

Article

Water Towers as Resilient Hydraulic Infrastructures: Typological Evolution, Construction Techniques and Rehabilitation Strategies

Luisa Lombardo , Manfredi Saeli  and Tiziana Campisi *

Department of Architecture, University of Palermo, Viale delle Scienze Bld 8-14, 90128 Palermo, Italy; luisa.lombardo01@unipa.it (L.L.); manfredi.saeli@unipa.it (M.S.)

* Correspondence: tiziana.campisi@unipa.it

Abstract

Water towers are historically significant hydraulic infrastructures that evolved from simple masonry structures to technologically advanced and architecturally expressive forms. This study presents a typological and material analysis of water towers, focusing on their construction techniques, durability, and potential for adaptive reuse. The research combines visual inspection, archival and bibliographic research, and photographic documentation, of selected European and Italian examples for comparative insights on design and materials choices. Data were collected and organized according to parameters such as construction materials, structural type, tank and roof form, access system, and current function. Assessments were conducted following the UNI EN 16096, providing a structured framework to evaluate heritage value, material conditions, and adaptive reuse potential. Main results demonstrate that water towers, beyond their original hydraulic function, retain significant technical, architectural, and cultural value, offering opportunities for adaptive reuse as cultural, educational, residential, or community spaces. Key findings identify material vulnerabilities, structural challenges (including wind, seismic, and thermo-hygrometric effects), and possibilities for sustainable interventions that respect historical authenticity. The study highlights how systematic typological assessment and documentation can guide evidence-based conservation and support innovative reuse strategies, integrating heritage preservation with urban regeneration and community engagement. Water towers exemplify the intersection of engineering, architecture, and cultural heritage, and their conservation requires a multidisciplinary approach between technical performance, material preservation, and socio-cultural significance. Finally, the implemented procedure is proposed as a methodological framework replicable and scalable for assessing similar infrastructures in other contexts.

Keywords: water towers; industrial heritage; architectural type; adaptive reuse; hydraulic infrastructure; smart rehabilitation



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1. Reframing Urban Infrastructure: Cultural and Spatial Legacy of Water Towers

Elements such as bridges, obelisks, fountains, water towers, vegetation, and building façades are often overlooked in traditional architectural analysis. However, as Bruno Zevi stated in *Saper vedere l'architettura* (1948) [1], these components are central to the spatial and symbolic definition of urban environments. Among these, water infrastructures have historically played a particularly crucial role. Since antiquity, the availability and management of water have been fundamental to the establishment, development, and

survival of human settlements. Civilizations such as the Mesopotamians, Egyptians, Greeks, and Romans devised highly sophisticated systems for water collection, transport, and distribution [2], fostering a rich culture of hydraulic engineering.

Aqueducts, cisterns, wells, canals, and reservoirs not only addressed essential functional needs but also became emblematic elements structuring the physical and symbolic organization of urban space. Water management has historically embodied political, cultural, economic, and identity values [3]. Recently, some international organizations, such as UNESCO, ICCROM, and ICOMOS [4], have emphasized the importance of water infrastructures as part of cultural heritage and traditional knowledge systems [5], including those of local and indigenous communities. Such recognition underscores the need to valorise water towers not only as historical artifacts but also as technical and cultural heritage assets requiring conservation, valorisation, and adaptive reuse.

Analogous solutions to water towers can be observed in other civilizations. The Roman aqueducts, the Ottoman *su terazisi* (water scales) [6], the Indian stepwells [7], the canals in Petra (Jordan) [8], the middle-east qanat [9], etc., and other water distribution mechanisms clearly demonstrate a widespread historical approach to the challenge of managing waters, especially to overcome elevations. More particularly, the concept of vertical water distribution, as the case of the water towers, is both historically significant and globally relevant.

As Tiago Saraiva in 2009 observed, XX century internal colonization projects often integrated technological innovation with landscape modernization within broader political narratives. Engineering, urban planning, and architecture were employed to reclaim and rationalize previously underdeveloped territories, generating settlements that visually and spatially expressed contemporary social and ideological models [10]. From the XIX century onward, rapid urban population growth and industrial expansion increased water demand, leading to the creation of increasingly complex and efficient supply systems [11]. Among the key innovations, water towers, also known as piezometric towers, played a significant role in the distribution of potable water by means of hydrostatic pressure, generated through gravity or pumping systems [12], in accordance with Stevin's Law [13]. These towers stabilized municipal pressure levels, decoupled local supply from mainline fluctuations, and ensured service continuity and sanitary safety.

Originally conceived as purely utilitarian structures, water towers gradually acquired architectural and landscape significance. Their verticality and visibility often transformed them into landmarks across urban and rural areas, embedding them in local identities and collective imaginaries [14]. However, advancements in pumping technologies, pressurized underground reservoirs, and evolving urban logics rendered many of these structures obsolete. Decommissioned and frequently neglected, water towers increasingly occupy marginal positions within the built environment, yet their symbolic potential remains substantial.

In recent years, the growing interest in industrial and infrastructural heritage has renewed attention to these constructions [15]. Hence, nowadays water towers are recognized not only for their technical and historical significance but also for their capacity to narrate the evolution of construction technologies, territorial transformations, and socio-environmental values [16]. Their conservation and adaptive reuse present both technical and conceptual challenges, requiring a sensitive approach that respects intrinsic typological qualities while accommodating new functions [17]. Successful interventions, including conversions into exhibition spaces, residences, hospitality facilities, community centers, artistic installations, or tools for urban regeneration, demonstrate the potential of water towers as a framework for "smart rehabilitation," integrating heritage conservation with sustainability, technological innovation, and contemporary spatial needs (Figure 1). Beyond their functional role, water towers embody significant cultural and technical value, repre-

senting a repository of traditional architectural knowledge, construction techniques, and historical ingenuity, which can inform contemporary design and adaptive reuse strategies.



Figure 1. Bernd and Hilla Becher, *Wassertürme* (Water Towers), Germany, United States, France, Belgium, Luxembourg, 1963–1995—Photographic study of water towers across multiple countries, documenting their industrial forms and typologies.; © Estate of Bernd and Hilla Becher, 1995.

1.1. Aim and Methodological Approach

This study examines water towers across the European territory as an architectural and infrastructural type through an evolutionary and interdisciplinary lens. The analysis focuses on morphological and functional variations, construction materials and techniques, and processes of degradation or preservation associated with disuse. Case studies were selected according to historical relevance, typology, conservation status, and representativeness at regional level.

The methodological framework combines the following:

- Visual inspection of the structures;
- Archival and bibliographic investigation;
- Photographic documentation;
- Typological classification, including construction materials, structural type, tank and roof form, access system, and current function.

No geometric surveys were conducted; however, all observations were organized systematically to ensure reproducibility. Condition assessments were conducted according to recognized standards (e.g., UNI EN 16096 [18]), providing a structured framework to inform conservation strategies [19] and support adaptive reuse. The proposed approach results in a replicable and scalable framework for similar hydraulic infrastructures in other European contexts.

1.2. Research Questions (RQs)

This study aims to restore visibility and value to this frequently neglected category of architectural heritage, highlighting its cultural, historical, and technological significance, and its potential contribution to urban quality, landscape identity, and social memory. The research questions are as follows:

- **RQ1:** How can water towers be valorised as meaningful assets within contemporary urban contexts?
- **RQ2:** Which types of water towers can be identified, and what construction technologies and materials have supported their historical evolution?
- **RQ3:** What are the main challenges in promoting the enhancement and smart rehabilitation of water towers within broader urban regeneration strategies?

By systematically documenting construction techniques, typological features, and material specificity, this study provides a foundation for interventions aimed at integrating water towers into contemporary urban environments, fostering cultural continuity and innovative adaptive reuse. Also, it contributes to the current debate on industrial and infrastructural heritage by proposing a replicable, assessment-oriented framework for the analysis and adaptive reuse of the historical “secondary” asset, integrating typological classification (Figure 2), material performance, structural vulnerability, and socio-cultural value within a single methodological approach.



Figure 2. Mostly Silesian water towers (Poland); © Water Tower Appreciation Society, 2025.

2. From Aqueduct to Water Tower

Throughout history, hydraulic engineering systems for water collection, distribution, and pressure regulation were fundamental in shaping urban and rural settlements. Among the earliest and most emblematic infrastructures, the aqueducts were an extremely complex networks specifically designed to transport water from distant sources to inhabited areas [20]. More particularly, the Roman aqueducts represent a pinnacle of the ancient engineering, combining functional effectiveness with architectural sophistication [21]. These systems relied entirely on the action of gravity: water flowed along carefully calculated gradients, forming a continuous descent that enabled movement without mechanical pumps. They supplied essential public and private functions, e.g., baths, latrines, fountains, and domestic use, while wastewater was evacuated through gravity-fed sewer systems [22]. Constructed using stone, brick, or Roman concrete, aqueducts adapted ingeniously to natural topography, tunneling through hills, traversing valleys with arcades, or following contours of the natural terrain. Pipes made of lead, ceramic, or carved stone conveyed water, while sedimentation basins and cisterns ensured flow regulation and rudimentary filtration [23]. While these systems elegantly met the demands of ancient cities, the pres-

asures of urban growth, industrialization, and increasing population densities, especially from the XIX century onward, required more advanced infrastructures. Water towers emerged as a key innovation, storing and distributing water while stabilizing pressure across municipal networks [24]. Unlike aqueducts, which depended on continuous flow from source to destination, water towers functioned as elevated reservoirs, allowing hydrostatic pressure regulation. Supplied by pumping stations rather than gravity alone, these structures enabled municipalities to decouple water storage from the main network, ensuring reliable service and mitigating pressure fluctuations. Their emergence marked a significant transition: from linear, gravity-based systems to flexible, pressurized networks capable of adapting to modern cities spatial and technical complexities.

This study follows a methodological framework grounded in historical analysis, typological assessment, and comparative engineering study. The selection criteria focused on preserved water towers with complete documentation, prioritizing case studies that allowed a comprehensive analysis of construction techniques, materials, functional types, architectural forms, and current conservation status. Data collection included archival research, field surveys, and technical drawings, while assessment criteria followed UNI EN 16096 [18] for condition evaluation of heritage structures. The proposed methodology enables replication to other regions and establishes a systematic basis for adaptive reuse proposals.

2.1. The First Roman Aqueduct

The Aqua Appia (Figure 3), constructed in 312 B.C., was the first aqueduct for the city of Rome, addressing the city's enormous growing water demands [25]. Engineered with a subtle, continuous gradient of about 2%, it ensured uninterrupted gravity-driven flow [26]. Roman aqueducts were not merely utilitarian infrastructures; in fact, many emerged above ground near urban centers, featuring elegant arcades that became enduring landmarks [27]. Examples like the Pont du Gard (France), the aqueducts of Segovia, Les Ferreres (Spain) illustrate how the Roman engineering extended across the vast territories of its empire and facilitated the transfer of technological knowledge [28,29]. The Aqua Virgo, commissioned by Agrippa in 19 B.C., still continues to feed fountains in Rome, including the Trevi Fountain [30,31]. These ancient systems (Figure 4) demonstrate how topography, material selection, and hydraulic design converged to produce durable, resilient infrastructures. Nonetheless, urban pollution and technological limitations eventually constrained their use, catalyzing the transition to elevated water towers capable of independent pressure regulation and flexible distribution.



Figure 3. The Appia Antica Aqueduct Park; © Italia.it, 2025.

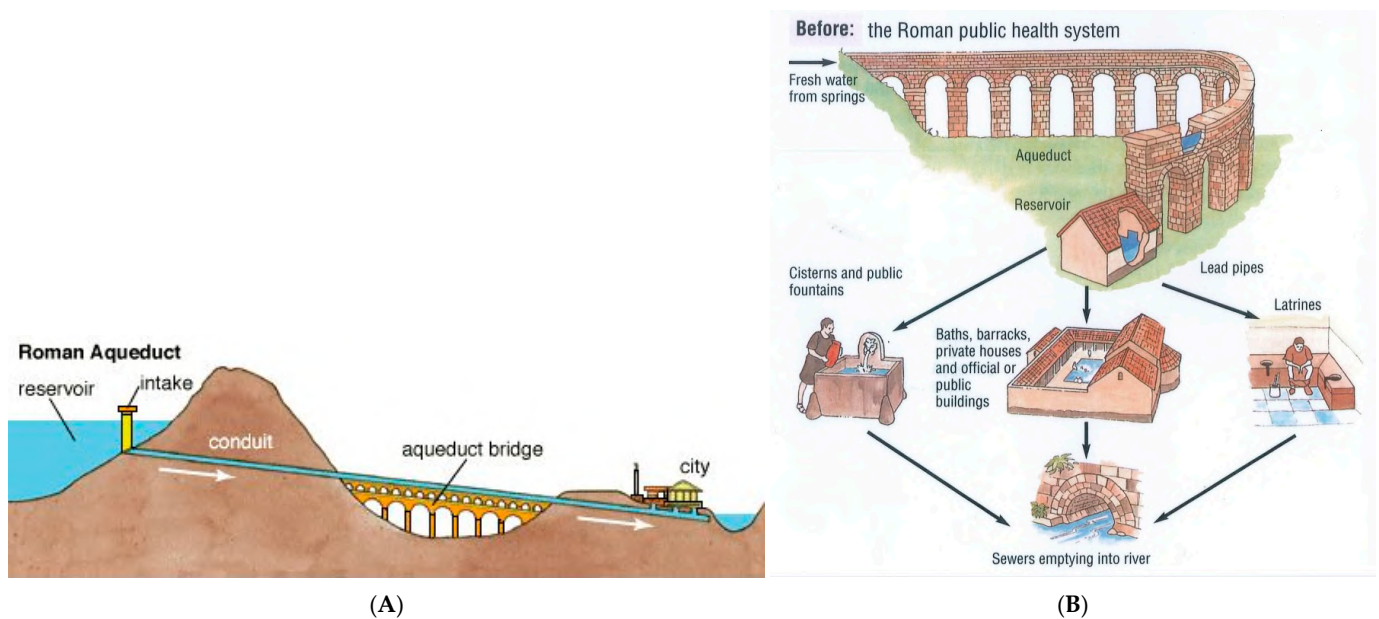


Figure 4. Representation of the Roman water system. **(A)** Cross-section of a Roman aqueduct illustrating the water’s path from the source (intake reservoir) to the city, highlighting the conduit and the arched bridge used to maintain a constant gradient; **(B)** Diagram of the Roman public health system, showing the capillary distribution of water from the urban reservoir to fountains, baths, public and private buildings, through to the final disposal in sewers and rivers; © Wayground, 2025.

2.2. Water Towers: History, Symbolism, and Function

Water towers, also known as elevated reservoirs, are hydraulic structures engineered to distribute water by means of the force of gravity, thereby maintaining consistent pressure across supply networks. Piezometric towers, a subtype incorporating pressurized distribution systems, allow water delivery even to the upper levels of multi-story buildings, facilitated by mechanical pumping stations installed at their base [32].

Initially linked to railway infrastructure, water towers rapidly became symbols of infrastructural modernization, particularly in newly colonized rural areas. In these contexts, they assumed the dual role of functionality and symbolism. Beyond their technical utility, such structures embodied the mastery over natural resources and the transformation of previously uninhabitable or agriculturally marginal lands. The image of water, flowing freely from elevated tanks, served as a potent metaphor for control, productivity, and the civilizing potential of modern technology. Elevating the tank enabled simultaneous water distribution to multiple points with uniform pressure. Typically, water was taken from subterranean wells or sourced via aqueducts, pumped into the elevated reservoir, and then distributed through a pressurized pipe network to urban or rural settlements, ensuring reliable delivery even at higher altitudes or to upper floors [33].

In industrial cities, water towers were commonly positioned near railway stations to meet the operational needs of steam locomotives. In contrast, in rural reclamation and colonization projects, however, they acquired a symbolic dimension linked to the “liberation” of subterranean water intake and, hence, an improved supply availability. Fascist-era propaganda in Italy, for instance, celebrated the conversion of stagnant marshlands into productive territories. Water, once confined underground or locked in unhealthy wetlands, was now raised and made visible, channeled through rectilinear canals or monumental tanks within newly planned settlements [33].

Beyond their functional and ideological significance, water towers provided fertile ground for technical and architectural experimentation. Engineers and architects progressively refined tank geometry, support-shaft design, and structural components to

accommodate specific climatic, seismic, and technological conditions [33]. In several cases, technical elements were intentionally concealed or integrated within heritage or representational architecture. A notable example is the Sforzesco Castle in Milan, where architect Luca Beltrami embedded water reservoirs within medieval-style turrets during restoration, successfully combining infrastructural necessity with heritage aesthetics [34] (Figure 5).



Figure 5. Pressurization system of the Milanese water network at the Sforza Castle. (A) Technical cross-section of the tower situated within the Sforza Castle, detailing the internal structure and the vertical arrangement of the two large storage tanks (labeled A and B) installed in the early twentieth century to ensure adequate pressure across the urban water grid; (B) Historical photograph showing the interior of the pumping station at the base of the tower, featuring the original electric pumps and machinery used to lift water into the elevated reservoirs.; © Milano Today, 2023.

The design of water towers has always been constrained by technical parameters such as location, elevation, tank capacity, and access to energy sources for pumping. Those aspects critically influenced both hydraulic performance and formal configuration. However, these functional requirements did not constrain architectural creativity; rather, they presented opportunities for expressive design. Engineers and architects often exploited these parameters to create visually striking structures that contributed to the identity of urban and rural landscapes [35,36]. Through sculpted envelopes, refined material selection, and carefully curated chromatic palettes, water towers transcended their infrastructural function to become civic landmarks, integrating utility with aesthetic expression.

Technically, water towers operated according to the principles of communicating vessels and hydrostatic pressure [37]. By elevating a water mass above the distribution network, they ensured stable and continuous water delivery, even when mechanical pumps were inactive or demand fluctuated. Unlike seasonal storage tanks, which primarily regulated water volume availability, water towers functioned as hydraulic buffers, absorbing pressure variations and preventing reverse flows or destabilization within the broader system. Their role extended beyond storage, maintaining equilibrium between upstream reservoirs and downstream consumers.

From the XIX century onward, as urban areas expanded and industrialization accelerated, water towers became increasingly essential, particularly in regions with uneven topography or hilly terrain. In those contexts, elevation differences challenged traditional gravity-fed systems, and the integration of piezometric towers enabled more reliable and adaptable distribution strategies. By harnessing fundamental hydrostatic principles within innovative engineering frameworks, water towers established as indispensable components of modern urban water infrastructure [38].

The Work System of Water Towers

Water towers represent prominent infrastructural elements within both urban and rural landscapes, historically conceived to ensure the efficient distribution of water to areas distant from natural or reliable sources. Initially implemented to serve isolated communities, their deployment progressively expanded into complex urban supply networks, guaranteeing consistent water access for domestic, industrial, and infrastructural demands [39]. The primary function of a water tower is to deliver water at controlled and stable pressure. Depending on contextual requirements, towers may operate continuously, serve as emergency reserves during interruptions of supply, or function as expansion buffers to mitigate pressure surges and hydraulic overloads within distribution networks. While the widespread adoption of water towers coincided with the Industrial Revolution, driven by the need to supply large quantities of water to steam-powered industries and rapidly growing urban centers, analogous systems had been previously employed in medieval contexts, such as in Sicily under Arab hydraulic influence [40]. Beyond their industrial and urban utility, water towers played a critical role in supporting the expansion of transportation infrastructure, particularly railways, and in supplying water to regions historically affected by scarcity or drought.

From an engineering perspective, a water tower, or piezometric tower, is fundamentally an elevated reservoir designed to exploit gravitational force and the principle of communicating vessels for water distribution. By storing water at sufficient height, the tower generates the sufficient hydrostatic pressure necessary to serve multiple delivery points across a service area. Tower elevation was typically calculated to meet or exceed the height of the most elevated distribution point of the network, ensuring efficient and uninterrupted flow [41]. From a functional point of view, water towers integrate (1) collection, (2) storage, and (3) distribution logics. Their design was adapted to local topography, service area extent, required water volume, and architectural or symbolic considerations. In many cases, the architectural form is harmonized with the surrounding environmental context, either urban or rural. Technically, the system relies on the ancient principle of communicating vessels, already documented in early Arab hydraulic engineering traditions [42]. Water is generally collected from higher-elevation sources, conveyed via underground conduits, and pumped to the tower summit. Once stored, it flows by gravity through the distribution network, with pressure regulated by the vertical height of the water column (Figure 6). This hydrostatic head determines the system's capacity to deliver water autonomously and evenly, even during demand fluctuations [43]. Interconnected towers enable cascading distribution across geographically dispersed networks, supplying fountains, public buildings, and residential areas with minimal energy consumption. During periods of low demand, pumping operations may be suspended, as gravitational pressure suffices; conversely, during peak consumption, the reservoir functions as a buffer, maintaining consistent outflow rates and preventing abrupt pressure drops (Figure 6).

The operation of water towers balances hydraulic functionality, energy efficiency, and adaptive infrastructure design. Their enduring presence within the built environment testifies not only to technical efficacy but also to their role in shaping the spatial, social, and visual identity of the territories they serve.

To ensure continuous supply, water tower reservoirs were regularly replenished, either to maintain service to lower-elevation distribution points or to supply end users directly. The proximity between the storage tank and served area was critical for maintaining appropriate pressure levels, particularly in networks with variable demand or elevation gradients [44]. Although hydraulic functionality imposed strict engineering constraints, tower exteriors allowed considerable architectural freedom. Over time, this formal latitude

generated diverse stylistic interpretations, reflecting local traditions as well as broader technological ideals.

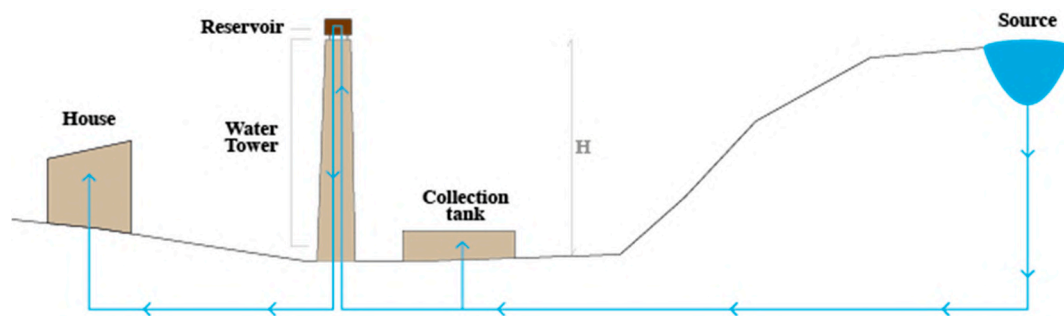


Figure 6. Operating diagram of a water tower: the arrow indicates the direction of water flow from the spring to the water tower and subsequently to the building; © Image by author, 2025.

Originally conceived as utilitarian infrastructure, water towers gradually acquired symbolic significance, becoming visual markers of technological progress, territorial control, and modernity. In certain urban contexts, they remain evocative vestiges of a past era, inscribed in collective memory; elsewhere, they are disused or repurposed relics whose striking forms continue to shape local visual identity. A notable example is the Pontine Marshes in central Italy, where large-scale Fascist-era land reclamation transformed water infrastructure into instruments of political messaging. The “bonifica integrale” (trad: full land reclamation) was framed as a “war” against the hostile and unproductive nature [45,46]. This transformation entailed not only the physical reshaping of the landscape, including road grids, canals, electrification lines, and water management systems but also profound demographic and ideological reordering. Seasonal laborers were replaced by permanent settlers from northern regions, and the rural landscape was redefined as rationalized, industrialized, and productive [47].

In this context, infrastructures such as pumping stations, hydroelectric plants, reservoirs, and water towers assumed powerful symbolic roles, defined by Kaika and Swynge-douw (2000) as “material sanctuaries of progress” [48]: tangible manifestations of the State technological and ideological ambition. Within newly established towns, these structures served simultaneously as utilitarian nodes and monumental expressions of modernity, embodying the regime promise of redemption through infrastructure.

The architectural treatment of water towers further amplified their symbolic and visual impact. Designed to be perceived from a distance, they introduced a sense of monumentality even in small settlements. Through verticality, material articulation, and often centralized placement, towers functioned as reference points within rational urban geometries. Their forms reflected formal clarity and ideological rigor: clean lines, exposed concrete, and symmetrical proportions conveyed ideals of control, hygiene, and order. Beyond the Fascist context, water towers expressive capacity has been acknowledged in various historical settings. In Palermo (Sicily), pre-industrial water towers, locally called “castelletti” (literary trad: little castle, for the presence of the tower recalling such structures), demonstrate a sophisticated hydraulic management system predating modern infrastructure. Integrated within the historical urban fabric, these towers remained operational up the early XX century, distributing water from the surrounding elevated natural springs through systems based on the principle of communicating vessels. Water was conveyed via underground channels, called “incatusati” because they were made of terracotta pipes called “catusi”, to intermediate reservoirs, regulated flow to individual households (Figure 7). Conical and divergent pipe sections enabled precise volumetric calibration, ensuring accurate water distribution across the pre-modern urban environment.

These historical hydraulic systems underscore the enduring relationship between water infrastructure, territorial organization, and urban identity. Whether subtle components embedded in traditional contexts or monumental statements of technological modernity, water towers embody the dual nature of infrastructure: technical and cultural, functional and symbolic.



Figure 7. “Catusi” water tower in Palermo wall (left) and in the Villagrazia suburban neighborhood (right) (Palermo, Sicily); © Image by author, 2025.

Despite the technical sophistication of the Palermo historical water distribution system, two critical challenges faced. The first was vulnerability to theft, arising from hierarchical water sales and unauthorized diversions. The second involved sanitary risks, due to material fragility (e.g., unglazed terracotta pipes) and potential external contamination through infiltrations and breaches. With technological innovations and evolving public health standards in the early XX century, these limitations became increasingly evident, leading to gradual decommissioning of the *castelletti* system, officially terminated in 1914 under municipal decree. Nowadays, 19 towers survive within Palermo, some retaining original brick construction, others modified during the Liberty period with decorative additions or integration into adjacent buildings. These structures represent a rich technical, architectural, and cultural heritage, offering insights into the city historical relationship with water, infrastructure, and social organization. Their distribution, typological diversity, and construction techniques provide unique opportunities for interdisciplinary study, bridging architectural history, engineering, urban studies, and sustainable water management. As silent witnesses to centuries of hydraulic ingenuity, the Palermo water towers exemplify both achievements and fragilities of the pre-modern infrastructure, while inviting for contemporary reflection on heritage preservation and adaptive reuse.

2.3. Construction Types of Water Towers

The construction of water towers is founded upon a relatively straightforward yet effective structural logic, consisting of two primary components: the shaft, or supporting structure, and the head (reservoir enclosure). The shaft is designed to include internal access systems, such as staircases, ladders, or service ducts, and is aimed at elevating the water tank to the necessary height to generate hydrostatic pressure. In certain historical examples, heating systems were also incorporated to prevent freezing during winter, ensuring a continuous functionality. The head accommodates and protects the water reservoir, shielding it from external weather conditions and providing access for inspection, maintenance, and repair. While the primary function of water towers is utilitarian, many

historical examples housed advanced technical equipment, reflecting the engineering innovation of their era.

Early reservoirs were typically small and constructed from wood; however, with increasing demand and technological progress, they evolved into larger riveted steel tanks capable of withstanding higher pressures and storing greater volumes of water. A notable development was the Intze-type tank, patented in 1883 (Figure 8).

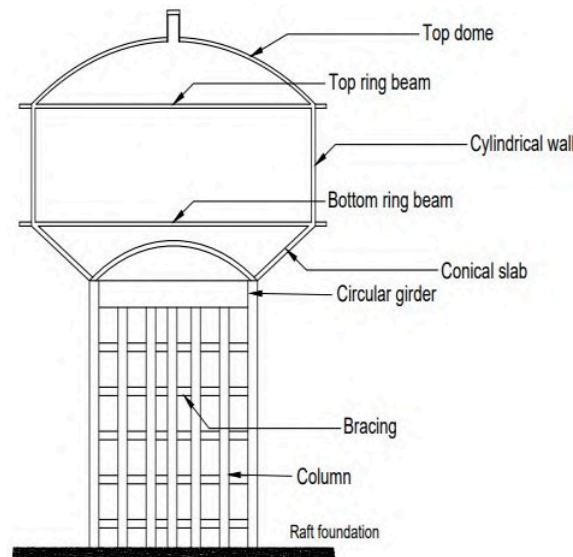


Figure 8. Intze Type Tank— Illustration of an Intze-type water tank showing its main structural components. The conical top dome and the bottom spherical dome contribute to the redistribution of stresses, reducing lateral thrust on the walls and allowing for thinner sections and lower reinforcement requirements; remastered from ModernCivilians, 2022.

This cylindrical design minimized wall stress by distributing loads in a more efficient way, permitting slimmer support shafts and a reduced footprint. By narrowing the shaft relative to the reservoir diameter, the Intze model also allowed for increased structural flexibility, beyond aesthetic instances. Geometrically, most towers were built on circular or polygonal plans, with conical or slightly tapered shafts and cylindrical or domed heads, optimizing structural stability while minimizing material use. Their operation relies exclusively on gravity: water was pumped from the supply source, wells, aqueducts, or reservoirs, into the elevated tank, which subsequently distributed water through the network without constant energy supply.

During the 1920s and 1930s, modernist architects began reinterpreting water towers as “metaphysical solids”, isolated yet expressive volumes establishing a visual dialogue with the surrounding landscape. Architect Angiolo Mazzoni, for example, treated the water tower not merely as a utilitarian object but as an urban marker that enhanced the spatial experience of the city (Figure 9) [49,50].

The formal clarity and verticality of these structures imbued them with monumental significance, particularly when integrated into civic or infrastructural complexes. In towns of the Agro Pontino, including Latina, Sabaudia, Pontinia, and Pomezia, water towers were deliberately positioned in strategic points useful to articulate the urban layout, often serving as focal points aligned with main roads, squares, or axes. In Pomezia, for instance, the tower functioned both as a civic landmark and a functional reservoir, addressing infrastructural requirements while embodying architectural symbolism. While in Sabaudia and Pontinia, towers were designed with monumental proportions, visible from multiple vantage points, reflecting the modernist ethos of rational planning and technical order.

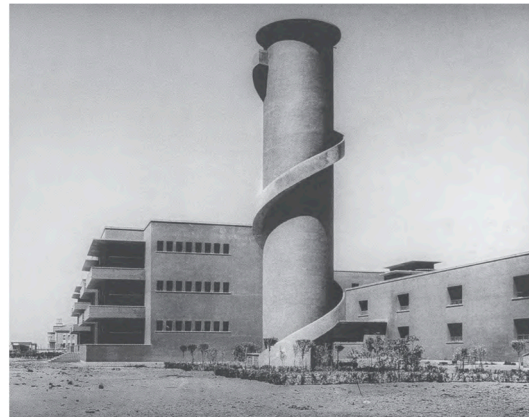


Figure 9. Angiolo Mazzoni, 1925–33: seaside colony at Calabrone (Livorno), water tank and dormitories (image from Aa.Vv., “Angiolo Mazzoni Architetto ingegnere del ministero delle telecomunicazioni”, Skira, Milan 2003, p. 63).

Water towers can be categorized into three principal types according to their intended function and users: (i) municipal towers serving residential neighborhoods and public services; (ii) railway towers supplying steam locomotives and station facilities; and (iii) industrial towers supporting factories, manufacturing plants, or hospital complexes. Early examples date back to the late 19th century, many of them are now recognized as heritage assets due to their architectural and historical significance. While some towers were bespoke designs, many followed standardized types, particularly in railway infrastructure. The so-called “mushroom” type, characterized by a conical corps and cylindrical reservoir, became widely adopted across Europe, reflecting a shared engineering culture and transnational aesthetic.

Architectural elements often mirrored contemporary stylistic trends. Late 19th-century structures exhibited neo-Gothic details such as brick cornices, ornamented portals, and rosettes (Figure 10), while towers constructed in the 1920s–1930s embraced modernist principles, featuring minimalist forms, reinforced concrete, and rejection of applied decoration. Municipal towers were frequently more elaborate and expressive than railway towers, highlighting their dual role as infrastructure and civic monument.

Water towers may be freestanding or integrated into larger architectural complexes, depending on function and context. Early examples were predominantly isolated, particularly in rural settings, supplying water to farms, irrigation systems, and rural settlements. In some historical examples, integration into existing structures was deliberate. In Palermo, for instance, several towers, “castelletti”, were incorporated into the historic city walls (Figure 11), exploiting pre-existing elevation to reduce structural height, minimize material use, and simplify construction. Embedding towers into fortified or civic structures ensured functionality and spatial economy in dense urban environments. From the late 19th century onward, urban integration became increasingly common, with towers supporting domestic supply networks, industrial installations, public institutions, and municipal infrastructures, reflecting the increasing complexity of urban systems.

Material selection also evolved over time. Early towers were constructed using locally sourced stone, such as limestone prized for availability and workability [49], often employing progressively smaller blocks toward the top to optimize load distribution and structural stability [50]. Most modern construction methods introduced reinforced concrete and steel, enabling lighter, modular, and prefabricated structures adaptable to diverse contexts. In some cases, the reservoir was integrated into the tower body; in others, it consisted in a separate elevated volume supported by slender pylons or sculptural frames. Access systems evolved from external ladders to internal spiral staircases, combining functional

necessity with architectural refinement. Consequently, water towers transcended utilitarian purposes, becoming symbolic and decorative elements embodying progress and modernity.

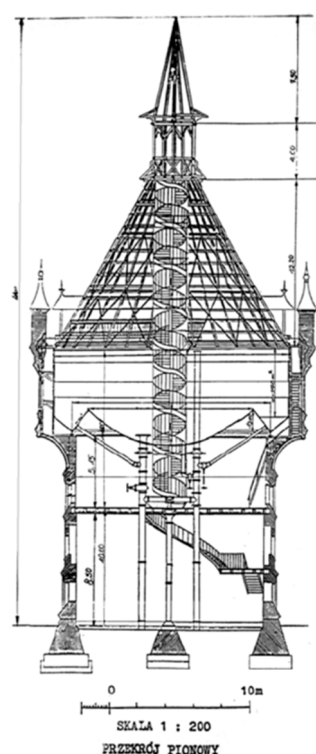


Figure 10. Section through Bydgoszcz urban water tower on Filarecka Street. Water tower with one of the biggest Intze II type tanks (capacity 1260 m³). Source: Archive of the Regional Conservator of Historical Monuments in Toruń.



Figure 11. Detail of the small towers (castelletti) integrated into Palermo's historic city walls. © Image by author, 2025.

Morphological diversity reflects structural, functional, and aesthetic considerations. Circular bases were structurally efficient, while square or rectangular plans facilitated urban integration, and polygonal configurations balanced stability with visual distinctiveness, providing elegant transitions between base and tank (Figure 12).



Figure 12. White Arkitekter's Våga water tower in Varberg, Sweden, is a striking 187 m-long (614 ft) concrete structure designed to supply drinking water to nearby villages while serving as an architectural landmark. © Joacim Winqvist, Anna Kristinsdóttir, 2024.

Despite stylistic, temporal, or geographical differences, all water towers share core components: an elevated load-bearing structure, summit reservoir, water intake and discharge systems, and mechanisms for monitoring water level and pressure. Variability exists around this core (in materials, construction techniques, access configuration, waterproofing, and maintenance) reflecting adaptation to specific technological, climatic, and cultural contexts.

Water towers exemplify the integration of hydraulic engineering and architectural design, where functional necessity intersects with technological innovation and aesthetic expression. Their evolution mirrors broader transformations in urban planning, infrastructure development, and societal values, making them enduring witnesses to landscape change and the ambitions of the societies that built them.

2.4. Water Towers in Railway Infrastructure

Within the context of railway engineering, water towers, often referred to as piezometric towers, played a pivotal role in the operation, logistics, and efficiency of rail transport during the steam locomotive era [51]. These infrastructures were indispensable for the continuous supply of water to locomotives, stations, and maintenance depots, thereby sustaining both the operational reliability and punctuality of railway services [52]. Their distribution closely followed the expansion of national and transnational railway networks, establishing as ubiquitous features at strategic points, including major junctions, terminal stations, engine sheds, and steep-gradient sections where uninterrupted water access was essential. Railway facilities equipped with dedicated locomotive depots or halting areas typically included at least one water tower as a core component of their infrastructure.

Over time, the architectural and structural design of railway water towers evolved alongside technological advancements and the standardization initiatives undertaken by different railway companies. Early examples frequently featured metal tanks, either cylindrical or prismatic, supported on masonry bases, iron columns, or timber trusses. Water was delivered to locomotives via movable tubular arms, commonly known as fillers or swing spouts, which connected the elevated reservoir to the locomotive tender. By the late 19th century, towers situated in prominent urban or passenger-facing locations were increasingly architecturally refined, occasionally adopting hexagonal floor plans or incorporating decorative elements inspired by Art Nouveau aesthetics. In the early 20th century, the Italian State Railways (Ferrovie dello Stato) introduced standardized cylindrical models characterized by expanded tank diameters, truncated conical roofs, and an overall emphasis on functionality, modularity, and formal cohesion throughout the national network [53].

More recent constructions, particularly those serving industrial complexes or modernized railway supply systems, typically adopt the “mushroom” configuration, comprising a wide tank supported by a slender vertical shaft. These structures were commonly built using pre-stressed reinforced concrete or steel, ensuring compliance with contemporary standards for structural efficiency, seismic performance, and durability [54]. Functionally, railway water towers were designed to store and deliver substantial water volumes with minimal delay. Tanks were generally refilled by gravity through high-capacity pipelines equipped with isolation valves, though mechanical pumps were occasionally installed at the base to accelerate replenishment. Water outlets were directed to movable hydrants, allowing direct refilling of locomotive tenders. Float-operated level indicators, frequently mounted externally, provided real-time monitoring of water levels, guaranteeing efficient and uninterrupted operation (Figure 13).



Figure 13. Water tower at Monopoli Railway Station; © Bari Inedita, 2016.

The study, documentation, and preservation of railway water towers constitute a crucial link between historical engineering practices and contemporary challenges in sustainable water management. These structures offer insights into past technological solutions while providing guidance for modern infrastructure resilience, energy efficiency, and adaptive reuse. Their conservation not only safeguards tangible industrial heritage but also facilitates the integration of traditional hydraulic knowledge into current standards for water resource management, highlighting their continuing technical and cultural relevance [55].

3. Materials and Methods: Evolution of Materials and Constructive Techniques of Water Towers

This study adopts a typological, material, and functional approach to analyze historical water towers, with the aim of supporting their conservation and adaptive reuse. The research focuses primarily on the water towers in Palermo, Italy, as representative case study, while selected examples from Europe provide comparative insights on type, material choices, and design solutions.

3.1. Research Objectives

The main objectives are to

- Identify and classify water towers according to constructive type, materials, tank form, roof type, and access system.
- Assess the current structural and material condition, highlighting vulnerabilities and maintenance needs.
- Evaluate the potential for adaptive reuse, considering architectural, functional, and environmental criteria.

3.2. Sampling and Selection Criteria

Water towers in Palermo were selected based on their historical significance, preservation state, and accessibility. In total, 19 towers were surveyed. Comparative cases from the UK, the Netherlands, Slovenia, the Czech Republic, Denmark, and Italy were selected based on their historical relevance, diversity of materials, and adaptive reuse examples.

3.3. Data Collection

Data collection involved a combination of archival research, on-site surveys, photographic documentation, and technical measurement. Historical documentation provided information on the original design, construction materials, and functional evolution of the towers. On-site inspections included detailed observations of masonry, concrete, steel, timber, and composite elements, as well as the assessment of tank and roof conditions, access systems, and environmental exposure.

3.4. Data Analysis

Collected data were organized into a typological assessment table, including parameters such as construction material, wall type, tank shape and volume, roof system, access type, date of construction, current function, and state of conservation. Condition assessments were conducted following UNI EN 16096 standards, enabling systematic evaluation of material degradation, structural stability, and vulnerabilities related to wind, seismic, and thermo-hygrometric stresses.

3.5. Adaptive Reuse Evaluation

Potential adaptive reuse strategies were evaluated based on tower morphology, volumetric configuration, accessibility, structural capacity, and integration with the surrounding urban or rural context. Opportunities for cultural, educational, residential, or community functions were identified, considering minimal interventions that respect architectural identity and historical integrity. Environmental sustainability aspects, such as embodied energy savings and potential for renewable energy integration, were also considered. This methodological framework provides a replicable and systematic approach for the assessment of historical water towers, supporting evidence-based conservation and adaptive reuse strategies that integrate structural, material, and cultural considerations. The following sections apply this methodological framework to the nineteen water towers of

Palermo, and selected European examples, providing a systematic typological, material, and functional analysis. The results, discussed in the following section, directly derive from the typological, material, and functional assessment framework outlined in Section 3, allowing a structured interpretation of structural performance, material vulnerabilities, and adaptive reuse potential.

3.6. Material Analysis and Vulnerabilities

Water towers reflect a long evolution in construction materials and building techniques from the 18th century onwards. In this section, material selection, assembly methods, and detailing are investigated, rather than purely structural or hydraulic behavior.

Early towers (18th–19th centuries) were built as load-bearing masonry structures, using locally sourced stone, limestone, or brick. Circular or polygonal plans were common, facilitating masonry assembly and enhancing durability. Wall thickness typically decreased with height: large blocks at the base provided stability, and smaller ones above formed a tapering shaft. Masonry often displayed detailed tooling, coursing, and decorative elements reflecting craftsmanship and, at times, social status [56].

Roofs and tank housings were generally timber framed, sometimes overlaid with metal sheeting for waterproofing. Timber elements employed traditional joinery techniques such as mortise-and-tenon, pegged connections-and layered planking for tank floors. Access was usually via external ladders, although in towers built for wealthy patrons or in more monumental settings, internal spiral staircases were included, underlining advanced material use and aesthetic care [57]. Hydraulic waterproofing in historic towers was achieved layering hydraulic mortars, additive-modified plasters, or lead/zinc sheeting in wetted surfaces, demonstrating early awareness of material-environment interaction and durability. With the Industrial Revolution, steel and iron became predominant, enabling lighter, modular, more rapidly assembled towers. Tanks became cylindrical or prismatic, supported by steel lattice frames; tank fabrication evolved from riveted or bolted plates to welded shells. Corrosion protection was provided by galvanization, industrial paints, and epoxy coatings [58]. The early 20th century saw the adoption of reinforced concrete, allowing slender shafts and larger reservoirs. Concrete mixes often included Portland cement, water-reducing admixtures, and crystalline waterproofing mortars. Construction techniques stressed proper formwork (shuttering), compaction, and curing to maximize material performance. Iconic “mushroom” shaped towers, with truncated-conical or lenticular tanks on tubular stems, became common in many regions, marrying experimental structural forms with modern material applications [59].

Lightweight solutions included timber trestle towers with stave-built tanks bound by steel hoops, particularly in rural or less permanent contexts. In more modern times, composite materials such as glass-reinforced polymers (GRP) have been used for modular, corrosion resistant, faster installation structures. However, GRP and similar materials demand careful detailed design due to thermal expansion, UV degradation, and joint integrity issues [60].

Each material carries specific vulnerabilities relevant for conservation:

- **Masonry:** cracking, local crushing, freeze–thaw damage, rising damp, salt crystallization, detachment of waterproof coatings.
- **Timber:** warping, fiber compression, fungal or insect attack, UV degradation.
- **Steel/Iron:** localized or general corrosion, fatigue, galvanic action.
- **Reinforced Concrete:** carbonation, cracking, joint leakage.
- **Composites (e.g., GRP):** microcracks from thermal shock, UV exposure, joint failures.

Understanding these is essential for restoration and preservation strategies that preserve material authenticity, compatibility, and durability. Restoration should be based on

thorough analysis of original materials, environmental exposure, and performance over time. This chronological and material-focused analysis shows the transformation of water towers from simple masonry constructions to technologically advanced and architecturally expressive structures. By comprehending material composition, assembly methods, and behavior under environmental stressors, conservation interventions can be designed to respect historical fabric while enhancing longevity and resilience [61].

The evaluation of water towers, based on the UNI EN 16096, provides a systematic approach to assess their heritage value, structural conditions, and adaptive reuse potential. This framework enables the translation of qualitative observations into a comparative, standardized analysis, facilitating the identification of appropriate conservation and reuse strategies. Table 1 presents a summary of the key criteria applied to the case studies, including construction materials, morphology, original function, heritage significance, vulnerabilities, and potential interventions.

Table 1. Application of the UNI EN 16096 Heritage Assessment Framework to historical water towers.

UNI EN 16096 Assessment Phase	Description According to the Standard	Application in This Study	Evidence from the Water Towers Case Studies
Identification of the heritage asset	Definition of the asset, its physical boundaries, and contextual setting	Identification of historical water towers as infrastructural heritage assets with architectural, material, and landscape relevance	Location, construction period, original function, urban or rural context
Analysis of heritage values	Assessment of cultural, architectural, technical, and social values	Evaluation of water towers as industrial heritage combining functional, symbolic, and typological values	Typological classification, historical role in water supply systems
Assessment of physical condition	Evaluation of material conservation state and structural integrity	Systematic survey of masonry, concrete, steel, timber, and composite elements	Material degradation, cracking, corrosion, moisture-related damage
Identification of vulnerabilities and risks	Recognition of factors affecting durability and safety	Identification of risks related to aging materials, environmental exposure, seismic, and wind actions	Roof deterioration, tank waterproofing issues, access system deficiencies
Evaluation of compatibility of interventions	Assessment of potential impacts of proposed actions on heritage values	Analysis of adaptive reuse potential based on morphology, accessibility, and structural capacity	Feasibility of cultural, educational, residential, or community reuse
Decision-support for conservation and reuse	Support for informed conservation and management strategies	Definition of evidence-based guidelines for conservation and adaptive reuse	Minimal and reversible interventions, material compatibility strategies

3.7. Application of the UNI EN 16096 Heritage Assessment Framework

The assessment of historical water towers provides a systematic and replicable framework to evaluate heritage condition and adaptive reuse potential. This framework provides clear phases for identifying, analyzing, and managing cultural assets, allowing a rigorous interpretation of material, structural, and functional characteristics. In this study, UNI EN 16096 has been adapted to the specific features of water towers, supporting both the evaluation of their state of conservation and the exploration of adaptive reuse potential.

To systematically compare the selected water towers, the key assessment criteria are summarized in Table 1. This allows a clear and structured overview of materials, morphology, heritage significance, structural condition, vulnerabilities, and adaptive reuse potential for each case study.

Following the methodological framework, the subsequent analysis involves the assessment phases of each selected water tower. For consistency and comparability, the same criteria—identification, heritage values, physical condition, vulnerabilities, and adaptive reuse potential—are systematically applied across all case studies. This methodology allows a structured evaluation of material, types, structural integrity, and functional characteristics, while providing a basis for cross-regional comparison. The tables presented in the following sections summarize the findings for both Italian and European water towers, demonstrating how the framework supports evidence-based conservation and adaptive reuse strategies. The systematic presentation of these elements facilitates a direct link between the technical-material analysis and the exploration of possible adaptive reuse strategies. By applying the same evaluation criteria across all the towers, this study ensures consistency, comparability, and evidence-based guidance for future conservation interventions.

4. Water Towers Around the World

Water towers constitute a global architectural and engineering phenomenon, reflecting both the technical management of water distribution and, increasingly, the cultural identity of the territories they serve(d). Initially designed to provide constant hydrostatic pressure and reserve capacity for potable water, over time these structures acquired aesthetic, symbolic, and historical significance, becoming recognizable landmarks in both urban and rural contexts. From early stone and brick constructions to modern reinforced concrete and steel towers, the evolution of materials and constructive techniques allowed a fusion of functionality and architectural expression. Nowadays, many water towers are valued not solely for their utilitarian purpose but also for their heritage and cultural importance. This study focuses on European and Italian examples, highlighting how local construction traditions, material availability, and regional design approaches shaped the towers form and function, while considering adaptive reuse strategies compatible with original materials and contemporary needs. The selected case studies do not aim to provide an exhaustive overview of water towers worldwide, but rather representative samples of different construction periods, materials, structural types, and adaptive reuse outcomes, enabling comparative insights across diverse European contexts.

Taken all together, the proposed selection highlight recurring relationships between construction materials, tower morphology, accessibility, and reuse strategies, confirming the relevance of typological and material analysis as a basis for evidence-based conservation and rehabilitation decisions.

4.1. Water Towers in Europe

4.1.1. England, UK—Aldeburgh Water Tower (Suffolk) and Appleton Water Tower (Norfolk)

The Aldeburgh Water Tower [62] (Figure 14), located in Suffolk and classified as a Grade II listed building, was constructed in 1870 as part of the town municipal water supply system. Measuring approximately 22 m in height, the structure is a typical example of Victorian industrial architecture, characterized by robust red-brick masonry, cast-iron tank components, and functional ornamentation. In the early 21st century, the tower was subject to a sensitive adaptive reuse project, transforming its use into a private residential dwelling. The intervention maintained the architectural integrity of the original envelope while integrating modern amenities and interior spaces. This project demonstrates how

disused water towers can be successfully rehabilitated, not merely preserved as static monuments but reimagined for contemporary living, balancing heritage conservation with modern functionality.



Figure 14. Priors Hill Road, Aldeburgh—England. © Savills, 2025.

The Appleton Water Tower [63] (Figure 15), situated on the edge of the Sandringham Estate in Norfolk, was constructed in 1877 to supply a consistent and pressurized water source to the royal residence. Designed by engineer James Manserghin in a neo-Byzantine architectural style, the nearly 18 m tall tower contains a cast-iron tank with a capacity of approximately 145,000 L. Notably, the structure includes a viewing room and panoramic terrace, originally intended for the royal family's exclusive use to enjoy vistas of the surrounding countryside. That was an unusual feature for a utilitarian structure, reflecting the tower's dual function as both infrastructure and architectural folly. The Appleton

tower was also restored and adaptively reused, further exemplifying the potential for such structures to be reintegrated into contemporary use without sacrificing their cultural or historical significance.



Figure 15. Appleton Water Tower; © The Landmark Trust, 2025.

Together, these examples underscore the diverse roles water towers can play in modern heritage conservation, combining technical, architectural, and symbolic values within broader narratives of reuse and sustainability.

4.1.2. Netherlands Amsterdamsestraatweg Water Tower (Utrecht) and Brežice Water Tower (Slovenia)

The Amsterdamsestraatweg Water Tower in Utrecht, the Netherlands [64] (Figure 16), was built in 1916 by the Utrechtsche Waterleiding Maatschappij and designed by architect W.K. de Wijs in the Amsterdam School style. Rising to a height of 42 m, the tower originally contained a 1000 m³ drinking water reservoir and was the fourth water tower constructed to serve the expanding urban population during the early 19th century. After being decommissioned in 1986, the tower experienced a period of neglect and disuse. However, adaptive reuse efforts in 1989, followed by more extensive works in 2020, led to its transformation into a mixed-use facility, incorporating residential units and public spaces while carefully preserving the tower's distinctive architectural character. This project exemplifies the successful integration of industrial heritage into contemporary urban life, respecting

both historical significance and modern functionality. Today, the tower holds the status of a *rijksmonument* (listed state monument), underscoring its cultural and architectural value within the broader narrative of water infrastructure in Dutch urban development.



Figure 16. Architecture firm transforms Utrecht Water Tower into luxurious apartments; © Zecc Architecten | Stijn Poelstra, 2023.

The Brežice Water Tower, located in the town of Brežice [65] (Figure 17), Slovenia, was constructed in 1914 as an integral component of the municipal water supply system. Rising to a height of 46 m, the tower exhibits a cylindrical base surmounted by an octagonal upper section housing the water reservoir and crowned with a pyramidal roof. The reinforced concrete tank measures 6 m in both height and diameter, with a capacity of 160 m³, and was fed by a reservoir situated approximately 3 km from the town center. Serving the community until 1983, the tower remains one of the most prominent examples of early 20th century Slovenian hydraulic engineering. Its significance is symbolically enshrined in the town coat of arms, reflecting its civic and technical importance. Following a period of abandonment, the tower underwent a series of transformations aimed at revitalizing its historic and functional identity. Initially, in 2001, the lower levels were adapted to house a restaurant under a long-term lease agreement. Subsequently, comprehensive restoration and adaptive reuse initiatives were undertaken, culminating in the full renovation of the structure as part of the Posavje Museum Brežice. Nowday, the tower serves as a museum dedicated to the history of water supply technology, presenting the evolution of water infrastructure in the region through both original objects and carefully crafted replicas. The seven floors of the tower are designed to engage visitors with interactive exhibits that illustrate technical innovations, the interplay between nature and culture, and the social significance of water. The former water tank at the apex of the tower has been transformed into a panoramic viewpoint, offering 360-degree vistas of Brežice and its surrounding landscape. Two drinking fountains, located at the entrance and on the sixth floor, allow guests to directly experience the local water. An adjacent pavilion functions as a visitor centre, information point, café, and educational space, hosting workshops and model-building exercises suitable for both children and adults.

This transformation exemplifies how historic water towers can be successfully reactivated through thoughtful conservation and adaptive reuse strategies, combining technological heritage with cultural revitalization. By interpreting both the technical and social narratives of water, the Brežice Water Tower fosters public engagement, heritage education, and the promotion of sustainable water practices. Its inclusion in the UNESCO Intergovernmental Hydrological Programme (IHP) endorsed Global Network of Water Museums (WAMU-NET) situates the tower within a wider international framework, promoting a

“new culture of water” and demonstrating the potential of historic infrastructure to serve as a catalyst for cultural, educational, and community-oriented initiatives.



Figure 17. The Posavski Museum Brežice/Water Tower—Brežice, SLOVENIA; © UNESCO, 2025.

4.1.3. Vinohrady Water Tower (Prague, Czech Republic) and Jægersborg Water Tower (Copenhagen, Denmark)

The Vinohrady Water Tower [66] (Figure 18), a neo-Renaissance landmark in Prague Vinohrady district, was constructed in 1882 by architect Antonín Turek under the Royal Town of Vinohrady. Its original function was to supply water to several Prague districts, including Strašnice, Žižkov, and Vršovice. The highest, seventh floor housed a tank with a capacity of 200 m³, initially fed from the Vltava River and, after 1912, from the Káraný water station. The tower ceased its hydraulic function in 1962 and was subsequently converted into apartments and offices. In 1991, it was designated a National Cultural Monument, although it has remained vacant and deteriorating in recent years.



Figure 18. Vinohrady Water Tower (on the **top** side); © Tripadvisor, 2025 and Jægersborg Water Tower (Copenhagen, Denmark) (on the **down** side); © Danish Architecture Center, Jens Markus Lindhe, 2006.

A major redevelopment, named Hydropolis, is underway to transform the tower into a water education center. The project will convert one underground tank into an exhibition space while reconnecting the other to Prague water supply. The seven floors will educate visitors about water management, and the roof will become a viewpoint over the city and the surrounding countryside. The centre will also include a conference hall for 150 participants and public relaxation areas with water features. The reconstruction, costing approximately CZK 450 million (about EUR 18 million), was scheduled to begin in September 2025, with the public opening anticipated by mid-2026. The project underscores Prague's commitment to sustainable water management and climate adaptation, while preserving the tower historic and technical heritage.

The Jægersborg Water Tower, designed by architect Edward Thomsen and completed in 1955, became a landmark in the rapidly growing post-war Jægersborg district. Positioned on a hill, the 45 m high reinforced concrete structure features a characteristic 3 m weathervane. The tower tank holds 2000 m³ of water, and its original design included nine floors beneath the tank. Due to acoustic concerns, the lower three floors were initially used as a youth club, while the remaining floors served as municipal and civil defense storage. In 1973, the tower gained notoriety when the Blekingegade Gang stole machine guns from the civil defense depot within the building. In 2006, the tower underwent a major renovation by Dorte Mandrup Arkitekter, converting the top five floors into affordable youth housing. The redesign introduced distinctive bay windows and three exterior terraces to break the cylindrical shape and improve natural lighting. Communal spaces were created in the tower's core, while the original youth club continued to operate on the lower three floors. The project demonstrates a successful adaptive reuse of a technical water infrastructure, combining residential, social, and historic functions while preserving the architectural identity of the tower.

4.2. Water Towers in Italy

Rome—EUR Piezometric Tower (“The Mushroom”, “Il Fungo”) and Budrio (Bologna) Budrio Water Towers

Known as “The Mushroom” (in Italian *Il Fungo*) [67], this piezometric tower (Figure 19) was constructed between 1957 and 1959 by the architect Roberto Colosimo, in collaboration with Sergio Varisco, Aldo Capozza, and Antonio Martinelli. It was planned to collect water from the nearby lake in the EUR neighborhood (Laghetto dell'EUR), supplied by the Cecchignola aqueduct, and redistribute waters to the gardens of the district. In 1961, the famous singer, the tenor Mario Del Monaco, decided to establish a luxury panoramic restaurant atop the water reservoir. The restaurant was designed by architect Lorenzo Monardo and operated by the Rosa family. Project modifications included outward-projecting windows to increase the interior space of the dining area. The restaurant was inaugurated on 20 January 1964 with a grand gala evening and quickly became one of the most exclusive venues of the 1960s and 1970s. In addition to the rooftop restaurant, the Fungo also housed a ground-floor bar. At the same time, a framework of scaffolding pipes was installed on the roof to host advertising spaces.

The Water Towers of Budrio, located in the heart of the town, are a cultural landmark and an example of industrial heritage. Originally part of the city aqueduct system built in 1912, the towers were fully redeveloped between 2006 and 2009 following the award of the “Centocittà Prize” by the Compagnia di San Paolo Foundation, which promotes creative and functional reuse of historic public buildings. Today, the towers work as a multifunctional cultural center, hosting exhibitions, concerts, theater performances, conferences, and educational activities. Their interiors feature varied volumetric spaces, including the notable “Octagonal Hall”, allowing flexibility for diverse events. The design blends modern materials, e.g., glass, wood, iron, exposed concrete, and water features, creating

a unique and evocative atmosphere. Large terraces complement the indoor spaces for recreational use during events. The Water Towers represent the successful transformation of an industrial architecture into a contemporary cultural hub, serving the community while preserving the historical identity of the town of Budrio.



Figure 19. Eur Piezometric Tower (“Il Fungo”) (on the left size) and Budrio (Bologna) Budrio Water Towers (on the right size), © Wikimedia Commons, 2021.

5. Water Tower as Technical and Cultural Heritage Asset

Beyond their historical function, water towers possess significant landscape and cultural value. Designed to provide adequate water pressure to local aqueducts, these structures are typically elevated, with common “mushroom” structures reaching heights of at least 15 m, with the tallest examples exceeding 50 m. These dimensions, strictly dictated by functional requirements, contribute to the towers visibility across the territory, making them prominent elements in both urban and rural landscapes. Thus they can be considered proper landmarks. To optimize hydraulic performance, mostly gravitational water flow, water towers were frequently constructed on natural elevations, such as hills or knolls, further enhancing their spatial prominence and landmark status. Especially in small settlements, water towers became recognizable features of local identity and orientation.

As Becher and Becher (1988) observed [68], the water tower is not merely a piece of utilitarian infrastructure; it is also a material artefact capable of documenting a specific historical period, technological advancement, and the evolving relationship between communities, territory, and water resources. The architectural type consolidates in a single architectural object, the memory of a water supply system, the technical and engineering expertise that enabled its function, and a formal language that translates hydraulic necessity into a visually and culturally recognizable structure [69,70]. In this sense, the water tower can be interpreted as a tangible archive of construction practices, materials, and technologies that, though originally conceived to satisfy essential needs, have assumed broader symbolic significance as expressions of cultural identity and collective memory [71]. This mnemonic and documentary value is intimately linked to the context in which each tower is located. Their integration with the local environment, both built and natural, is often deliberate and expressive, reinforcing the link between landscape, memory, and

function. The physical elevation or visual isolation of many water towers transforms these structures into strong territorial markers, shaping the perception and orientation of the observer across the environment.

The contemporary valorisation of water towers must be framed onto a broader debate on water heritage and urban sustainability. In a time when water management has become a strategic global concern, these structures can be reimagined as educational and interpretive centers, exhibition venues, or community hubs. Thus, their potential adaptive reuse offers opportunities to align conservation with innovation, combining architectural preservation with goals of resilience, environmental awareness, and civic participation [72]. Developing appropriate guidelines for the conservation and adaptive reuse of water towers is therefore essential. These guidelines should preserve the specific type, material, and formal features of the original structures, avoiding alterations that could compromise their historical integrity. Simultaneously, they must allow the integration of contemporary technologies, such as monitoring systems, climate-responsive materials, or energy-saving solutions, that could update their functionality while maintaining a heritage value. The critical challenge lies in balancing conservation with innovation [73]: maintaining the original symbolic and technical significance of the water tower while enabling its continued relevance within the evolving needs of contemporary urban and social contexts [74].

Application of the UNI EN 16096 Heritage Assessment Framework to Selected Water Towers

The UNI EN 16096 [18] is a European standard that establishes a methodological framework for the condition survey and assessment of buildings, providing harmonized procedures aimed at inspecting, documenting, and evaluating the physical state of existing buildings in a systematic and reproducible manner. This standard is primarily intended to support maintenance planning, asset management, refurbishment strategies, and decision-making processes throughout the building life cycle, in line with the Renovation Wave, flagship of the European Green Deal. This standard clearly defines a structured method based on visual inspections and, where necessary, complementary investigations, specifying the terminology, inspection principles, data collection procedures, and reporting requirements necessary to ensure consistency, comparability, and scalability of results across different scenarios, and contributing to a standardized diagnostic procedures enhancing transparency, objectivity, and traceability in building condition assessments.

Starting from this framework, Table 2 summarizes the main elements of the water towers considered in this study. The main purpose is providing a comparative overview of the case studies, highlighting materials, morphology, original function, historical and cultural value, structural conditions, vulnerabilities, and potential for adaptive reuse. This approach allows a transition from qualitative, descriptive analysis of individual buildings to a systematic and comparable assessment, useful to define guidelines for conservation and interventions of functional adaptation. Employing this methodological framework also facilitates the identification of correlations between types, material, architectural style, and valorisation strategies, providing a clear link to the previous analysis of the considered European and Italian water towers in Section 4 “Water Towers around the World”.

Table 2. Comparative assessment of water towers case studies according to UNI EN 16096.

Case Study/Location	Construction Material	Typology (Form/Morphology)	Original Function	Heritage Value	Condition/Vulnerabilities	Adaptive Reuse Potential	Notes/Key Interventions
Aldeburgh Water Tower, UK	Red brick masonry, cast-iron tank	Cylindrical shaft with elevated tank	Municipal water supply	Grade II listed building	Good; minor interventions for residential adaptation	High; converted into private residence	Victorian industrial style; preserved envelope; modern interiors
Appleton Water Tower, UK	Brick masonry, cast-iron tank	Cylindrical with panoramic terrace	Supply to royal estate	Cultural-historical; restored	Good; fully restored	High; residential/interpretive spaces	Neo-Byzantine style; viewing room; restored and reused
Amsterdamsestraatweg Tower, NL	Brick masonry, reinforced concrete tank	Cylindrical shaft with tank crown	Municipal water supply	Rijksmonument	Good; adapted to mixed-use	High; residential and public spaces	Amsterdam School style; preserved architectural character
Brežice Water Tower, Slovenia	Reinforced concrete	Cylindrical base, octagonal upper section	Municipal water supply	Civic and symbolic; integrated in coat of arms	Medium; restored after abandonment	High; museum, restaurant, panoramic viewpoint	Part of Posavje Museum; adaptive reuse; UNESCO WAMU-NET recognition
Vinohrady Water Tower, Prague	Brick masonry, steel tank	Cylindrical shaft with tank	Municipal water supply	National Cultural Monument	Deteriorated; vacant	High; planned as water education center	Neo-Renaissance; seven floors, roof viewpoint, exhibition and conference hall planned
Jægersborg Water Tower, Copenhagen	Reinforced concrete	Cylindrical shaft with tank	Municipal water supply, civil defense	Landmark	Good; renovated	High; youth housing, community spaces	1955 post-war style; terraces, bay windows; youth club on lower floors
EUR Piezometric Tower (“Il Fungo”), Rome	Reinforced concrete	Mushroom shape	Piezometric tower for EUR district	Cultural landmark	Good; maintained	High; panoramic restaurant, bar	Modernist architecture; rooftop restaurant; scaffolding for advertising
Budrio Water Towers, Bologna	Masonry, concrete, steel	Cylindrical with octagonal halls	Municipal water supply	Cultural-historical	Good; renovated	High; multifunctional cultural center	“Centocittà” Prize; exhibitions, concerts, theater; terraces and water features

The comparative analysis of the case studies reveals several common patterns and significant differences. Older towers, constructed in brick or masonry, often retain robust structural integrity but show some vulnerabilities often related to material degradation and lack of seismic standards. On the other side, 20th-century reinforced concrete structures display greater resistance but require functional and technical upgrades. The vertical morphology and strategic siting endow all towers with a visual and identity-defining landmark role, regardless of their size, formal aspect, or urban context. Application of the UNI EN 16096 [18] framework enables the identification of concrete adaptive reuse opportunities in cultural, educational, and social terms, demonstrating how towers can be transformed into museums, community centers, residential spaces, or multifunctional hubs without compromising their historical and architectural value. Overall, the selected case studies confirm that a structured, normative assessment can support coherent and sustainable intervention decisions, integrating conservation, technological innovation, and public engagement, while reinforcing the connection between infrastructure, territory, and local communities.

6. Results and Discussion

The conducted analysis demonstrates that water towers, in addition to their historical, architectural, and symbolic relevance, retain significant structural, technical, and environmental potential for contemporary adaptive reuse. Originally engineered to satisfy rigorous hydraulic performance criteria (ensuring constant pressure, reserve capacity, and gravitational distribution) they were often sited in strategic topographical locations and constructed with remarkable attention to durability and structural efficiency [72].

From a structural engineering standpoint, water towers represent a unique combination of vertical load-bearing capacity and resistance to lateral actions, such as wind and seismic forces. The vertical concentration of mass in the elevated tank generates substantial axial compressive stresses in the supporting shafts or legs, often counterbalanced by robust masonry or reinforced concrete foundations. Lateral forces are critical, particularly for slender towers located in open or elevated terrains, where wind exposure is more pronounced. In seismic-prone areas, dynamic amplification effects may occur due to the oscillating water mass, requiring careful assessment of sloshing phenomena, foundation stiffness, and structural ductility. Historical towers often lack standardized seismic detailing, and rehabilitation efforts must consider these original design limitations. Modern diagnostic tools such as finite element modeling (FEM), structural health monitoring (SHM) systems with fiber-optic sensors, strain gauges, accelerometers, and modal testing, could provide detailed data for vulnerability assessment and conservation planning. These methods support predictive maintenance and risk mitigation, reducing the need for invasive interventions and ensuring long-term structural resilience [74].

It is important to note that this study does not aim to perform detailed structural calculations or design verification, but rather to adopt an assessment-oriented engineering perspective, supporting heritage conservation and adaptive reuse through diagnostic, monitoring, and vulnerability evaluation tools.

Thermo-hygrometric behavior is another key issue, particularly relevant in historic towers built with uninsulated masonry or early concrete. Seasonal and diurnal thermal cycles, coupled with rainwater infiltration or condensation, can induce cracking, material degradation, and loss of original finishes. Energy retrofitting must be approached conservatively, prioritizing reversible and non-invasive insulation systems [74,75] (e.g., aerogel plasters, innovative thermoplasters, lime-hemp composites, etc.) compatible with heritage preservation guidelines. Advanced breathable membranes and internal ventilation strate-

gies can further mitigate moisture accumulation, enhance indoor environmental quality while protecting material integrity [76].

Understanding the material properties, structural vulnerabilities, and historical construction techniques provides the necessary foundation to explore adaptive reuse. This transition highlights how technical assessments inform intervention strategies, ensuring that any designed reuse respects both the towers heritage values and their functional capacity.

Regarding adaptive reuse, water towers present a distinctive architectural morphology that is typically characterized by narrow vertical shafts and wide reservoir crowns. They can easily accommodate a variety of functional transformations to adapt the structures to contemporary needs [61]. Depending on volumetric configuration, load capacity, and accessibility, water towers can be repurposed as

- Cultural spaces (e.g., galleries, archives, interpretation centers, etc.);
- Educational facilities (e.g., science centers, water-themed museums, etc.);
- Community hubs (e.g., libraries, co-working spaces, youth centers, etc.);
- Residential or hospitality venues, especially in urban redevelopment contexts.

Minimal intervention strategies such as panoramic viewpoints, cafés, or exhibition areas, are preferable in towers with limited floor area or preservation constraints. On the other side, more intensive conversions (e.g., housing, hotels, public services) require the insertion of new horizontal elements (floors, mezzanines), vertical circulation systems (elevators, staircases), and compliant fire safety measures. The external architectural identity must be always preserved, with any additions (such as glass volumes or steel structures) clearly distinguishable yet harmonious, in accordance with contemporary conservation principles. The urban and landscape integration of reused towers is a fundamental component of a successful rehabilitation. Their inherent landmark character, often linked to their height, siting, and silhouette, makes them reference points within both urban and rural contexts. Redevelopment projects should capitalize on this visibility by enhancing accessibility, creating pedestrian zones, integrating surrounding green spaces, and encouraging public interaction. Subterranean or peripheral zones may house mechanical systems, storage, or accessibility ramps, reduce visual intrusion and preserve towers vertical monumentality. From a cultural and socio-spatial perspective, water towers function as repositories of collective memory and industrial heritage that must be preserved in light of the most recent European policy frameworks. In fact, they embody a period in which water infrastructure symbolized not only technological progress but also civic identity and territorial modernization. Adaptive reuse initiatives can re-establish this connection through interpretive storytelling, community engagement programs, and participatory design processes that foreground local narratives and foster a sense of ownership [17].

The environmental dimension is increasingly central to the rationale for water tower reuse. Rehabilitating existing structures avoids the significant embodied energy and carbon emissions associated with demolition and new construction. When coupled with life-cycle assessment (LCA) and carbon footprint analyses, adaptive reuse strategies can quantify environmental benefits, including material savings, waste reduction, and decreased urban sprawl. Additionally, the installation of renewable energy systems (e.g., photovoltaic panels on tank roofs, rainwater harvesting systems, etc.) can further enhance sustainability outcomes [60]. Water towers also serve as testbeds for circular and regenerative urban practices, allowing cities to experiment with hybrid models that combine heritage protection, environmental performance, and social innovation, assessable by implemented social impact analyses (S-LCA). By embracing water towers as multifunctional infrastructures, blending historical memory, architectural form, and contemporary use, they can become catalysts for urban regeneration, especially in peripheral or post-industrial contexts. The findings confirm that water towers offer a unique opportunity to combine technical in-

genuity, material conservation, and cultural reinterpretation within a single architectural entity. To fully realize this potential, interdisciplinary approaches, encompassing structural engineering, architecture, heritage science, urban design, and environmental studies, are essential.

Future research should focus on creating types-specific guidelines for structural assessment, material compatibility, and sustainable retrofitting, ensuring that these iconic structures could continue to serve both functional and symbolic roles in the evolving urban landscape and contemporary society.

7. Conclusions

Water towers represent complex technical and cultural artefacts whose preservation and adaptive reuse demand an integrated, multidisciplinary approach, drawing on structural engineering, architectural conservation, urban planning, sustainability, and social science. Their vertical development, materials variety, and infrastructural origins impose both constraints and opportunities for compatible reuse, positioning them as strategic assets in the contemporary urban landscape. Municipal water towers, often located in central or accessible urban areas, tend to exhibit higher adaptability to new functions compared to decommissioned railway or industrial towers, which are frequently located in marginal zones and present significant technical deterioration. However, in both cases, primary structural elements typically composed of masonry, reinforced concrete, steel, or timber, often remain sound, enabling intervention without full demolition. Targeted structural assessments, including non-destructive testing and detailed material characterization, are essential to guide appropriate conservation strategies [77]. The water towers examined in this study illustrate the capacity of this industrial architecture to combine functional logic with formal and typological experimentation. The conducted analyses confirm the typological evolution of water towers from simple masonry shafts, with polygonal or circular plans, to reinforced concrete and steel structures, with mushroom-type or lenticular tanks. This demonstrates how building and construction materials, and constructive techniques shaped both functional performance and architectural expression. Far from being anonymous infrastructural artifacts, they have played (and can continue to play) a central role in shaping urban and rural identities. Their prominent verticality and distinctive silhouettes render them visible markers across landscapes, often imbued with symbolic, aesthetic, and historical value. These characteristics, if properly interpreted, can support meaningful reinterpretation of even the most utilitarian buildings, fostering new relationships between built environment, infrastructure, and community identity.

From a design perspective, the conversion of water towers involves a series of architectural and engineering challenges: restricted floor areas, vertical circulation constraints, limited natural lighting, and the need to comply with contemporary building codes and local constraints. These challenges can be overcome through carefully designed interventions, including the insertion of lightweight intermediate floors, the addition of external access structures, and the strategic use of underground or peripheral technical spaces. When appropriately implemented, such strategies preserve the original architectural identity of the towers while enabling the transformation into residential, commercial, cultural, or educational spaces [78]. Preservation must go beyond mere material conservation to include the revitalization of the surrounding spaces and the activation of new cultural and social functions. The integration of modern technologies, such as structural monitoring systems, energy-efficient retrofits, and climate self-control, ensures long-term stability and resilience. Digital cataloging, GIS-based mapping, and 3D modeling could further enhance the management, accessibility, and dissemination of the knowledge related to these heritage assets.

Adaptive reuse also provides significant socio-cultural benefits. Water towers, once purely functional infrastructures, can be repositioned as sites of public engagement, co-design, education, and interpretation. Their possible conversion into museums, community hubs, or interpretive centers fosters dialogue between past and present, reinforcing the value of water heritage and promoting public awareness of sustainable resource management. Such processes not only contribute to heritage conservation but also generate new narratives and uses that respond to contemporary societal needs [79]. The application of standardized heritage assessment frameworks proves essential in guiding systematic, evidence-based conservation and adaptive reuse decisions. By providing clear evaluation criteria and structured investigations, this ensures that interventions balance technical integrity, historical authenticity, and contemporary functional needs, reinforcing the towers role as resilient and meaningful urban heritage asset.

To conclude, water towers thus embody a rare intersection of engineering, architecture, and cultural symbolism. Their preservation and adaptive reuse offer a unique opportunity to bridge historical memory with future-oriented urban strategies. As multifunctional infrastructures, they can actively contribute to sustainable urban development, foster inclusive cultural participation, and reinforce the visual and functional identity of cities and territories.

Looking ahead, future research will focus on the following priorities:

- Developing standardized protocols for the structural and material monitoring of historic water towers, including long-term analyses of mechanical behavior, thermal response, and material durability under diverse climatic conditions;
- Evaluating the impact of different rehabilitation and reuse approaches on structural performance, particularly in masonry and early reinforced concrete constructions;
- Quantifying the environmental and energy savings of adaptive reuse through rigorous LCA implementations and carbon footprint analysis, supporting evidence-based decision making;
- Extending pilot projects and functional adaptation experiments to the urban scale, integrating towers into broader regeneration frameworks and community planning initiatives;
- Investigating the socio-cultural implications of reuse, including the negotiation between conservation ethics and contemporary usability, and the evolving perception of water towers as heritage, also by the implementation of LCC and S-LCA analyses;
- Applying digital tools such as GIS-based heritage mapping, Building Information Modeling (BIM and H-BIM), and predictive maintenance algorithms to optimize conservation management, accessibility, and integration into smart city infrastructures [7].

Although the suggested methodological framework was here applied to the case of Palermo and selected European examples, it is anyway scalable to other historical water towers and vertical hydraulic infrastructures, provided that local construction traditions, materials, and environmental conditions are appropriately considered. By pursuing these research directions, water towers can be re-established as living, active components of contemporary cities, connecting technical innovation with historical continuity, and contributing to sustainable, inclusive, and resilient urban futures. By combining technical assessment, material knowledge, and cultural interpretation, water towers can be reactivated as resilient and meaningful infrastructures, capable of bridging historical memory with contemporary urban and environmental challenges.

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