes :textarea

Stairs Info
Ramp :bool
Stairs :bool
Railing :bool
Staircase_Side :select(around, front, right, back, left)
Staircase material :select(wood, brick, stone, concrete, tile, marble, other)
Number of steps
Number of bad steps

Staircase_Cleanliness :rating(1, 2, 3, 4, 5)
Staircase_Sturdiness :rating(1, 2, 3, 4, 5)
Railing_Sturdiness :rating(1 2, 3, 4, 5)
Stairs_Info_Notes :textarea

Wall Thickness and Windows
Block_Height_stairs_cm
Block_Width_stairs_cm
Block_Depth_stairs_cm
Wall_Material :select(brick, stone, cement, plaster, brick/plaster)
Wall thickness
Window_Total_per_landing
Window_Side :select(front, right, back, left)
Window_Height_cm
Window_Width_cm
Window_Depth_cm

Interior Doors
Interior door_Front :bool
Interior door_Right :bool
Interior door_Back :bool
Interior door_Left :bool
Interior door height_cm
Interior door width_cm
Interior door depth_cm
Interior door notes :textarea

Restoration
Restoration_sides :select(front, right, back, left)
Number of ties and bands_Front
Number of ties and bands_Right
Number of ties and bands_Back
Number of ties and bands_Left

Tower Defects
Number_Cracks_and_Holes_Front
Number_Cracks_and_Holes_Right
Number_Cracks_and_Holes_Back
Number_Cracks_and_Holes_Left
Length_of_Cracks_and_Holes_Front
Length_of_Cracks_and_Holes_Right
Length_of_Cracks_and_Holes_Back
Length_of_Cracks_and_Holes_Left
Number_Damage_Stone_Front
Number_Damage_Stone_Right
Number_Damage_Stone_Back
Number_Damage_Stone_Left
Number_Misaligned_Brick_Front
Number_Misaligned_Brick_Right
Number_Misaligned_Brick_Back
Number_Misaligned_Brick_Left

Decorations and Inscriptions
Number internal inscriptions
Internal_transcription
Number of internal decorations
Internal decoration locations
Internal decoration description
Internal_average_legability :rating(1, 2, 3, 4, 5)
Internal_average_conservation :rating(1, 2, 3, 4, 5)

Belfry_Only
Frame type :select(A-frame, H-frame, other)
Frame restoration :bool
Frame material :select(wood, metal, other)
Frame missing screws or bolts :bool
Frame_rust :bool
Number_of_Frame_cracks
Frame_cleanliness :rating(1, 2, 3, 4, 5)
Frame_warping :rating(1, 2, 3, 4, 5)
Number_of_Frame_dents
Frame_Overall_condition :rating(1, 2, 3, 4, 5)
Bell_locations_side_view
Bell_locations_top_view
Frame notes :textarea
Belfry_Opening_side :select(front, right, left, back)
Belfry_Width
Belfry_Length
Condition_of_inside_of_roof :rating(1, 2, 3, 4, 5)
Bird_net_condition_front :rating(1, 2, 3, 4, 5)
Bird_net_condition_right :rating(1, 2, 3, 4, 5)
Bird_net_condition_back :rating(1, 2, 3, 4, 5)
Bird_net_condition_left :rating(1, 2, 3, 4, 5)
Drain_holes :rating(1, 2, 3, 4, 5)
Closest_bell_towers

Tower_Exterior
Tower_Exterior
Exterior_General
Type
Date_Visited
Number_of_Bells
Bell tower part
Bell tower parts
Picture_Drive
Tower height_m
Material
Exterior block height_cm
Exterior block width_cm
Exterior block depth_cm

Orientation and Inclination of Tower
Orientation degrees_Front
Orientation degrees_Right
Orientation degrees_Back
Orientation degrees_Left
Inclination_rating :select(none, slight, serious)
Inclination direction
Inclination calculated
Plumb line length
Plumb bob distance
Overhang calculated_m

Public Access, Accessibility, and Doors
Public access :bool
Accessibility_Front :bool
Accessibility_Right :bool
Accessibility_Back :bool
Accessibility_Left :bool
How_to_Access_tower
Exterior door_Front :bool
Exterior door_Right :bool
Exterior door_Back :bool
Exterior door_Left :bool
Exterior door height_cm
Exterior door width_cm

Exterior_Base / Exterior_Shaft / Exterior_Belfry / Exterior_Roof
General
Exterior_Material
Percentage_of_tower_height

Visibility of Tower
Public_visibility :select(on Grand canal, near tourist spot, along a canal, by a shopping street, none)
Visibility_Front :bool
Visibility_Right :bool
Visibility_Back :bool
Visibility_Left :bool
Visibility_Distance_Front
Visibility_Distance_Right
Visibility_Distance_Back
Visibility_Distance_Left

Notes
Exterior tower notes_Front :textarea
Exterior tower notes_Right :textarea
Exterior tower notes_Back :textarea
Exterior tower notes_Left :textarea

How it is connected to Church
Connected_to_Front
Connected_to_Right
Connected_to_Back
Connected_to_Left
Length_attached_percentage_Front
Length_attached_percentage_Right
Length_attached_percentage_Back
Length_attached_percentage_Left

Decorations Outside
Num_Plants_Front
Num_Plants_Right
Num_Plants_Back
Num_Plants_Left
Number of art pieces_Front
Number of art pieces_Right
Number of art pieces_Back
Number of art pieces_Left
Number Exterior inscriptions
Inscription
Inscription description
Avg_inscription_legability :rating(1, 2, 3, 4, 5)
Number of decorations
Decoration description
Decoration_condition :rating(1, 2, 3, 4, 5)

Tower Defects
Num_cracks_holes_Front
Num_cracks_holes_Right
Num_cracks_holes_Back
Num_cracks_holes_Left
Num_brick_colors_Front
Num_brick_colors_Right
Num_brick_colors_Back
Num_brick_colors_Left
Number of ties and bands_Front
Number of ties and bands_Right
Number of ties and bands_Back
Number of ties and bands_Left

Windows
Number of windows_Front
Number of windows_Right
Number of windows_Back
Number of windows_Left
Blocked window number_Front
Blocked window number_Right
Blocked window number_Back

Blocked window number_Left
Barred window number_Front
Barred window number_Right
Barred window number_Back
Barred window number_Left
Meshed window number_Front
Meshed window number_Right
Meshed window number_Back
Meshed window number_Left

Restoration
Restoration visible_Front
Restoration visible_Right
Restoration visible_Back
Restoration visible_Left

Clock
Clock
Clock side :select(front, right, back, left)
Clock working
Clock mechanism landing

Belfry only
Number_lesene
Number_sections
Arches Front
Arches Right
Arches Back
Arches Left
Belfry_style
Drum_type
Number of lessene
Balustrade
Attic
Cross :bool
Weathervane :bool
Lightning rod :bool
Finial :bool
Finial type
Finial description
Spire Description
Connected_wire
Connected_unclear
Import_notes
Calculated_vibration

Bell_info
BellX
Bell Name/Number

number_and_or_name: "",
Tower_id: “”,

Note and Ringing Times
Musical_Note
Frequency_Hz
Chiming_frequency
Ringing_Times_Monday
Ringing_Times_Tuesday
Ringing_Times_Wednesday
Ringing_Times_Thursday
Ringing_Times_Friday
Ringing_Times_Saturday
Ringing_Times_Sunday

Engravings and Inscriptions
Date_on_bell
Crown_Engraving_Front
Crown_Engraving_Right
Crown_Engraving_Back
Crown_Engraving_Left
Body_Engraving_Front
Body_Engraving_Right
Body_Engraving_Back
Body_Engraving_Left
Lip_Engraving_Front
Lip_Engraving_Right
Lip_Engraving_Back
Lip_Engraving_Left
Crown_Inscription_Front
Crown_Inscription_Right
Crown_Inscription_Back
Crown_Inscription_Left
Body_Inscription_Front
Body_Inscription_Right
Body_Inscription_Back
Body_Inscription_Left
Lip_Inscription_Front
Lip_Inscription_Right
Lip_Inscription_Back
Lip_Inscription_Left

Clapper and Stock
Clapper_description_material
Clapper_condition :rating(1, 2, 3, 4, 5)
Clapper_Rust :bool
Clapper_Length
Belt_description_material
Belt_condition :rating(1, 2, 3, 4, 5)

Stock_description_material
Stock_condition :rating(1, 2, 3, 4, 5)
Skidmark_1_Side :select(front, right, back, left)
Skidmark_1_Left_cm
Skidmark_1_Right_cm
Skidmark_2_Side :select(front, right, back, left)
Skidmark_2_Left_cm
Skidmark_2_Right_cm

Conservation_state :rating(1, 2, 3, 4, 5)
Number_of_Chips
Safety_cable :bool
Cracked_side :select(front, right, back, left)
Crack_length

Ringing Method and Info
Swing_direction :select(R-L, F-B)
Hammer_side :select(front, right, back, left)
Reason_not_rung
Ringing_method
Automatic :bool
Manual_working :bool

Historic Information
First_casting
Second_casting
Historic_info
Cleanliness :rating(1, 2, 3, 4, 5)
Discoloration :rating(1, 2, 3, 4, 5)
Number of decorations
Number_of_Inscriptions
Belt
Overall_condition :rating(1, 2, 3, 4, 5)
Foundry
Place_of_Casting

Physical Dimensions
Thickness_mm
diameter_cm
height_internal_cm
height_ground_cm

BellCode_F
BellCode_L
BellCode_B
BellCode_R
BellCode_F_dec
BellCode_L_dec

BellCode_B_dec
BellCode_R_dec
BellCode_I

Bell Tower General Info
General
General
Church name
Common name
Tower_Code
Bell Tower ID
Last_Visited
Proprietor
Pastor Name
Danger zone
Number of bells
Number of landings
Significant history
Tower style
Construction year
Repair year
Repair description
Renovation and restoration years
Renovation and restoration description
Architecture
Architect

Location
Longitude
Latitude
Sestiere
Time open 1
Time open 2

Fire Protection Info
Distance_from_nearest_canal_m
Number_and_type_of_water_source

Media
Tower Images
Images
CODICE_ext_tower
CODICE_ext_top
CODICE_ext_skyshot
CODICE_ext_F
CODICE_ext_L
CODICE_ext_B
CODICE_ext_R
CODICE_int_landing_ground
CODICE_int_landing_belfry

CODICE_int_landing_attic
CODICE_floorplan
CODICE_machine
CODICECC_1
CODICE_view_0

External Media
Media
Video Links
Tower_Video

Models Links
Matterport_Model
Belfry_Model
Bell_1_Model
Bell_2_Model
Bell_3_Model
Bell_4_Model
Bell_5_Model
Bell_6_Model
Bell_7_Model
Bell_8_Model
Bell_9_Model
Bell_10_Model
Bell_11_Model

Ricoh Links
360_Belfry_Link
360_GroundFloor_Link
360_Landing_1_Link
360_Landing_2_Link
360_Landing_3_Link
360_Landing_4_Link
360_Landing_5_Link
360_Landing_6_Link
360_Landing_7_Link
360_Landing_8_Link
360_Landing_9_Link
360_Landing_10_Link
360_Landing_11_Link

Audio Links
Bell_Chorus_Audio
Bell_1_Audio
Bell_2_Audio
Bell_3_Audio
Bell_4_Audio
Bell_5_Audio
Bell_6_Audio

Bell_7_Audio
Bell_8_Audio
Bell_9_Audio
Bell_10_Audio
Bell_11_Audio

Venipedia Links
Page name
Bell_1_Venipedia
Bell_2_Venipedia
Bell_3_Venipedia
Bell_4_Venipedia
Bell_5_Venipedia
Bell_6_Venipedia
Bell_7_Venipedia
Bell_8_Venipedia
Bell_9_Venipedia
Bell_10_Venipedia
Bell_11_Venipedia

Appendix B - Code

- The code for the http://bells.veniceprojectcenter.org website is private, but given the correct promissions can be found at https://github.com/cityknowledge/venicebells.
- The code for the bell input app can be found at https://github.com/veniceprojectcenter/bellsinput.
- The Tower Ranking code can be viewed at https://github.com/Ve16Bells/TowerRankings.
- The code created to create the skeleton (field category).htm partials for the bells.veniceprojectcenter cite can be viewed at https://github.com/Ve16Bells/fields-to-form.

Appendix C - Process of Ranked Towers

The fields we used to rank towers is listed in Appendix D. With these fields we used the following process to rank towers.

Step I: Convert Fields to Grade of 0 - 100
There are five different types of fields we collected, rating (0 - 5), boolean (yes, no), selection, number, and text.

For rating fields we multiply the (0-5) value by 20 to make it a (0 - 100). For boolean fields we assigned a 'yes' a value of 100 and a 'no' a value of 0. Frame material was the only field that was selection field. For this field we assigned 50 to metal and 100 for wood.

If a field has no data it is given a value of 'NR' which represents no record.

Step II: Aggregate The Average of Each Field That is Collected in Bells or Landings
The 0 - 100 value of fields that are collected for each Landing or Bell of the Belltower are averaged into one value out of 100. For example, if a bell tower with 3 landings and a belfry received a 4, 3, 2, 5 rating for Frame_cleanliness it would be converted to 80, 60, 40, 100 and averaged to 70. Thus making the rating for Frame_cleanliness for that belltower 70.

Step III: Multiply 0 - 100 Rating By Weights
Each 0 - 100 calculated rating is then multiplied by its fields respective weight which can be found in Appendix D. The resulting value is the weighted field rating.

Step IV: Calculated Tower Rating
All of the weighted field ratings of the bell tower is summed up. If a field was given a 'NR' in step I it is ignored. The tower's sum is then divided by the sum of the weights of the fields that were used (the weights of the fields that were not assigned a value of 'NR').

Step V: Rank Towers
Once an overall rating ranked with all of the other towers who have received a total tower condition rating.

To calculate the rankings of Interior, Exterior, Bells and Belfry you follow the same steps of the overall rating but only with the fields that correspond to that section. These corresponding fields can be found in Appendix E.

Appendix D - Tower Ranking Weights

The following is a list of all the fields we used to rank towers. The list is structured as follows (Field : Weight). Field is field collected for each tower, and Weight is the value that multiplies the calculated value of the corresponding that field for rankings.

Landing_Sturdiness : 2
Landing_Cleanliness : 1
Natural_Lighting : 0.4
Artificial_Lighting : 0.1
Staircase_Cleanliness : 1
Staircase_Sturdiness : 2
Railing_Sturdiness : 2
Number_Misaligned_Brick_Front : 0.25
Number_Misaligned_Brick_Right : 0.25
Number_Misaligned_Brick_Back : 0.25
Number_Misaligned_Brick_Left : 0.25
Frame material : 1
Frame_cleanliness : 1
Frame_warping : 0.1
Frame_Overall_condition : 2
Condition_of_inside_of_roof : 0.5
Drain Holes Rating : 1
Railing : 2
Bird_net_condition_front : 2
Calculated_vibration : 1

Conservation_state : 1
Safety_cable : 1
Cracked_side : 2
Cleanliness : 1
Discoloration : 0.2
Overall_condition : 2
Clapper_condition : 0.5
Belt_condition : 0.5

Inclination_rating : 1

Appendix E - Tower Section Ranking Fields

From the master weight list in Appendix D we used the following fields to calculate Bell rankings:

Conservation_state
Safety_cable
Cracked_side
Cleanliness
Discoloration
Overall_condition
Clapper_condition
Belt_condition

From the master weight list in Appendix D we used the following fields to calculate Belfry rankings:

Landing_Cleanliness
Frame material
Frame_cleanliness
Frame_warping
Frame_Overall_condition
Condition_of_inside_of_roof
Drain Holes Rating
Bird_net_condition_front

From the master weight list we used in Appendix D the following fields to calculate Landing rankings:

Landing_Sturdiness
Landing_Cleanliness
Natural_Lighting
Artificial_Lighting
Staircase_Cleanliness
Staircase_Sturdiness
Railing_Sturdiness
Railing
Number_Misaligned_Brick_Front
Number_Misaligned_Brick_Right
Number_Misaligned_Brick_Back
Number_Misaligned_Brick_Left

Appendix F - How to best use the MatterPort

The following is a list of general use, possible issues and how to avoid them as well as suggestions for using the MatterPort to get the best possible results.

General process - when the camera is placed and the operator is either out of view of the camera or able to walk behind the camera during the scan the scan is started with the iPad. During the scan the camera stops and takes a picture 5 times. Once the scan is complete the camera transfers the data to the iPad. The iPad then aligns the scan with the others and generates a mesh floor plan view and displays the location of the scan with a blue dot. The floor plan with be black in locations that the camera has not been able to see yet. The initial scan will have a black circle around the dot as the camera cannot see directly under itself.

Errors - there are two error messages that may appear after the iPad receives the data from the camera. If the iPad is unable to align the newest scan with any of the previous scans a "No Alignment" notification will appear. No scan will be added to the floor plan. This typically means the camera needs to be placed closer to a previous scan. The other error is a "Low Overlap" error. This means the iPad was able to align the scan but with a low level of confidence. This was never an issue for any of our models. This will likely happen when scanning into the belfry when the opening into the belfry is small.

Scans - the camera must be level and stable on the tripod. The tripod and camera mount that MatterPort recommends, and sent with the loaned camera, each have a level on them to assist with making sure the camera is level. The camera needs to be in view of the location of at least one of the other scans in order to align after the initial scan.

Distance between scans on the same floor - when there is good lighting and the location being scanned is relatively open, the camera can be moved about 10 feet from scan to scan. If it is dark, the sun is shining directly into the lenses, the space around the camera is cramped, or any combination of these things are present then the distance to the next scan will likely need to be less than 10 feet.

Scanning stairs - for a normal staircase the camera can be placed every four to six stairs. The steeper the staircase the more often the camera will need to scan. Some of the final stairs that go up into the belfry had to have a scan on every stair.

New floors - when scanning up stairs, add a new floor on the iPad for the first scan on the new floor. When going up a bell tower this should be done on each landing. In towers the staircases are typically one per wall. If there are more than 4 between landings then a new floor should be created at the top of the fourth staircase to prevent the scans from overlapping on the iPad. If scans start to overlap then create a new floor and move the scans that are overlapping onto the new floor.

Scans in the wrong place - scans may show up on the iPad in the wrong place. This is rare but happens when the space being scanned is almost entirely uniform; typically a tower. The camera may not see enough variation in the space and place it on top of an earlier scan. The scan placed incorrectly must be deleted and the camera should be placed closer to a previous scan.

Going through doors - when the path of scanning goes through a door there should be a scan near the door, directly in the door frame, and near the door on the far side. This allows the camera to properly scan the spaces on either side of the door and prevent a failed scan.

Appendix G – List of Tower ID Codes

CARM - Santa Maria del Carmini
CASS - San Cassiano
FRAR - Santa Maria Gloriosa dei Frari
GESU1 - Santa Maria del Rosario dei Gesuati
MEND- San Nicolo dei Mendicoli
ORIO - San Giacomo dell'Orio
PANT - San Pantalon
RAFF1 Sant'Anzolo Raffaele
RAFF2 - Sant'Anzolo Raffaele
SALU1 - Santa Maria della Salute
SEBA - San Sebastiano
SIMG - San Simeon Profeta
SIMP - San Simeon Piccolo
STAE - San Stae
TOLE - San Nicola da Tolentino
TROV - San Trovaso
ZAND - San Zandegola