CONTEMPORARY ARCHITECTURE IN A HISTORIC CONTEXT: USING PRESENT-DAY CONSTRUCTION TECHNIQUES TO MITIGATE THE EFFECTS OF SINKING IN VENICE, ITALY

by

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Venice, Italy, has captured the hearts and intrigue of people for centuries. From its status as a major power in the Western world during the Medieval and Renaissance period to its contemporary status as a destination for romance and art, the city is considered among the most beautiful and the most beloved in the world. However, love alone is not enough to save the city of Venice from a fate many fear: that the water, which was once the lifeblood of Venice, will turn against the city and make it unhabitable.

News reports and scientists consistently say that water levels in Venice are rising, which would further damage the buildings in its course. This terrifying news for Venetians and tourists alike is due to many factors, including the rising sea level and soft foundations the city was built on, causing it to sink. With the rising waters comes greater damage to Venice’s delicate brick building fabric, meaning that buildings more frequently require repairs, and often, details of buildings, from plaster siding to valuable woodwork in carved doors, are partially or fully decayed. Despite the many proposals to save the city from a watery grave, many seem unobtainable due to lack of support. Even current implementations, such as the MOSE, are not sustainable financially or environmentally, and Venetians are losing faith in preserving their beloved city.

This thesis analyzes how architectural design, and particularly wall design, can be implemented into Venice's existing buildings, especially those on canals, to preserve the city. While many of the city's buildings are rightfully landmarks, numerous others can be classified as "historic" yet do not take on a significant landmark status and are often used as residential or light commercial buildings. By analyzing one of these latter buildings, the thesis explores how individual, historical buildings can be protected in a flooding event or from rising waters by redesigning the ground-floor walls.

Acknowledgments

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Chapter 1: Background of Venice and the Selected Palazzo

A Brief History of Venice and its Architecture

Venice, Italy, has become a world-renowned city for its unique condition of being densely built on 118 islands in the Adriatic Sea. Early Venetians figured out that by sharpening the end of a large wooden pile, they could drive it down deep into the sand of the lagoon. A row or square of these piles could provide a stable foundation for a building. The earliest form of Venice emerged as a small fishing village in the Adriatic Sea. By the 800s, Venice had emerged as its own city and republic as people moved out over the water to avoid land invaders. The Republic of Venice, or "La Serenissima," became incredibly wealthy and powerful by the Middle Ages, with some of the city's finest buildings built during this period in a style that would later be dubbed "Venetian Gothic." Some of these buildings include the Palazzo Ducale and Ca D'Oro. The Renaissance and Baroque periods continued to be important and prosperous times for Venice and the Venetian Republic, creating what was, at the time, masterpieces of architecture and engineering, including the Ponte Rialto and Ca' Rezzonico. During this period, Venice and the Venetian Republic produced some respected artists and architects, including Palladio, Vivaldi, and Canaletto.

The 18th century was seen as a period of decadence for the Venetian Republic, and Napoleon finally conquered the Republic, ending it for good in 1797. The city then swapped between French and Austrian rule until Italy gained independence in 1861. As the Grand Tour became popular in the later 19th century, the City of Venice responded by filling in some of its canals and becoming more accessible for people without a boat. However, the city continued to decay quietly, and buildings such as Ca D'Oro even had pieces removed and sold off. In 1966, a historic flood hit Venice, calling to the world for the first major time the perils that Venice continues to face, issues that were only further amplified in a similar flood in 2019.

Venice is Sinking: Causes and Proposed Solutions

Both land subsidence and sea level rise prove dangerous to Venice, as they are factors in the relative sea level rise for the historic city. The average relative sea level rise in Venice throughout the 20th century was 3.4mm per year. (Klein et al.; Parker and Ollier). This means that the water level of our Venice is well over a foot higher than the water level of the Venice that John Ruskin wrote about in the 19th century. Currently, Venice has about four major flooding events per year, but with no action taken to prevent or mitigate relative sea level rise, such events could balloon to 250 events per year by the end of the 21st century (Carbognin et al.). While the rise in sea level is happening, it is not as much of a risk in Venice versus land subsidence. Levels of sea level rise across the Mediterranean appear to be nonuniform, with waters in the eastern Mediterranean and along the coast of Tel Aviv rising significantly quicker than the waters of the Adriatic Sea and in areas like Venice (Klein et al.). Additionally, the rise of sea level has not historically accelerated in or around Venice (Parker and Ollier).

One large factor that is believed to have endangered Venice's architecture and infrastructure is recent action in the vicinity of the city since the Industrial Revolution. In the 1920s, corporations and industrial manufacturers in the mainland near the center of Venice were permitted to pump water out of a large aquifer located beneath the historic city center for their operations. This aquifer had been acting as a "bubble" and preventing the city from sinking further, but when these industries started pumping it out, they likely caused Venice to sink at an accelerated rate during the middle of the 20th century (Keahey, Fletcher, and Da Mosto). Upon reviewing data on relative sea level rise in Venice throughout the 20th century, a correlation appears where the city experienced a significantly larger relative sea level rise during the height of the period when the groundwater was pumped out (Keahey; Klein et al.).

Some people have proposed, and some have even implemented, solutions. One solution already underway is the MOSE Barriers, which rise if the water level gets too high. The MOSE barriers work in a complex system that automatically and slowly raises large walls that block the three entrances between Venetian barrier islands and the rest of the Adriatic Sea in the event of an acqua alta. When these barriers rise, it is impossible for higher water to get into the Venetian Lagoon, effectively protecting the city from acqua alta events. The MOSE successfully stopped a potentially devastating acqua alta in 2022. However, after talking to Venetians and Italians, they have little faith that it will last long due to the prohibitively expensive costs needed to raise and lower it. In the event that an *acqua alta* will barely cover Piazza San Marco, it is unlikely at all that the MOSE would even rise due to the costs. However, any amount of water in the city could be dangerous, as Venetian architecture, primarily made of soft brick, will readily soak up water.

Another method of addressing the decay that has been suggested and is partially implemented at the time of writing this thesis is reducing tourism in Venice. According to Clement et al., overtourism is a severe issue in Venice and needs to be reduced. The city can make more money from tourists by charging day trippers, banning dangerous cruise ships from the historic center, and giving Venetians a chance to reclaim their city. Money made from tourist taxes could go towards improving infrastructure and bolstering themselves against high waters, including funding the aforementioned MOSE.

Perhaps the most interesting proposal for solving the city's issues involves the previously mentioned aquifer. Castelletto et al. suggest putting wells around the city of Venice to raise it up. By re-pumping water into these wells, the "bubble" could be reinflated, raising the city up by

30cm in a decade. If this is implemented and works, nearly a century of sinking could be undone in only ten years, earning time for the city to implement much longer-term strategies for saving their city from further damage. Unfortunately, due to the high cost and the chance that it might not work, this potential, longer-term solution has largely been put on the shelf for the time being.

Water Damage to Venetian Architecture

Water promotes the decay and rot in many materials, including wood and brick, which make up a large portion of Venice's architectural fabric. The city has historically built itself up as water rises, but Venice has built up so much in the past that building it up any further would effectively take away significant portions of the ground floors and cover the historic bridges of the city. Even though it is likely inevitable that water will soon cover the "ground level" of Venice, adding more stone to the ground floors would only make the city heavier, accelerating its sinking.

Water now regularly laps against the previously dry, historic canal-side doors of the Doge's Palace, allowing shipworms and other organisms to bore into and destroy them. Tagliapietra et al. discovered that the doors of the Palace could be recreated and spared from the shipworms by using non-native wood. However, areas of Venice that do not have funds to import non-native wood will only continue to deteriorate. Transporting non-native wood to Venice is expensive and creates significant carbon emissions, which will only further contribute to sea level rise in Venice and elsewhere. Additionally, growing non-native wood around Venice will only bring invasive species to the Venetian Lagoon, potentially causing permanent ecological damage in the area and perhaps even greater damage than the factories and ports that already exist in Venice. Finally, planting these non-native species would take decades or potentially centuries before they are ready to be harvested. By this time, the fabric of Venice could significantly change, and the fragile wooden elements of Venetian architecture could be gone, the places they should have been long submerged.

Venetian brick is also regularly assaulted by water. Brick is porous enough that water can wick up through capillary action, causing both the brick and often the plaster covering it to become saturated and rot away. This was never intended to happen as the bricks would have originally been above a layer of a near-impermeable stone, known as Istrian stone or "Pietra d'Istria," which the Venetians quarried out of Croatia during their rule over the region. Artigas and O'Brien suggest a strong vapor barrier to protect delicate materials like bricks from rotting; however, given Venice's unique situation, it is generally agreed that the bricks should instead be given a better chance to "dry out" if saturated with water. However, bricks cannot dry out when the buildings are partially submerged, always being exposed to water. Letting the bricks rot and get replaced is unsustainable due to the continuous shipping of bricks into the city and the resources needed to constantly replace them. Since many brick walls in Venice are load-bearing, the rotting of the brick walls also puts the entire building's structural integrity in jeopardy. Additionally, grout itself can decay, which is just as dangerous as bricks themselves decaying. As the grout is the "glue" holding the bricks together, once the water erodes them away, their absence will cause the collapse of the bricks and potentially the buildings.

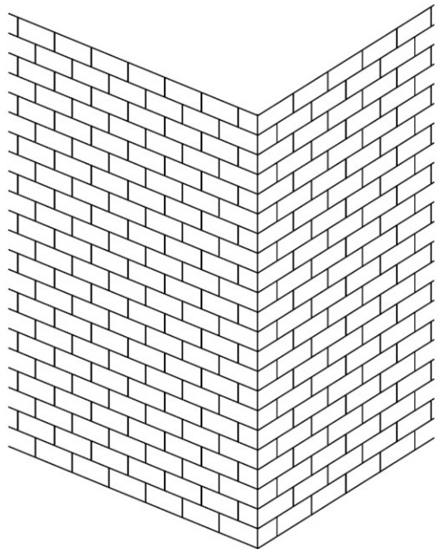

Figure 1: Venetian Wall Diagram

Diagram of a typical Venetian brick wall after being built, presumably up against a canal.

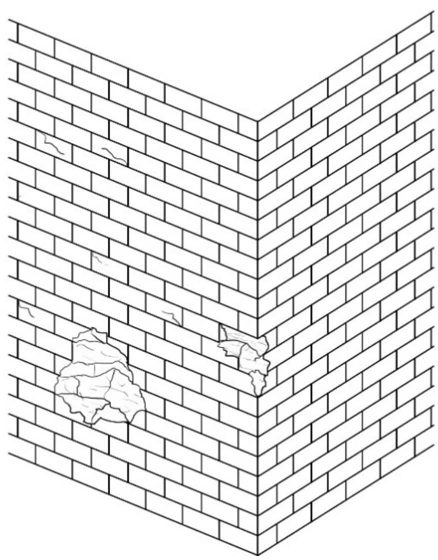

Figure 2: Venetian Wall Diagram

Diagram of the same Venetian brick wall depicted above, with signs of no maintenance, including some bricks chipping away.

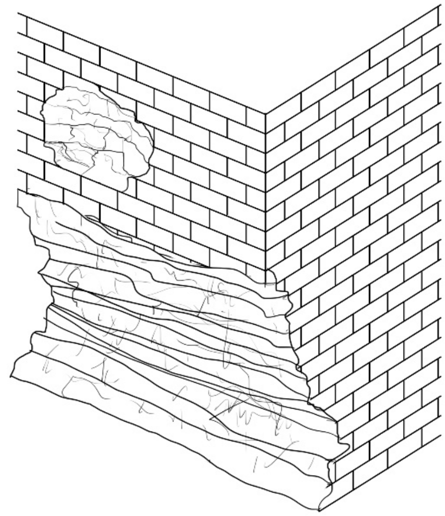

Figure 3: Venetian Wall Diagram

A diagram depicting the same wall as above, now with serious neglect. This amount of neglect could put the structural integrity of the building in jeopardy.

Palazzo Celsi-Donà: History and Architecture

Palazzo Celsi-Donà is a historic former palazzo located in the northern end of the Castello neighborhood of Venice, close to the walls of the Arsenale and near the Church of San Francesco della Vigna. There is not a lot of written history of the building, and its legacy mainly exists in the building itself, which is largely extant.

Palazzo Celsi-Donà was built sometime in the 17th century, likely for the Celsi family, a noble family of Venice at the time. The front of the palazzo faced the back of the Church of Santa Ternita. However, at a later point in time, the palazzo was turned over to another family of Venetian nobility: the Donà family, who have numerous palazzi throughout the city. The Church of Santa Ternita was closed and torn down following Napoleon's victory over Venice, and eventually, an apartment building went up in its place. The historic palazzo was subdivided into apartments, likely in the 19th century, and it is still an apartment building to this day.

Palazzo Celsi-Donà was built in a vernacular Baroque style with no particularly special ornamentation. At the canal level, it contains a large, arched door flanked by two windows, with smaller windows on either side. A floor exists between this canal-side door and the piano nobile. The piano nobile provides the most visual interest, containing a balcony accessed by a door of three arches, the middle arch being larger than the two on the sides. These arches are supported by simple columns. At some point, most of the arches had their top, round parts bricked up to fit a more conventional square window. The top floor contains another set of three windows, which are square, unlike the ones on the piano nobile. There are balusters against the bottoms of these windows. On every floor, there are two windows extending from each side of these sets of three windows. The interior contains some woodwork, but it is unknown if there are frescoes inside.

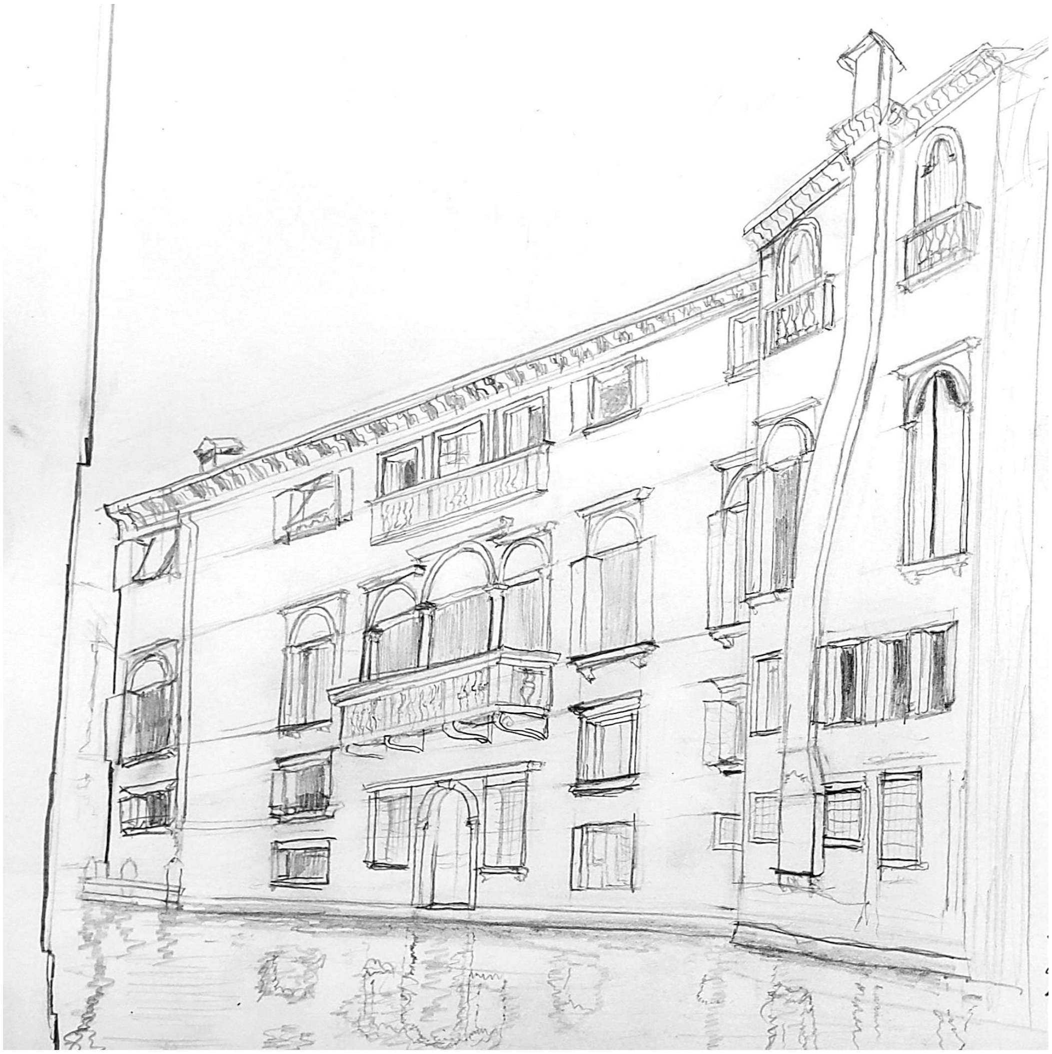

Figure 4: Drawing of the Palazzo Celsi-Donà

Drawing of the Palazzo Celsi-Donà done by the author in May 2023.

The building is in a state of mild decay; bricks and plaster continue to erode off the building, and no significant work is being done to maintain it. The doors and windows on the ground floor do not seem to be well-sealed, leaving the lower floor prone to flooding. The building sits in a precarious position; it is historically significant enough to preserve, yet it is not something so valuable that it should be a museum. Yet, if no action is taken to maintain it, the building will continue to rot from water damage. The building is actively decaying; Google Street View images from 2013 compared to the author's photographs in 2023 show consistencies in the decomposition of bricks, plaster, and the failure of a downspout, which has caused even more water damage. An intervention or reconstruction of the exterior wall would aid in the preservation of the building as a whole.

Figure 5: Palazzo Celsi-Donà

A photograph by the author of the Palazzo Celsi-Donà, taken in May 2023. Note the large iron bracket to the left of the chimney above the lowest window; this is something that needs discussion.

Figure 6: Palazzo Celsi-Donà

Another photograph by the author of the Palazzo Celsi-Donà, from a different view. Deterioration of plaster and brick is visible, and brick has especially worn away around the base of a downspout, which failed at some point in time. More iron brackets are visible.

Why This Palazzo?

Palazzo Celsi-Donà is certainly not the only palazzo in Venice to be suffering from decay, and it is certainly not a stylistically unique palazzo; there are likely many, potentially, hundreds of other buildings that I could have chosen. I chose Palazzo Celsi-Donà for several reasons, however. The first is because the building is one of a handful that contains all the criteria needed in a palazzo to study: historic architecture, a canal-side wall, and already some moderate deterioration. On a personal level though, this palazzo was a personal choice due to a blissful personal experience upon discovering the old building. I had taken a walk up into the quiet parts of Venice, yearning to get away from tourists and wanting to spend time in quiet places. I came across the Campo Santa Ternita among other things, and while waiting for a reservation at a nearby restaurant, I decided to sit across the canal from the Palazzo Celsi-Donà, feet dangling off the Istrian stone ledge over the canal. It was quiet, with the setting sun painting the whole scene gold against the azure sky. As I sat there, taking in everything, a man in the window of another building started playing piano music, completing the scene for me. That singular moment, despite only lasting for a couple minutes, was one of the most memorable and perfect moments of my life. Such an intense and beautiful impression has left the Palazzo Celsi-Donà lingering in my mind, and when it came time to pick a palazzo, I knew that I wanted to study the most memorable building of my trip.

Chapter 2: Potential Materials for Wall Reconstruction

Introduction: What Materials Are Out There?

Many materials exist that have been submerged in seawater, so the effects are known. In a setting like Venice, great care has to be taken when choosing materials, both for sensitivity towards the strong historical context and the continual destruction of the architecture by rising water and capillary action. Given that Venice is primarily built with brick and stone mass walls, it makes sense that a similar or identical material should be chosen in the restoration and reinforcement of the walls. Four materials have been selected for analysis. The first two are brick and Istrian stone, both very historical and vernacular building materials for Venice. The other two are unreinforced and fiber-reinforced concrete, which have seen little but slowly increasing use in Venice.

Admittedly, there is a whole world of materials beyond just these four. Other materials that are perhaps of interest include terracotta and other types of waterproof stones. However, these materials were not too heavily considered due to a variety of factors, including the understanding of historical cladding in Venice to the potential of using materials as part of mass walls. However, further research into these materials is something that is encouraged for those interested in other strategies for protecting Venetian wall systems.

Brick

Brick is a long-used material of Venice, making up the superstructures in many of the buildings. Many of the most remarkable buildings in the city have brick walls just underneath the delicate marble facades. A large amount of the campanili in Venice has exposed or decorative brick, including the campanile for Basilica San Marco. Bricks have been used for a long time in

Venice because they are affordable and durable. However, brick fails spectacularly in interactions with seawater. When water gets into the brick, the brick softens, expands, and becomes weaker over time. When that water is saltwater, such as the water of the Venetian Lagoon, the brick erodes even faster. This has been a constant problem plaguing Venice, and many of the architectural failures in Venice are often due to bricks plunging straight into canals or being directly exposed to acqua alta, as mentioned earlier. It is likely that many of the partially submerged brick walls in Venice would only last another 50-100 years without significant maintenance and change, if even that much. The collapse of St. Mark's Campanile in 1902 could potentially be attributed, at least in part, to water damage over centuries, even though it does not directly touch a canal. The upside to brick is that brick walls are very easy and quick to construct, making them a ready and easy choice for architects or restorers who want to work on an old Venetian building. The work can be done in sections by removing triangular portions of brick, allowing it to corbel back up to a point, thus keeping the upper floors supported.

Istrian Stone

If bricks were the building blocks of Venice, then Istrian stone would be the foundation upon which Venice was built. Istrian stone is a type of stone quarried from the Istria region of Croatia, which was an area Venice controlled in the Middle Ages. Venetian individuals highly valued Istrian stone for its durability and shine and Istrian stone was used both as purely structural elements and as entire façades. Istrian stone was valued because of its water-repellent properties; it is a highly impermeable stone. Historically, the brick superstructures of Venetian buildings were built on plinths of Istrian stone during a time when those Istrian stone bases were above the high-water lines. However, as Venice sank, so did the Istrian stone bases, exposing the fragile brick to the dangerous seawater. Despite the sinking of the city, many buildings, even those that are hundreds of years old, retain their original, historic Istrian Stone bases, showing that its longevity in a climate like Venice can last centuries or potentially millennia. Even in images of the Palazzo Celsi-Donà, the portions of the building built out of Istrian stone have shown remarkable durability, especially when compared to the bricks around them. Additionally, Istrian stone was another material that was relatively easy to build with, as stone quarried from Istria would be cut into blocks and then laid down like large bricks. The only drawbacks to this “miracle material” of Venice are the cost and the rarity. Istrian stone is a very expensive material; if it were cheap, then it is likely that many of the grand palaces, such as Ca D’Oro, would have been built entirely out of Istrian stone to improve their longevity. Additionally, given that the stone is only in one small region of Croatia, it has a limited supply, which can certainly run out. While rebuilding Venice entirely out of Istrian stone would certainly make the city much more resistant, it is an extreme and impossible idea when considering the prohibitive cost and limited supply of material available.

Unreinforced Concrete

Unreinforced Concrete is a material with both historic and modern connotations. Ancient Romans put concrete in numerous structures that still stand today, such as Trajan’s Market and the Pantheon. Its recipe was lost until the 19th century when it was reinvented into the modern building material. Unreinforced concrete works very similarly to a masonry building, with concrete being allowed to pour over larger blocks as opposed to small bricks. Concrete, both unreinforced and reinforced, has been used to support docks and other seawater structures and usually fares well in these scenarios, lasting over 100 years. This could potentially make it a good candidate for the reinforcement of buildings in Venice, as the concrete has a longer lifespan than brick. However, unlike Istrian stone, unreinforced concrete is not completely impermeable to water, meaning that water can wick up the concrete due to capillary action, which would potentially decay any brick laid directly on top of it. Additionally, unreinforced concrete, while it is easy to lay initially, is difficult to remove and repeat the process, should it need repeating at any time after the initial process is done. There are also different qualities of concrete, some of which have a high cement content and are very water-impermeable. However, such high-cement concrete is prone to both shrinking and incredible brittleness, which could cause failure in the building very quickly. In typical construction methods, these drawbacks are addressed with steel reinforcement, which adds a level of ductility to the concrete. However, steel reinforcement rusts and erodes quickly in water, and especially in salty waters such as the Venetian Lagoon. Steel-reinforced concrete would only last a couple of years in a Venetian building before failing. Thus, it is not a viable option for the reinforcement of historical Venetian buildings. If the concrete is to be reinforced, other options must be considered.

Fiber-Reinforced Concrete

Fiber-reinforced concrete is a new way to reinforce concrete without the need for steel reinforcing bars. This is desirable in a place such as Venice, where steel bars would rust, as mentioned above. Fiber-reinforced concrete is created by mixing fibers, which could be steel fibers, fiberglass, or another spun material, with the cement. Fiber-reinforced concrete, which is more expensive than unreinforced concrete, has a comparable strength to steel rebar-reinforced concrete, but with the advantage that the form can be more freeform without the need for the rigid bars to be inserted. Fiber-reinforced concrete on its own could also be made in such a way that it is even more impenetrable to water than normal concrete. However, the one flaw in fiber-reinforced concrete that makes it a less favorable choice for a city like Venice is the lack of research that has currently gone into it. Because it is so new, fiber-reinforced concrete is significantly understudied, with most studies being done recently and only analyzing fiber-reinforced concrete structures that are around 10-15 years old. In these older fiber-reinforced concrete structures, scholars have noted that the concrete develops small hairline cracks in the concrete at the fibers, which, in the context of Venice, could potentially allow small amounts of water. As water and salt seep into the cracks, they could further erode the concrete. Thus, in a situation like Venice, fiber-reinforced concrete may potentially only have a lifespan of 50 years before it needs to be replaced; this would be a painstaking process due to the complicated removal of any reinforced concrete. Studies continue to be done into the effects of fiber-reinforced concrete and its use as a viable option to replace steel-reinforced concrete, such as those done by Bernhard Wietek. If Venice continues to prosper and survive, then it is likely that in the not-so-far-future, fiber-reinforced concrete could be a viable, durable, and long-term option to rebuild damaged Venetian walls.

The other challenge with using fiber-reinforced concrete comes in its practicality for a solution such as in Venetian architecture. With the construction of such a wall mandating that these walls be built in increments to maintain the building's structural integrity throughout construction, the issue of how to secure fiber-reinforced panels becomes a challenge, especially given that steel cannot be used because of its susceptibility to corrosion. The most likely way to secure the panels would be through "keys," molding the concrete so that it has dug-out holes that another panel could be molded into and interlocked with. Additionally, at the end of a fiber-reinforced concrete wall's life, the reinforcing would make removing it and replacing the wall much more difficult and expensive than replacing an unreinforced concrete wall, as mentioned above.

Conclusion

These four materials all provide different outlooks on the way that a Venetian wall could be reconstructed. Brick is a very vernacular but fragile material, which was originally held up by the much tougher Istrian stone. While Istrian stone would certainly be the best material to use in Venice, it is extremely costly and could run out. If it is used, it must be used very sparingly to make sure that it can be used across the city. Unreinforced concrete would need an efficient way to remove it, and it would likely need a barrier to protect it from most water. Fiber-reinforced concrete is a poor choice due to the fact that it is still a new material, and such a new material would be unstable in an environment as unforgiving as the Venetian lagoon. Below is a summary table of the four materials and the criteria analyzed:

	Brick	**Istrian Stone**	**Unreinforced Concrete**	**Fiber-Reinforced Concrete**
Lifespan (yrs.)	50	500+	100+	50
Blocks Capillary Action?	No	Yes	No	No
Cost	Mid-Range	Expensive	Cheap/Mid	Expensive
Constructability	Easy	Easy/Inter.	Intermediate	Inter./Difficult
Repeatability	Easy	Intermediate	Difficult	Very Difficult

Table 1: Material Feasibility Table

Table illustrating the main issues that must be considered when designing new walls for Venetian buildings.

Ultimately, there are other considerations to look at when designing a new wall, one crucial one not mentioned is weight. Given that Venice is already sinking into the soft ground of the Lagoon, weight is another reasonable concern to have in a wall redesign. There is potential to add significant weight to a building’s structure, which could cause the building or even a block of the city to sink faster. Reasonable alternatives could be used in these cases, such as hollow bricks or a lighter-weight concrete. This is one of several other important aspects when considering a wall type to use; other considerations can include appearance and thermal properties.

Chapter 3: Wall Construction Types for Water Mitigation

Introduction

After looking at the various materials, it was determined that the Istrian Stone and the brick would be the best for simple and low-cost wall renovations; despite the cost of Istrian stone, a simple renovation (dubbed the “Simple Wall”) could make sparing use of Istrian stone. However, a wall using unreinforced concrete (dubbed the “Complex Wall”) should be used in situations where a building is exceptionally important as an institutional or commercial space. Residential spaces should be considered for the “Complex Wall” when there are funds and enough residents living in a building to warrant such construction. Any tenement building beyond four stories should be considered for the “Complex Wall,” especially if such buildings have a canal front. In the case of the Palazzo Celsi-Donà, an incremental wall approach is taken when considering how the building might evolve over time. The first approach, for its immediate use as a small tenement building, would involve the “Simple Wall,” whereas if the building were to take on new life as a commercial or institutional building, builders might want to switch to the “Complex Wall.”

The “Simple Wall”

The “Simple Wall” is based on traditional Venetian wall construction and involves minor interventions to the existing brick façades with courses of Istrian stone and flashing. One major issue with wall rot, especially in a primarily medieval city like Venice, is that the water from capillary action can damage floors. If the beams are laid perpendicular to the canal wall, which is typical on upper floors of Venetian buildings, then the end-grain is directly on the canal wall, allowing moisture to get directly in. If the floors are laid parallel to a canal wall, which is more typical in lower floors of Venetian buildings, then the end grain is not against the vulnerable wall. In both scenarios, though, it is not unusual to see metal brackets on the outside of buildings, tying the beams to the wall, which likely helps to stabilize the beams and keep the floors and walls from collapsing. These brackets are especially needed on lower floors to keep the wall from shifting away from the floor. For brackets in the lower portions of the walls, the water can easily corrode such walls or damage the brickwork the brackets are embedded in, which could cause such brackets to become weaker over time, leading to the eventual failure of the bracket and the collapse of the floor. The "Simple Wall" aims primarily to protect the floor beams to prevent the collapse of the building and the floor. It is best suited for interventions in low-unit residential buildings, where crafty residents can do the project themselves with minimal materials.

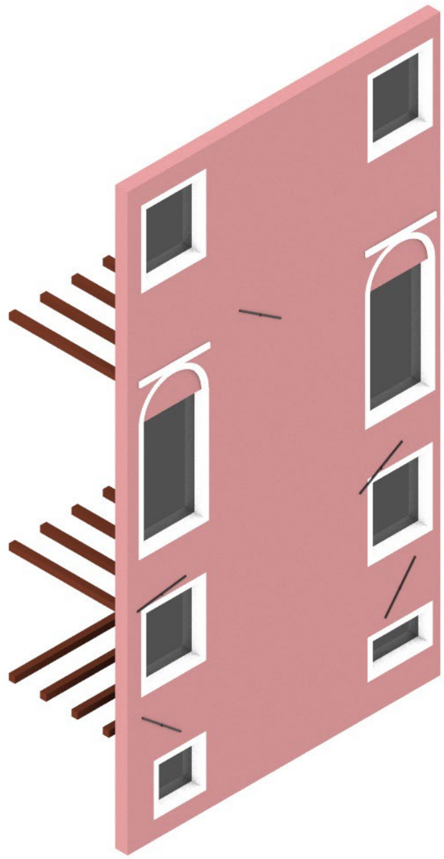

Figure 7: Iron Bracket/Floor Beam Diagram

Simple diagram showing how walls are laid in a typical Venetian setup. Notice the big metal brackets on each floor. This is not indicative of the real situation in the Palazzo Celsi-Donà.

In the Palazzo Celsi-Donà, the end-grain beams running perpendicular to the canal-side walls start at the second story, evidenced by the metal ties on the outside of the building that anchor such beams to the wall. However, there is also a mezzanine level in the Palazzo Celsi-Donà that must be accounted for. At this level, as evidenced by the large doorway and the lack of ties, it is likely that these beams run parallel to the canal-side walls and thus do not touch. Instead, the coursing of Istrian stone to protect the end grain should be placed right below the second story. To do this, one or two courses of brick would have to be taken out and replaced with Istrian stone. Given the low water permeability of Istrian stone, this does not have to be a large coursing. If the Venetians want additional protection at this level, a thin layer of flashing could also be put in over the Istrian Stone: it would be nearly invisible to the passerby but could block the little water that may make its way through the Istrian stone layer.

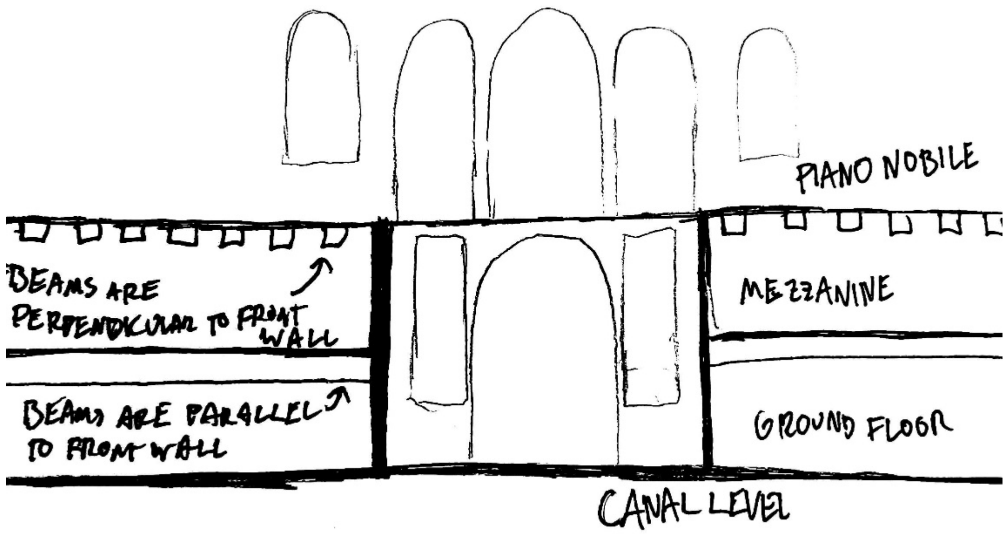

Figure 8: Section Sketch Diagram

Section sketch of the lower floors of the Palazzo Celsi-Donà, showing how the floor levels and orientations of beams work.

Putting these Istrian stones directly below the mezzanine floor line has multiple advantages. As previously said, it does protect the floor beams and metal brackets from severe water damage and rot. Additionally, the higher up the coursing of Istrian stone is placed, the higher the *acqua alta* would need to be to reach the wall above, meaning that the wall of the upper floors would be protected nearly all the time from the canal's water if the stone is placed high enough.

However, up high is not the only place that Istrian stone should be placed. Most *acqua alta* only lasts for a couple of days out of the year, so it is not a primary, permanent event that happens year-round. Instead, the waters of the canal fluctuate up and down with the tides. So, another coursing of Istrian stone should be put about 10cm above the common high-tide mark of the water, protecting the majority of the lower wall from regular water interaction. The downside to this is that the lower bricks may get more saturated over time. However, these bricks can also incrementally be replaced with Istrian stone, at least on the canal-side façades, where they deal with most of the water intake. If the people living in Palazzo Celsi-Donà wanted to be extra careful, additional layers of Istrian stone could be installed at regular intervals between the low coursing and high coursing. This incremental change means that each higher section of the wall would receive less water damage, and it would allow the residents to incrementally replace the façade-side bricks with Istrian stone in organized areas rather than trying to piecemeal it together.

One important thing to reiterate is that this wall type would work much better for the Palazzo Celsi-Donà with the assumption that the people living in the building are ambitious and have some construction knowledge. Obtaining a contractor warranty for this type of wall would be difficult, if not impossible. Free time would have to be invested by the apartment owners for the restoration of Palazzo Celsi-Donà. Financing would also likely have to be out-of-pocket because an architect would also likely not ensure such an experimental project's success. External forces such as acqua alta, frost, and existing decay can affect the success of such a wall type. This project is also aimed at doing the work longer and more incrementally, adding interventions over decades or potentially centuries to protect the building from the water. This works well with the financing issue, as homeowners can save up over several years for the next restoration increment in the building.

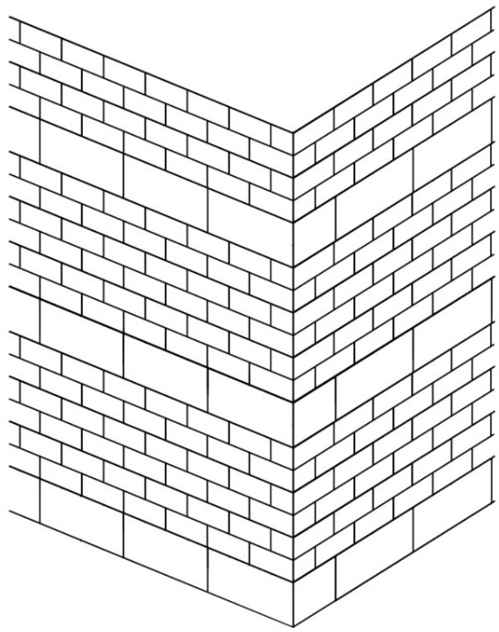

Figure 9: Simple Wall Diagram

Diagram of the Simple Wall in its first phase, with Istrian stone placed at regular intervals.

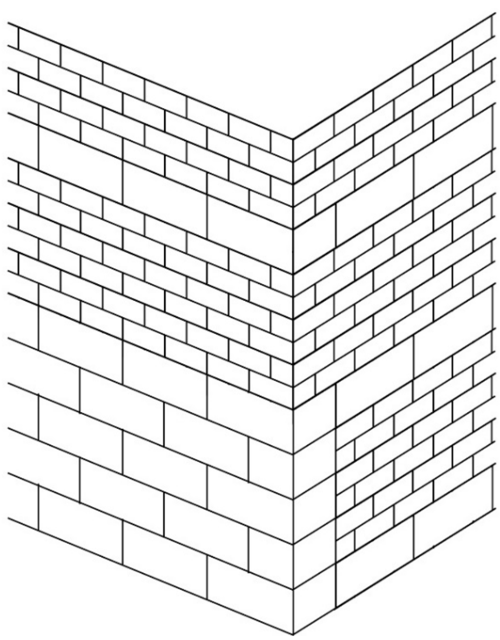

Figure 10: Simple Wall Diagram

Diagram of the Simple Wall in its second phase, now with Istrian Stone covering the canal-side front in the bottom half.

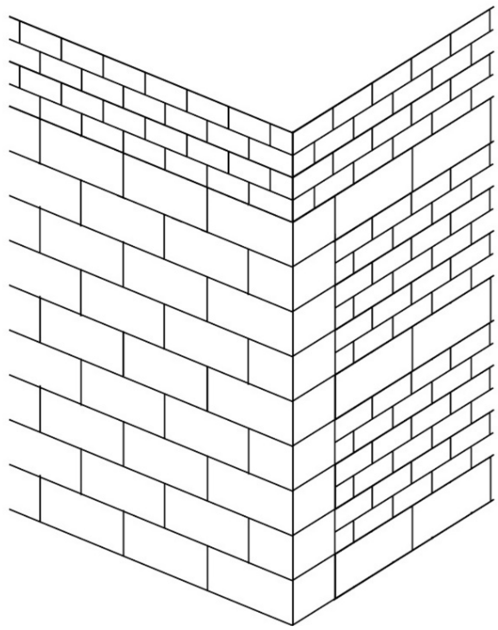

Figure 11: Simple Wall Diagram

Diagram of the Simple Wall in its third and final phase, with Istrian stone now covering the entirety of the canal-side wall, presumably up to at least the level of the mezzanine.

It can be argued that, due to the expensive nature of Istrian stone, such an approach is a waste of valuable material, and the same approach could be taken simply by using sheets of metal flashing. However, metal flashing inserted between brick courses will only allow the water to saturate faster. While this could also be said of Istrian stone, flashing alone does not adhere well to the incremental and simple approach of building or rebuilding the wall. A large sheet of metal flashing could be put in front of the building, but that would be a gross dishonor to the expression of Venetian buildings and is highly undesirable. While a layer of flashing could be put behind the first layer or two of brick, these outer layers of bricks then have nothing to adhere to since the rest of the wall is covered in smooth metal. Because of this, these bricks are in danger of falling off the building and potentially causing injury. Anything else done to secure these bricks would become complicated enough to warrant a variant of the other proposed wall type, the “Complex Wall.”

The “Complex Wall”

The “Simple Wall” does have its drawbacks. While it will mostly mitigate the effects of the water, it will not fully block the wall from getting wet, and the wall will still eventually need replacement. This could make getting a warranty or guarantee on the wall’s safety risky. Thus, for institutional or important commercial buildings, a better wall must be created. The future of Palazzo Celsi-Donà can also not be told right away, and there is a chance in the future that the building will be sold to developers who would rather turn the Palazzo Celsi-Donà into a hotel, museum, or other institution. Or perhaps the residents will pool enough money to rebuild the outer wall to be better rated and even more resistant than the “Simple Wall.” In these cases, a new wall must go beyond what the “Simple Wall” can do.

The “Complex Wall” replaces the primary brick-bearing walls in the lower levels with concrete-bearing walls. It retains the concept of thermal mass seen throughout Venetian architecture using concrete, but the front of the building retains a brick veneer façade. Between the brick veneer and the concrete structure sits a water-resistant barrier. This barrier is adhered to the concrete and is completely impenetrable by any water. Such adhesion can be done through liquid asphalt and a “formwork” that is not unlike the formwork used to pour concrete. A bond-breaking substance would be needed between the asphalt and the formwork so that the formwork can be removed without damaging the barrier. This would help create a continuous water-resistant barrier to fully encase and protect the wall from damaging canal waters. The interior may be left as raw concrete, or it may be finished in a variety of materials, including brick, plaster, or gypsum board.

The “Complex Wall” looks feasible on paper, but the constructability of such a wall gives rise to several problems. To start, the wall would have to be constructed in increments. Brick corbels to a triangle point, which means that the wall would have to be constructed in portions. While this would not be too much of an issue for the “Simple Wall,” this may raise problems for how the concrete is laid in the “Complex Wall.” Additionally, when laying down the weather-resistant asphalt, it may be difficult to get a fully continuous finish. However, the most challenging part of such a design is the brick veneer. Given that this would only be one wythe thick, the brick veneer has to be firmly anchored to the building, or it will peel off and fall into the canal or streets, potentially injuring someone. Brick ties are the traditional way in which brick veneer walls are anchored, but this is not feasible in Venice, where a brick tie would penetrate through the weather-resistant barrier and potentially allow a passage for water to infiltrate the wall. To get around this, there must be alternative, non-penetrable ways to attach brick to the wall. One alternative would be to apply mortar to the exterior face of the asphalt or liquid water-resistant barrier and then lay the brick. A scratch coat could also be used to attach the finish to an underlying material. Since a scratch coat would address vertical loading, the mortar above would only need to address lateral loads. The mortar would adhere to both the asphalt and the brick to keep it in place. This would keep bricks from falling as long as the mortar remains intact and does not get damaged by the water. Another way would be to use an adhesive and brick ties at the top and bottom of the wall to attach strips of metal, known as furring strips, upon which the brick could be hung. Both of these still have the potential to fail with enough moisture content from the canal and neglect from the building owners, but both these options are still viable ways to prevent bricks from falling off the building.

Because the brick, in this case, will be less structural, more care can be taken to emphasize its decorative and characteristic aspects. By playing with patterns, colors, and other similar motifs, the contemporary versus historic nature of the new concrete wall on the ground versus the historical brick wall above can be revealed. Because the brick is not load-bearing, other, more valuable materials, such as Istrian stone or Verona marble, can also be brought in for decorative aspects on the wall. Such an expression could also use significantly less Istrian Stone than the "Simple Wall" or any major Istrian Stone sections in load-bearing wall scenarios.

Finally, the "Complex Wall" is also a step up from the "Simple Wall" in construction standards. Since this is based on a tested wall type, the Complex Wall will presumably hold up with an architect guaranteeing its success and a contractor giving a warranty. The contractor will also be held up to a high standard of craftsmanship and performance due to the nature of working in Venice, which could ultimately grant the owner the financing needed to build such a wall.

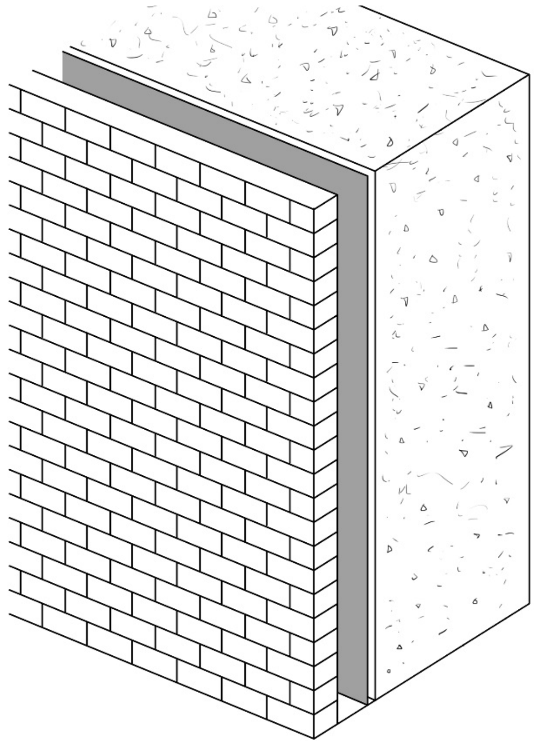

Figure 12: Complex Wall Diagram

The “Complex Wall” has a brick facing with a water-resistant barrier and an unreinforced concrete wall behind it. The water-resistant barrier helps protect the structure behind from water, even when water significantly rises.

Chapter 4: Long-Term Mitigation Strategies

Introduction

The reconstruction of the walls is the first step in repairing Venice's fabric. However, with rising waters, one must expect that water will eventually permanently rise above the ground floor level of typical Venetian buildings, including the Palazzo Celsi-Donà. A century from now, it is speculated that the average relative sea level rise in Venice will be at least one foot if no action is taken to mitigate the general sea level rise or attempt to stop or reverse the sinking of the city. All the buildings in Venice are vulnerable, but the most vulnerable are the ones on canals, such as the Palazzo Celsi-Donà. Even with a wall redesign, steps must be taken to ensure the structural integrity and preservation of the Palazzo Celsi-Donà for years to come.

Neighboring Buildings and Potential Collapse

Neighboring buildings are a reasonable concern for people living on canals in Venice. The neighboring buildings can collapse and potentially cause structural damage to a repaired Venetian building. This is reasonable concern as the Palazzo Celsi-Donà touches two other buildings. The first is a small red building that likely would not severely damage the Palazzo Celsi-Donà if it did collapse, and the other building, known as the Palazzo Celsi, was recently renovated. If the Palazzo Celsi does collapse, it is still unlikely that the Palazzo Celsi-Donà would also collapse. Given that the buildings touch at narrow ends, this is a fear that many Venetians would not have to worry about. Additionally, many buildings would show warning signs, such as decaying brick, long before they collapse. If multiple buildings in a block exhibit warning signs and the residents become concerned, they can do wall repair and reconstruction together on entire blocks rather than individual buildings.

Incremental Reconstruction and "Sacrificing" of the Ground Floors

The two parts that would help the Palazzo Celsi-Donà the best would be incrementally replacing the wall and replacing the floor. Given that the walls and floors are the first steps of protection against water damage and the primary parts of the building that bear loads, these places are the most important to monitor and keep safe. However, the unfortunate reality is that if nothing is done, there will eventually come a point where the ground floors of Venetian buildings will be completely underwater. The enclosure of the ground floors in Venice must be bolstered to prepare for such an event.

With the two wall types in mind, the "Simple Wall" and the "Complex Wall," each has its own challenges in preparing them for rising waters. The "Simple Wall" is designed for incremental replacement of bricks with Istrian stone, allowing for time and money to be saved by putting the wall together in small pieces over a long period of time. However, if the brick is not replaced with Istrian stone in a timely manner, then there is an increasing chance that the wall could decay. A decaying wall could be more costly to replace in the future and could jeopardize the structural integrity of the building. Therefore, bricks must be replaced with Istrian stone in a timely manner as the water level rises. While it is riskier than the "Complex Wall," it remains a better choice for the Palazzo Celsi-Donà. Because the Palazzo Celsi-Donà is a fully residential building with some historical significance, making small interventions to the building is much more desirable due to the lower, more affordable costs for residents, the preservation of large portions of the original wall, and the honoring of traditional Venetian construction techniques.

With the "Complex Wall" in mind, it is thought of as a "one-and-done" long-term solution. However, with rising waters, much more pressure could be put on the fragile brick veneer. As water rises, the bricks could potentially be pushed into the wall, potentially chipping or scraping away portions of the water-resistant barrier. If this happens, then water could penetrate into the concrete layer of the building, which could cause structural damage later on. To secure the “Complex Wall” as the waters rise, one of two methods would be mandatory: either the brick veneer is secured with a breathable yet solid anchoring system, such as a water-permeable mortar, or the bricks would need to be easily removable to fill in the cavity space with concrete or another similar material. If Istrian stone is used to clad the bottom of the building, then the waters could rise naturally as long as the mortar between the stone and the barrier is strong enough, given the impermeability of the material. In the case of the Palazzo Celsi-Donà, as a fully residential building with no institutional needs, this would likely be prohibitively expensive and severely alter the character of the original building, making this solution undesirable.

The floor presents a new and entirely different challenge in the Palazzo Celsi-Donà. These issues stem from two primary concerns. First, filling in too much of the floor could cause the floor to become too heavy for the foundations, which could accelerate the sinking of the Palazzo Celsi-Donà, among other structural issues. Second, with a chance that Venice could be raised further in the future, it is imperative that any changes made to the floor must be easily reversible in a future restoration. One unexpected material that may work positively in the Palazzo Celsi-Donà’s floor is concrete. Concrete, and particularly unreinforced concrete, might be the most viable option for preserving the historic fabric of the fragile Palazzo due to its relatively low cost and simplicity of installation. While it is a heavier material, mixing it with such materials as fiber can help to lighten its weight, which will likely not affect the concrete if it is primarily underwater. One form of concrete, Expanded Clay Aggregate Concrete, is lightweight and buoyant, and it could ultimately have a negligible impact on the building’s structure and weight if implemented. If concrete does not work for the Palazzo Celsi-Donà, another economic option would be filling in the floor with lightweight bricks. Because brick is already a vernacular material for Venice, it is a sensible choice for the Palazzo Celsi-Donà. Additionally, brick, in particular, is an easy material to remove in the event of uncovering and restoring underwater portions of the ground floor. New layers of brick could be continually added as the water level rises.

Chapter 5: The Next Steps?

Beyond the Ground Floor

Palazzo Celsi-Donà is more than one story, and while the enclosure on the ground floor is the most vulnerable, water still has the potential to wick up and/or damage portions of the upper floors. Buildings near Palazzo Celsi-Donà already have significant visible decay well above the ground-floor windows. Combatting this with long-term solutions is another problem to consider while working with the ground-floor walls.

The first and perhaps the most effective long-term solution is blocking capillary action from allowing the water to even reach the upper floors. In both the “Simple Wall” and the “Complex Wall,” a line of water-impermeable material, either Istrian stone or metal, is placed right below the second-floor beams, protecting them from significant water damage. Despite this simple solution, work must be done with the utmost quality to fully confirm the water impermeability of the ground floor to the upper floors.

However, water does not just penetrate from the canals directly. Given the city’s heavy rains during storms and typical high humidity, buildings must have adequate cladding to stay protected from other forms of water-based decay. In the case of monumental buildings such as the Doge’s Palace, high-quality and more water-resistant materials were used hundreds of years ago that were not able to be used on smaller palazzi in the city. Instead, the majority of Venetian buildings, including the Palazzo Celsi-Donà, have brick enclosures susceptible to other forms of water penetration. In the case of Palazzo Celsi-Donà and many other buildings, a layer of plaster covers the upper floors of the building to protect it from the dangerous waters. Unfortunately, even such a plaster will eventually decay away and expose the fragile bricks once again. To encourage drying of the bricks, more breathable plaster should be used than what is typically on the conventional market; this helps to keep the plaster on longer and requires fewer repairs. By letting water dry out of the building, the bricks can remain dry and stable for longer, even if the climate in Venice should get wetter in the future. The use of brick as a historical material is ubiquitous nearly all across Europe, not just in Venice or Italy. Because other European cities have humid climates and must deal with similar issues of humidity as Venice, products for breathable plasters have already hit the market.

The future of the MOSE and the future of Venice

Currently, the MOSE is the most effective strategy for protecting Venice from any significant flood damage. So far, it has done an effective job. However, the MOSE itself is in danger of becoming obsolete one day. There are several scenarios that may happen in the distant, or even not-so-distant, future that threaten the effectiveness of the MOSE and the future of Venice as a whole.

The first issue with the MOSE is that it is built out of steel-reinforced concrete. Under the absolute best conditions, it is likely that this concrete will only last 100 years since the steel will eventually rust in the unforgiving saltwater. However, 100 years is a long time for Venice, considering its current state. If the MOSE is still effective in 100 years, then it is possible that it would only simply need to be repaired or replaced in order to continue working.

There is a good chance, however, that the average level of the water, or the level of the acqua alta, a century from now, could be higher than the top of the MOSE barrier or higher than the barrier islands themselves, which would place Venice in a much tougher situation. In this case, if nothing can be done to raise the city up, then the ground floors would have to be filled in and the streets raised. It would be an incredible expense for the city to raise its streets and, presumably, to also raise its major landmarks, such as the Rialto Bridge.

Conclusion

Palazzo Celsi-Donà represents a unique case of Venetian architecture. While many buildings in Venice either fall on one far end of buildings built as monumental landmarks and cultural treasures or the other far end of buildings built as simple and unassuming and replaceable apartment or tenement buildings, there exist unique, hidden gems in the city that exude both the grandeur of historical craftsmanship but also provide the vital service of housing. These buildings especially need to be cared for to preserve the integrity and history of Venice. The care that goes into these restorations should be both historically informed and provide the framework needed for long-term protection. I proposed two solutions for such careful restorations. The first solution, the "Simple Wall," is a do-it-yourself approach that involves minimal materials and simple craftsmanship, something that has enough historical background that it could have been done as easily in the Renaissance period as in the modern age. The second approach is a uniquely contemporary solution that takes its cues from modern enclosure framing and ideas that many architects and contractors are familiar with and adapts it to the unusually harsh environment of a partially submerged building.

I hope that the ideas and strategies presented here can be looked into further and potentially implemented in the near future, as Venice is in increasing peril from rising water. Even with systems in place, such as the MOSE, I believe preparing for the worst possible scenarios is better. Should the MOSE fail, the residents must be prepared to protect their homes from *acqua alta* at a building level. If residents of the Palazzo Celsi-Donà can gather funds to build the "Simple Wall," the Palazzo Celsi-Donà could potentially be among the first residential buildings in Venice to implement longer-term strategies for protection from the water.

No matter what happens to Venice, though, the preservation of such valuable and endangered architecture is important to the preservation of architectural history for both the local and international community. Even in a building as seemingly insignificant as Palazzo Celsi-Donà, it, along with the many other historical buildings of Venice, remains a standing testament to the architectural beauty of centuries past.

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