Surviving in Venice

Good Design Practices for Hard Times

By

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Introduction

Venice, the birth of the anticipatory community

There is a unique type of project born in "hard times" that leads to the creation of extraordinary beauty. Venice is a perfect example of this — a civil and collective project rooted in proactive strategies that anticipate and resolve the challenges of living in an environment otherwise deemed uninhabitable. From its very inception, Venice was designed to overcome the constraints imposed by a hostile environment. It stands on a foundation of soft, yielding terrain that constantly settles, submerged in salt water that rises and falls four times a day, corroding and distorting the foundations of its buildings. The city lacks potable water, is scarce in building materials like stone and timber, and devoid of natural food resources. Its climate is constantly under low atmospheric pressure, highly humid, and exposed to seasonal winds like the Bora and Scirocco, which bring severe sea storms and cause damage to structures. The brackish air of the lagoon accelerates the deterioration of building surfaces and materials.

In the images: The evolution of the urban fabric of Venice in three periods: 1200, 1300 and 1500

In addition to these harsh environmental factors, Venice has faced relentless demographic pressure. From a population of 30,000 in the early 13th century, it grew to 120,000 by 1338 and reached 150,000 by 1548.[1] This rapid growth resulted in impressive building and living densities, even by the standards of the time. Such population pressure intensified the demand for resources and necessitated new ways to adapt the city's built environment to sustain the growing populace.

The difficulties posed by the Venetian Lagoon's environment demanded the development of innovative devices and techniques to mitigate these challenges. These adaptations not only allowed for survival but also played a decisive role in shaping and refining the urban form of Venice as we know it today. What may have seemed insurmountable environmental obstacles became opportunities for urban transformation, driving the adoption of high-performance architectural principles that significantly improved the city's resilience and aesthetic quality.

The history of Venice, shaped by its waters and the disasters they brought, is a centuries-long story of humanity's determination to tame a fragile and inhospitable world. For centuries, Venetians battled floods, swamps, and diseases like malaria to create a city that could not only survive but thrive in such conditions. This history is not merely a record of the past but an ongoing narrative that offers valuable lessons for the present and future. In a world increasingly aware of its own environmental limitations and vulnerabilities, Venice serves as a reminder that adversity can spark ingenuity and resilience.

As historian Piero Bevilacqua points out, there is a profound reason to revisit Venice's history today. "In our time, there is a deeper and more special reason to put [the history of Venice and its waters] back at the center of contemporary attention. [...] It is our present condition, our precarious relationship with limited resources, our location within environmental frameworks that are increasingly degraded, and for us increasingly dense with risks, that make us turn to that singular past

1 M. Ginatempo, L. Sandri (1990). L'Italia delle città. Il popolamento urbano tra medioevo e rinascimento (secoli XIII-XVI). Firenze: Le Lettere. p. 82.

as a history that faces, in a certain sense, our own problems, today and tomorrow, several centuries in advance."[2]

Venice's story is one of proactive adaptation — a continuous struggle to transform an inhospitable environment into one of great beauty and function. The city exemplifies how necessity can drive innovation, and how the constraints of nature, when approached with creativity and determination, can lead to stunning architectural and urban achievements. The Venetian Lagoon, with its challenges, became a laboratory of design, where architects and builders invented new techniques to combat the daily threats of erosion, subsidence, and flooding. From the earliest use of wooden piles to stabilize the ground, to the complex system of canals that manage water flow, Venice's urban fabric is a testament to human ingenuity in the face of adversity.

Today, the challenges of Venice resonate with global concerns about climate change, rising sea levels, and the sustainable use of resources. The city's survival and prosperity for over a millennium in such a fragile environment offer valuable insights into how we might approach our own environmental challenges. The lessons of Venice — proactive planning, innovative solutions, and a deep respect for the balance between human habitation and nature — remain relevant as we navigate the complexities of modern urban living.

Venice is not just a city of great historical and architectural importance; it is a living example of how human civilization can thrive in even the most adverse conditions. Its proactive approach to urban planning, grounded in a deep understanding of the environment and its constraints, allowed it to flourish where others might have failed. This model of resilience and foresight offers a powerful example for future generations as they confront the growing challenges of environmental degradation, resource scarcity, and climate change. Venice's history reminds us that, even in the face of overwhelming difficulties, there is always room for beauty, innovation, and hope.

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2 Bevilacqua, P. (1998). Venezia e le acque: una metafora planetaria. Roma: Donzelli. p. 4

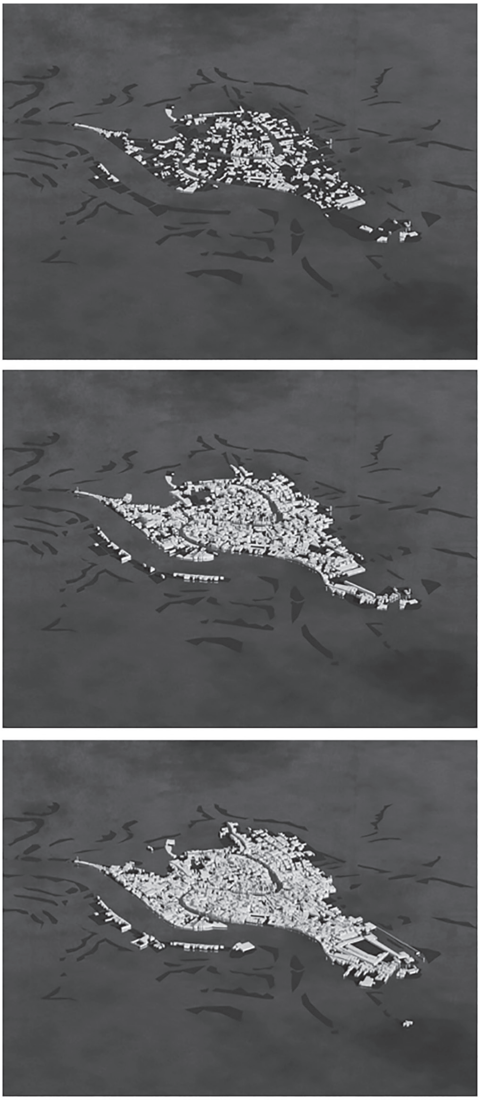
The speed of invention

The success of the Venetian building system can be largely attributed to the challenging and unforgiving environmental conditions in the Venetian Lagoon. As the renowned scholar Mario Piana notes, Venice developed an "absolutely singular building concept"[3] that defied one of the fundamental principles inherent in virtually every other building tradition — namely, the reliance on masonry techniques using stone or brick. In Venice, a revolutionary and highly specialized approach to construction took shape, and no other Italian building culture adopted such innovative techniques within such a short span of time. This swift evolution of building procedures was directly linked to the conditions in the lagoon, which allowed for a rapid assessment of construction quality and performance.

Piana further explains that construction cultures, prior to the systematization of modern engineering theories, advanced through gradual refinements. These refinements came about as builders accumulated experience by observing signs of instability or degradation in their structures. Corrections were applied in response to the visible failures of buildings, often emerging as remedies to issues that were empirically observed. Thus, traditional construction knowledge was the result of a slow process of trial and error, with builders adjusting their techniques based on evidence of structural weakness or failure.

In Venice, this iterative learning process — a "learning-by-doing" approach — occurred with remarkable speed compared to other regions. While it might have taken decades or centuries in other geographical areas to fully understand the evolving behavior of a building, in Venice the settlement of the buildings and their responses to environmental pressures could be assessed almost immediately. This was due to the poor mechanical qualities of the marshy, unstable soils on which the city was built. The soft and shifting terrain of the lagoon presented

3 Piana M. (2004). 'Materiali, tecniche, sistemi costruttivi dell'architettura lagunare; problemi di conservazione e di nuova utilizzazione' in: Gallego Roca J. *La Imagen de Venecia en la cultura de la restauración arquitectónica*. Universidad de Granada: Granada, p. 163



In the images: The evolution of the urban fabric of Venice in three periods: 1200, 1300 and 1500

extreme challenges, but it also provided builders with instant feedback on their construction techniques.

The rapid sinking, settling, or deforming of newly constructed buildings allowed Venetian builders to promptly evaluate the success or failure of their methods. While in other regions, signs of building failures like leaning walls, cracked masonry, or warped floors might take generations to manifest, in Venice these issues could surface much sooner due to the unique properties of the land. As a result, construction errors were identified and corrected with unprecedented speed, transforming what seemed like a major disadvantage into an invaluable advantage. The extreme softness of the ground, which might have been a significant liability elsewhere, became a catalyst for innovation in Venice.

The builders of Venice, therefore, were able to rapidly refine their methods. The constant and visible feedback from the environment forced them to perfect their techniques. As Piana describes, the process was characterized by the "immediate evaluation"[4] of their

4 Piana M. (2004). 'Materiali, tecniche, sistemi costruttivi dell'architettura lagunare; problemi di conservazione e di nuova utilizzazione' in: Gallego Roca J. *La Imagen de*

work, allowing them to implement necessary corrections on the fly. What might have been a structural failure in other contexts became an opportunity for adaptation in Venice. This process led to the creation of buildings that, although fragile in their individual elements, achieved a remarkable equilibrium as a whole, displaying an extraordinary capacity to maintain balance and stability over time.

Despite the long historical trajectory of Venice's building practices — spanning at least eight centuries — the city's public institutions, known as the *Magistrature*, emerged within a much shorter period. These governing bodies were established between 1224 and 1297, and their role was to oversee and safeguard the city's structural integrity. The rapid formation of these institutions was driven by the urgent need to find solutions for living in such a harsh and hostile environment. The swift response of Venice's public authorities to the pressing environmental challenges demonstrates the proactive nature of the city's approach to urban development.

The series of technological devices invented by Venetians, the specialized professionals who managed their installation, and the tools and methods used to move and position these devices, represent a unique chapter in the city's history. These innovations were exceptional in the broader context of architectural development and stand out as a testament to the city's proactive, collective efforts to survive and thrive in an environment that was otherwise uninhabitable.

These professionals worked closely with the *Magistrature* to ensure that the city's delicate balance was maintained. The constant threat posed by the lagoon's waters and the ongoing pressure from population growth required a continuous cycle of innovation and adaptation. Venice's building system was not static; it was a dynamic and evolving process that responded to the environment in real time.

The methods and practices developed in Venice were not just reactive, they were proactively designed to anticipate future challenges. The city's builders and authorities worked together to create a resilient

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Venecia en la cultura de la restauración arquitectónica. Universidad de Granada: Granada, p. 163

urban fabric that could withstand the environmental pressures of the lagoon. This collective effort led to the creation of one of the world's most unique and enduring urban environments — a city that continues to captivate architects, engineers, and historians alike.

The success of the Venetian building system is a direct result of the extreme environmental conditions of the lagoon. The rapid feedback loop created by the soft soils forced Venetian builders to quickly adapt their methods, resulting in a highly refined and innovative construction system. The collaboration between public institutions, specialized professionals, and the local environment enabled Venice to overcome the challenges of its surroundings and create a thriving urban center. The city's history of proactive building practices offers valuable lessons in resilience, adaptability, and the power of collective effort in the face of adversity. Venice stands as a living example of how human ingenuity can transform even the most inhospitable environments into spaces of great beauty and functionality.

The birth of Venetian beauty

In the images: The so called "casoni" (large houses) in the lagoon. The houses in Venice where all like this in the first part of the Middle Ages. ph. Giuseppe Bruno

Venice stands as an extraordinary example of how human ingenuity can transform adversity into beauty. The city's ability to thrive in an environment that is inherently hostile to habitation reflects a universal characteristic of beauty — the kind that emerges not despite difficulty, but because of it. This concept of making virtue out of necessity, as seen in the construction and development of Venice, aligns with the thoughts of Oratio Greenough, a 19th-century American sculptor and theorist who advanced ideas on organic functionalism. His insights, which were also echoed by figures like John Ruskin and Emerson, help us understand the profound connection between beauty, economy of means, and function, all of which are embodied in the Venetian experience. Greenough's critique of traditional aesthetic values, particularly Edmund Burke's emphasis on the sublime, paved the way for a new understanding of beauty as something inherent in the functional and the organic. As Greenough and Emerson proposed, beauty is not an ornamental addition to a structure but something that arises naturally from the harmony between form and function.[5] This idea that "beauty depends on necessity" is clearly reflected in Venice, a city that grew out of a continuous and intricate negotiation with its harsh environment. In this way, Venice exemplifies Greenough's belief that the principles of construction can be found in nature, much like the skeletons and skins of animals are perfectly adapted to their environments.

In the images: The houses of Lio Piccolo.
ph. Giuseppe Bruno

5 Albrecht, B. (2012). Conservare il futuro: il pensiero della sostenibilità in architettura. Padova: Il poligrafo. p. 144

In fact, the reference to Renaissance theorist Leon Battista Alberti,[6] who believed that true beauty is intrinsic to the object and not merely decorative, is particularly relevant when we look at Venice. Alberti likened buildings to living organisms, with each part serving a functional purpose within the whole. He argued that beauty arises naturally when a structure fulfills its function effectively. In Venice, this philosophy took on a very literal meaning. The city's architecture is not simply a response to aesthetic desires but a carefully constructed solution to the environmental challenges posed by the Venetian Lagoon. Its buildings, foundations, and waterways are all perfectly attuned to the peculiarities of the site, making Venice a colossal organism, as Ruskin once called it, capable of adapting to the most difficult of conditions.

Ruskin's description of Venice as a "colossal mad-repore"[7], a massive coral-like structure composed of many small, interdependent parts, encapsulates the city's organic complexity. Like coral, Venice is made up of countless small elements—individual buildings, streets, canals, and islands—all working together to create a harmonious whole that can withstand the pressures of its environment. The city's success lies in its ability to respond creatively to the challenges of living in a landscape of swamps, tides, and shifting ground. In this sense, the city itself becomes a metaphor for sustainability, a term we use today to describe the ability to live in balance with our environment. Venice, by necessity, has always lived sustainably, using limited resources efficiently and finding ways to coexist with nature rather than dominate it.

Ruskin's advocacy for intergenerational responsibility[8] is another critical aspect of Venetian architecture and urban planning. For Ruskin, the true value of any work of architecture lies not only in its immediate utility or aesthetic appeal but in its ability to endure and serve future generations. When we build, Ruskin argued, we should build with the intention that our structures will last forever, or at least as long as they are needed. This idea resonates strongly in Venice, where the city's very survival has

6 L. B.Alberti ((1966), L'Architettura (De re aedificatoria), Book VI, 2, Milano: Il Polifilo. p. 446.
7 Ruskin J. (1987) *Le Pietre di Venezia.* Rizzoli: Milano.
8 Albrecht, B. (2012). Conservare il futuro: il pensiero della sostenibilità in architettura. Padova: Il poligrafo. p. 160

always depended on the careful conservation of resources, both material and cultural. The preservation of Venice is not merely about maintaining its physical form; it is about sustaining the values and knowledge embedded in its architecture, values that have been passed down through generations. This concept of "durability," which the French term "durabilité" captures, underscores the need to think of architecture as a long-term investment in both the present and the future.[9]

This sense of responsibility to future generations ties Venice's legacy to modern concerns about sustainability and environmental stewardship. Ruskin's call to build with the future in mind can be seen as an early precursor to today's sustainable architecture movements. The Venetians, though they may not have used the same language, practiced sustainability out of necessity. They designed their city to function efficiently in a harsh environment, ensuring that it could support not only the current population but also future generations. Venice, therefore, offers us a model for how we might think about urban development in the face of today's environmental challenges. William Morris, a contemporary of Ruskin, further developed these ideas, linking the imaginative work of architecture to broader social and environmental concerns. Morris was deeply critical of the capitalist division of labor, which he saw as alienating workers from the products of their labor and degrading the quality of both work and life. Like Ruskin, Morris believed that architecture had the power to reshape society, and that the principles of craftsmanship, community, and sustainability should guide the design of buildings and cities. For Morris, Venice represented the embodiment of these values, a city where the organic unity of form and function, craft and community, was still visible and tangible.

In "The Stones of Venice," Ruskin wrote about the "Nature of Gothic," in which he saw the mutual dependence of the particular and the whole. This philosophy of interdependence is mirrored in the Venetian lagoon, where the city is both part of the natural landscape and a product of human ingenuity. Venice, in Ruskin's view, was "the Paradise of Cities,"

9 See: Jacobus A.Du Pisani (2006), Sustainable Development, Historical Roots of the Concept, in: "Environmental Sciences", June 2006, 3(2), pp. 83-96: 85. And: Albrecht, B. (2012). Conservare il futuro: il pensiero della sostenibilità in architettura. Padova: Il poligrafo. p.

[10]not because of its aesthetic appeal alone, but because it represented a harmonious relationship between human beings and their environment, between art and function, between the past and the future. It was a Gothic community extended into three dimensions, a living, breathing organism that could teach valuable lessons about how to live sustainably in a complex world.

In the images: The façades od Ca' da Mosto on the left and Ca' Dolfin on the right. ph. Paolo Monti

Venice's example is not merely one of architectural or artistic brilliance; it is a model for how societies can adapt to and mitigate the impacts of adverse environmental conditions. The city's positive methods of labor, its collective problem-solving approach, and its commitment to long-term sustainability offer us strategies that are just as relevant today as they were in the past. In an age where cities around the world are grappling with the effects of climate change, overpopulation, and resource scarcity, Venice's proactive approach to urban development provides a blueprint for how we might build more resilient, sustainable, and beautiful cities. Venice's beauty lies not in its superficial appearance, but in the way it embodies the organic relationship between form,

10 See: Leon D. (1841), Ruskin: The Great Victorian, London: Routledge, p. 65. And: Hewison R. (2009), *Ruskin on Venice: 'The Paradise of Cities'*, New Haven - London: Yale University Press.

function, and environment. It is a city that made a virtue out of necessity, and in doing so, it created a universal model of beauty that continues to inspire architects, artists, and urban planners to this day. The lessons of Venice, as articulated by thinkers like Ruskin, Greenough, Alberti, and Morris, remind us that true beauty is not an end in itself, but the result of a deep understanding of nature, community, and the long-term consequences of our actions. As we face our own environmental challenges in the 21st century, Venice's example offers us a way forward, showing us that beauty and sustainability are not mutually exclusive, but are in fact one and the same.

Unstable Soils

The city of Venice is renowned for its beauty, unique architecture, and its stunning location on a network of islands within a shallow lagoon. However, the charm and splendor of Venice are only part of its story. Beneath its beautiful buildings and canals lies a much more complex narrative, one rooted in the physical characteristics of the soil on which the city is built. Unlike most cities, Venice is not situated on solid ground but on a landscape made up of soft, unstable sediments—primarily silt, sand, and clay. This soil presents unique challenges that Venetian builders have had to overcome since the city's inception.

The primary issue that these builders faced was the poor mechanical properties of the soil. The upper layers of the ground, composed of loose silt and sand, offer very little resistance to the forces exerted by the heavy buildings constructed on them. Beneath these upper layers lies a clay layer known as "Caranto." While the Caranto is more compact and slightly more stable than the sediments above, it still lacks the strength to independently support the significant loads imposed by the city's structures. The combination of these weak soils makes it difficult, if not impossible, to construct durable and stable buildings without taking additional measures to stabilise the ground.

Venetian engineers and builders, confronted with these adverse conditions, developed innovative methods to deal with the challenges posed by the unstable terrain. One of the most crucial techniques used was the installation of wooden piles, which were driven deep into the soil to provide a solid foundation for the buildings above. These piles, often made of oak, pine, or larch, were driven through the soft, unstable layers of silt and sand until they reached the more solid Caranto below. The dense Caranto provided a better base for the wooden piles, even though it, too, could not fully support large loads without reinforcement.

The key to the effectiveness of this method lay in the way the piles interacted with the wet, anaerobic environment of the lagoon. The lack of oxygen in the submerged soil prevented the wood from rotting, allowing the piles to remain strong for centuries. Once the piles were securely in place, horizontal platforms *of wood and stone were laid on top of them, creating a stable base upon which buildings could be constructed. This technique allowed Venice's magnificent architecture to flourish despite the poor quality of the soil.*

In some parts of the city, where particularly heavy buildings were constructed, builders had to take even further precautions. For instance, to support structures like the massive Basilica di San Marco or the Palazzo Ducale, a greater number of piles were driven into the ground to distribute the load more evenly across the unstable soil. In addition, buildings were designed with lightweight materials such as brick and marble to reduce the pressure on the foundations, helping to prevent sinking or collapse.

As Venice expanded and grew more populated, the challenge of stabilising the soil became even more critical. The weight of new structures, along with the increased demand for infrastructure, created additional stress on the foundations. To address these ongoing challenges, Venetian engineers and builders began experimenting with more advanced technologies and materials over the centuries. The introduction of reinforced concrete in the 19th and 20th centuries, for example, allowed for stronger foundations, while modern soil consolidation techniques have been employed to stabilise the ground beneath newer developments.

One of the most significant modern challenges is the phenomenon known as "acqua alta" or high water, where the city experiences periodic flooding due to rising sea levels and sinking ground. This has forced engineers to develop new methods of protecting and reinforcing the foundations of Venice. Projects like the MOSE (MOdulo Sperimentale Elettromeccanico) system have been designed to protect the city from extreme flooding by temporarily blocking high tides from entering the lagoon. Though not directly related to the soil itself, this project represents a continued effort to preserve Venice in the face of its challenging natural environment.

Beyond these large-scale infrastructure projects, techniques such as injecting grout or other stabilising materials into the soil have also been used in modern times to reinforce the ground and prevent the settling of historic buildings. These methods work by filling the voids in the unstable soils, reducing their tendency to shift or compress under the weight of the city's buildings. Additionally, *engineers use monitoring systems to track the movement of buildings and soil over time, allowing them to respond to any signs of instability before significant damage occurs.*

Despite all these efforts, the city continues to face challenges related to its unstable foundation. The weight of modern buildings, ongoing construction, and environmental changes, including climate change, pose a constant threat to the delicate balance of Venice's infrastructure. However, the resilience and ingenuity of Venetian builders and engineers, both past and present, have enabled the city to not only survive but thrive in an environment that would seem entirely unsuitable for large-scale urban development.

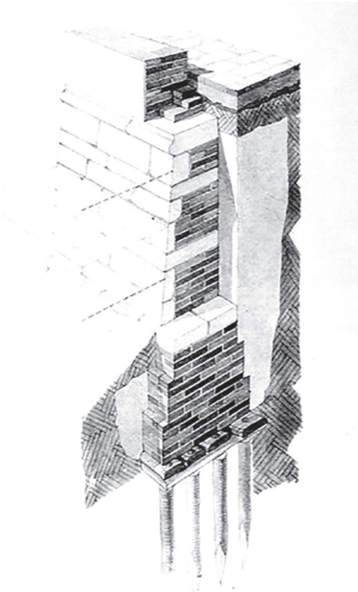
In conclusion, Venice's unique soil conditions, composed of silt, sand, and Caranto, present significant challenges for construction. The poor mechanical properties of the soil require extensive stabilisation efforts through traditional methods such as wooden pile foundations, as well as modern techniques like soil consolidation and concrete reinforcement. These measures have allowed Venice to grow and sustain itself over centuries, showcasing the resourcefulness and innovation of its builders. However, as the city continues to face new environmental and structural challenges, ongoing efforts to protect and stabilise its foundations will be essential to preserving this architectural marvel for future generations.[11]

Devices for Building Adaptation to Unstable Terrain

Pile foundations

The Venetians developed a remarkable system of foundation construction to overcome the significant challenges posed by the soft, unstable soils

11 For a complete notion of the geological nature of the Venetian Lagoon see: Baschieri P. (1996). Cenni generali sulla morfologia lagunare. In: "La laguna di Venezia: un patrimonio da riscoprire". FORUM della Laguna. Venezia, Filippi Ed., pagg. 58-64.; Carbognin L., Teatini P., Tosi L. (2005). Land subsidence in the venetian area: known and recent aspects. Giornale di Geologia Applicata, 1: 5-11.; Cavazzoni S. (1995). La Laguna: origine ed evoluzione. In G. Caniato, E. Turri e M. Zanetti (eds.) La laguna di Venezia, Verona: UNESCO, Cierre Ed., pp. 41-67; Gatto P.,E Carbognin L. (1981). The lagoon of Venice: natural environmental trend and man- induced modification. Hydrol. Sci. B., 26(4): 379-391; Gatto P., Previatello P. (1974). Significato stratigrafico, comportamento meccanico e distribuzione nella laguna di Venezia di un'argilla sovraconsolidata nota come "caranto". Rapporto Tecnico 70, CNR, Istituto per lo Studio della Dinamica Grandi Masse, Venezia, 45 pp; Favero V., Parolini R., Scattolin M. (1988). Morfologia storica della Laguna di Venezia. Arsenale Editrice (Venezia) 89 pp.



In the image: Drawing scheme of a pile foundation in Venice.
Image: Mario Piana

of the Venetian lagoon. This system, which involved the use of wooden pile foundations, allowed the city to rise and flourish on terrain that would otherwise be unsuitable for the construction of large and heavy buildings. The method involved compacting the surfaces on which buildings were to be erected by driving wooden piles deep into the ground, effectively stabilising the soil and creating a solid base for construction.

The foundation piles used by the Venetians were wooden stakes, typically made from elm, alder, oak, poplar, and, later, from more durable woods such as fir, pine, and especially larch. These materials were chosen for their resistance to decay and their ability to withstand long-term immersion in water. The piles ranged in diameter from 10 to 25 cm, depending on the size and requirements of the structure being built. The selection of specific woods evolved over time as the Venetians learned which types were most suitable for the challenging conditions of the lagoon, with larch becoming particularly favored due to its strength and resistance to water.

To stabilise the often loose and waterlogged soil, the Venetians used thinner piles driven into the ground at close intervals. This method of tightly spacing the piles increased the overall stability of the foundation. By planting hundreds or even thousands of these wooden stakes into the soft sediments, the builders created a dense network of piles that functioned together to provide a solid, uniform surface. This network dispersed the weight of the buildings evenly, preventing the structures from sinking into the weak soil.

In the image: Detail of the plan of the 'muri di spina' walls of Venice

A critical aspect of this technique was ensuring that the wooden piles remained submerged below the water surface, even during low tides. The anaerobic conditions in the waterlogged soil created a low-oxygen environment that helped preserve the wood. Without oxygen, the wood did not rot or decay, allowing the piles to maintain their strength over centuries. This principle was key to the longevity of Venice's buildings, as the piles, once planted in the ground, became a stable and durable foundation that could support the city's ever-growing structures.

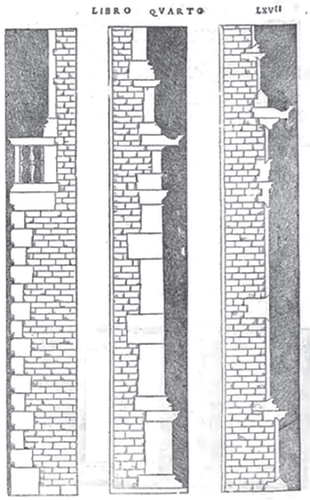
In the images: Axonometric view of the 'muri di spina' walls of Venice

Once the wooden piles were driven into the ground, they were capped with horizontal layers of wooden planks or stone slabs, forming a platform known as the "sole" (in Italian, "zatterone"). This platform spread the load of the buildings across the entire foundation, further distributing the weight and reducing the risk of subsidence. On top of this platform, the builders would then construct the walls and foundations of the buildings themselves, often using lightweight materials such as brick and marble to reduce the load on the piles.

This method of pile foundations was used extensively throughout Venice and is one of the key reasons why the city was able to grow and thrive despite the challenging natural environment. Iconic structures such as the Doge's Palace, the Basilica di San Marco, and countless other buildings, both large and small, were constructed using this technique. The durability of the wooden piles, combined with the ingenuity of Venetian engineers and architects, ensured that the city's buildings would stand for centuries.

In the image: Plan of the 'muri di spina' walls of Venice

The effectiveness of the pile foundation system is demonstrated by the fact that many of these ancient wooden piles are still in place today, supporting some of Venice's most famous landmarks. Even though the buildings themselves have been renovated and repaired over the centuries, the original foundations remain largely intact, a testament to the ingenuity of the Venetians and their mastery of engineering in difficult conditions.



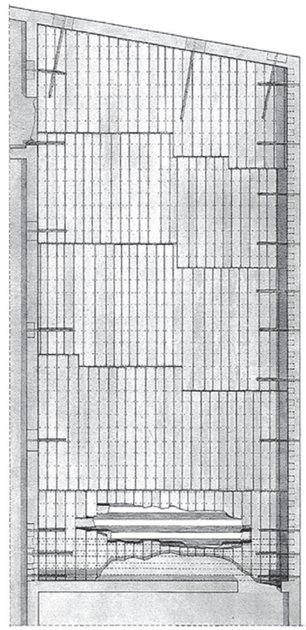
In the image: Types of walls in Sebastiano Serlio's Seven Books of Architecture.

As Venice grew and expanded, the pile foundation technique continued to evolve. Builders experimented with different materials and methods, but the basic principle of using wooden piles to stabilise the soil remained a cornerstone of Venetian construction. In more modern times, the Venetians have supplemented the traditional wooden pile foundations with newer technologies, such as concrete reinforcements and soil stabilisation techniques. However, the foundation piles remain an essential element of the city's infrastructure.

The system of foundation piles developed by the Venetians represents one of the most ingenious engineering solutions in the history of architecture. By driving wooden piles into the soft and unstable soils of the lagoon, the Venetians were able to create a stable surface on which to build their city. This method allowed Venice to grow into a thriving metropolis despite its challenging environment, and it continues to support the city's structures to this day. The pile foundations, with their use of durable woods like larch and their careful placement beneath the water's surface, are a lasting testament to the creativity and skill of Venice's builders.

I muri "fuori piombo". Uneven Walls and "Muri di spina"

The deep structure of the city of Venice is defined by a highly methodical and consistent architectural approach that can be seen in the repetition of a specific module known as "muri di spina" or "piedritti". This design framework, which is present across nearly all Venetian buildings, reflects a structural logic that has allowed Venice's architecture to endure for centuries despite the challenging environmental conditions of the lagoon.



In the image: Plan illustrating the attachment scheme of the 'plug walls' to the floors. Image: Mario Piana

At the heart of this architectural system is the use of a "tripartite floor plan", which organises each building into three distinct bays. These bays are created by four parallel walls, dividing the space into a central bay and two lateral bays. The central bay, often referred to as the "portego", serves as a large, elongated space that stretches the length of the building, acting as a sort of mezzanine hall or corridor. On either side of the portego are the two lateral bays, which typically house the rooms of the building. This tripartite layout is not merely a spatial arrangement but is central to the "structural stability" of the building.

One of the most significant aspects of this layout is the "differentiation in the thickness" of the foundation stones that support the four walls of the building. The perimeter foundation stones, which are the stones that support the outer walls of the structure, are designed to be much "thicker" and more robust than the foundation stones used for the two interior walls. This variation in thickness is not arbitrary but is dictated by several critical factors related to the environmental and structural forces at play.

The "perimeter foundations" need to be stronger for three primary reasons. First, the "external walls" are exposed to significant "external stresses from water", given Venice's location within a tidal lagoon. The weight of the water and the pressure it exerts against the building requires the perimeter walls to have a much stronger foundation. Second, the perimeter walls often bear the additional weight of the "roof". Unlike the internal walls, which primarily support the internal structure of the building, the outer walls must also carry the load of the roof, making their foundations even more essential to the overall stability of the building. Finally, the perimeter walls form a barrier that encloses the ground on which the foundations for the two central alignments are laid. This barrier serves a dam-like function, helping to enclose the soil within the structure and protect the interior foundations from additional external forces.

Once these foundations are laid, construction of the walls begins. However, this process is not without challenges. As the weight of the building increases, it begins to exert significant pressure on the soil below. This pressure compresses the soil, causing it to expel the water it contains, a phenomenon that becomes more pronounced as the weight increases. In essence, the soil undergoes a kind of metamorphosis, transforming from a soft, pliable substance into something more consistent and compact. This process is crucial because it enhances the stability of the soil, creating a more solid foundation for the structure.

As the walls are built upwards, an interesting phenomenon occurs: the walls begin to taper or become thinner as they rise. This tapering, which creates what are known as uneven walls, is a vital aspect of the building's overall stability. The tapering ensures that the walls lean slightly inward, forming a shape similar to a truncated pyramid. This inward slope is not merely an aesthetic choice but serves a critical structural function.

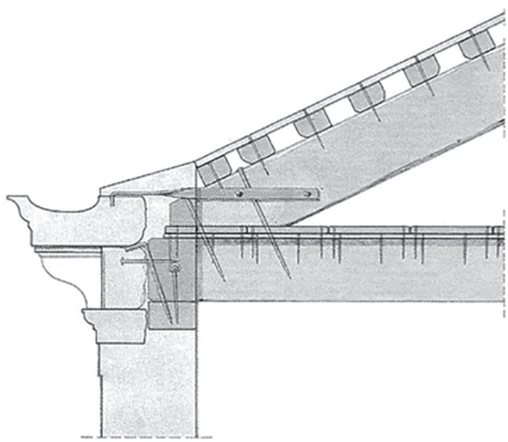
The inward sloping of the walls helps to maintain the static equilibrium of the building. If the walls were constructed with a uniform thickness from the base to the top, the weight of the upper portions of the building would create a horizontal thrust on the foundation stones. This horizontal force would place too much pressure on the perimeter foundations, potentially causing the walls to collapse outward under the force. By tapering the walls as they rise, the Venetians created a structure that directs the force downward, ensuring that the load is transferred vertically rather than horizontally. This design feature is especially important in a city like Venice, where the soft, waterlogged soil would be unable to support the additional horizontal stresses of uniformly thick walls.

The combination of these structural techniques—the tripartite wall system, the differentiated foundation stones, and the tapering of the walls—forms the basis for the remarkable durability of Venice's architecture. Despite being built on a challenging and unstable environment, Venetian buildings have remained standing for centuries, thanks in large part to the careful planning and engineering principles that went into their construction.

This architectural approach not only allowed Venice to grow and thrive but also enabled the city to become a living museum of historical buildings, with many structures dating back hundreds of years still intact today. The "muri di spina" system represents a brilliant fusion of form and function, demonstrating how thoughtful engineering can overcome the most difficult environmental challenges to create something both beautiful and enduring.[12]

Iron

Once the "muri di spina" or "thorn walls" were constructed, the next significant challenge in Venetian architecture was to install floors that could bear heavy loads without compromising the overall stability of the building. Venice's soft, waterlogged soil posed unique structural difficulties, as the foundations could shift or settle unevenly. Therefore, the development of a system to handle these weight-bearing floors without creating additional stress on the



In the image: Section illustrating the attachment scheme of the 'plug walls' to the floors.
Image: Mario Piana

12 For a complete notion of the Venetian techniques of building up see: Piana M. (2004). 'Materiali, tecniche, sistemi costruttivi dell'architettura lagunare; problemi di conservazione e di nuova utilizzazione' in: Gallego Roca J. *La Imagen de Venecia en la cultura de la restauración arquitectónica.* Universidad de Granada: Granada: and: Piana M. (2023) Costruire a Venezia. I mutamenti delle tecniche edificatorie lagunari tra Medioevo e Età moderna. Venezia: Marsilio. p. 13-36; Foscari A. (2009). 'La costruzione della casa veneziana' in *Ateneo Veneto. Rivista di scienze lettere ed arti.* anno CXCVI, terza serie, 8u, pp. 161-176

walls was crucial. The introduction of iron into lagoon construction marked a real technological revolution, enabling Venetian builders to construct taller and more resilient buildings.

The use of iron tie rods, chains, restraints, and metal "fiube" (small metal devices used to secure various structural elements) transformed the traditional Venetian building system. This introduction of iron elements allowed for the creation of a flexible yet durable structural framework that was used for at least six hundred years in the construction of most Venetian buildings. These small but crucial devices provided an elastic anchoring system between the thorn walls and the floor beams across multiple levels of the building. Unlike traditional rigid connections, which could lead to fractures in the event of foundation settlement or structural movement, these iron connections allowed the masonry and wooden floor beams to move independently of each other without generating dangerous internal stresses.

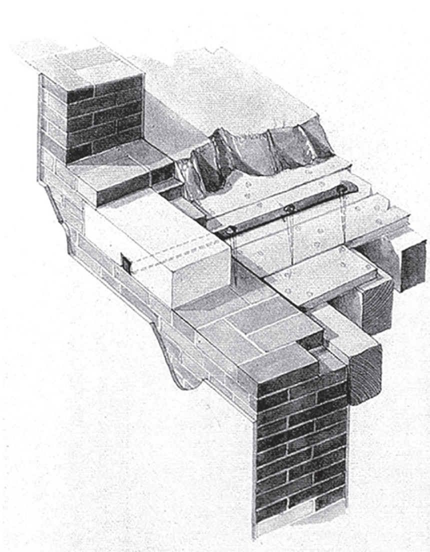
This flexible anchoring system meant that Venetian buildings could better withstand the uneven subsidence often caused by the soft soils below them. The iron tie rods and other metal devices acted as a kind of cushion, absorbing movement while maintaining the overall integrity of the structure. The introduction of iron ties, therefore, made it possible to build taller and more complex structures while ensuring that the foundations could handle both vertical loads from the upper floors and horizontal forces without creating critical points of failure.

This system led to the invention of an entirely new type of structural arrangement in Venetian architecture, one that can be described as a vertical frame. The walls, which acted as full-height piers, were connected to the floors at multiple levels, but in a manner that allowed them to hinge or pivot slightly at these points of connection. This isostatic connection—where walls and floors could move independently—was a necessity due to the dynamic nature of Venice's unstable foundations. The use of iron tie rods and chains allowed for this movement while preventing the walls from collapsing outward or inward.

The isostatic design concept was essential because the masonry projections (the sections of wall that rose vertically through the building) could not be stabilised at their base in the same way as they would be in buildings constructed on solid ground. Therefore, these walls needed to be hinged to the horizontal structures to maintain their stability as the foundation shifted. This created a unique system of free-floating masonry, where the building could move slightly in response to external forces without generating the kinds of stresses that would cause the walls to crack or the building to collapse.

Despite this innovative system, the resulting configuration of Venetian buildings was inherently shaky by conventional architectural standards. The flexible connections, while preventing catastrophic failure, did not provide the kind of rigidity that would be found in a typical building constructed on solid ground. The reliance on iron ties and chains to hold the structure together created a building that was somewhat delicate, where every part of the structure had to be in balance with every other part.

This fragility, however, was compensated for by the redundancy built into the system. Each floor, supported by its own set of beams and iron ties, functioned almost independently from the others. This layered approach allowed each floor to respond to the movements of the foundation and the walls without creating a domino effect of structural failure. If one part of the building settled more than another, the entire structure would adjust itself without transferring dangerous stresses to other sections. This method of construction turned out to be remarkably effective in Venice, where buildings often experience small shifts over time



In the image: Drawing of a link between walls and tie rods.
Image: Mario Piana

due to the constant movement of the lagoon's waters and the soft, compressible soils below.

In addition to supporting the structure, these iron devices also contributed to Venice's iconic architectural aesthetic. The metal chains and tie rods became visible features on the façades of many Venetian buildings, their presence often signified by small decorative plates that helped to distribute the forces evenly. These devices were not hidden away but integrated into the visible architecture, becoming part of the city's unique identity.

This system of elastic anchoring and isostatic wall-to-floor connections ultimately gave Venice the flexibility it needed to survive on unstable ground. By allowing the buildings to "breathe" and move freely, the Venetians managed to create structures that could withstand both the weight of their upper floors and the slow, unpredictable movements of the foundation. The introduction of iron, in particular, was a technological breakthrough that fundamentally changed the way Venetian buildings were designed and constructed. It enabled the city to grow vertically, creating the skyline of grand palazzi, churches, and civic buildings that we see today.

The result of these innovations is a structural scheme unlike any other in the world. It is a delicate balance of forces, with the iron tie rods and chains functioning as the invisible glue that holds the city together. These metal elements, combined with the walls of thorn and the intricate system of floor beams, created a system where buildings are neither fully rigid nor completely flexible. Instead, they exist in a state of balance, adapting to the constant shifts of the ground beneath them while standing tall against the waters of the lagoon.

The introduction of iron elements into Venetian construction enabled the creation of taller, more resilient buildings that could withstand the unique environmental challenges of the city. The use of elastic anchoring systems, which allowed for free movement between walls and floors, was key to ensuring that these structures did not collapse under their own weight or due to foundation shifts. This combination of traditional