Gardella's Lost Legacy: The Church of Alessandria.

Study, 3D Documentation and Analysis

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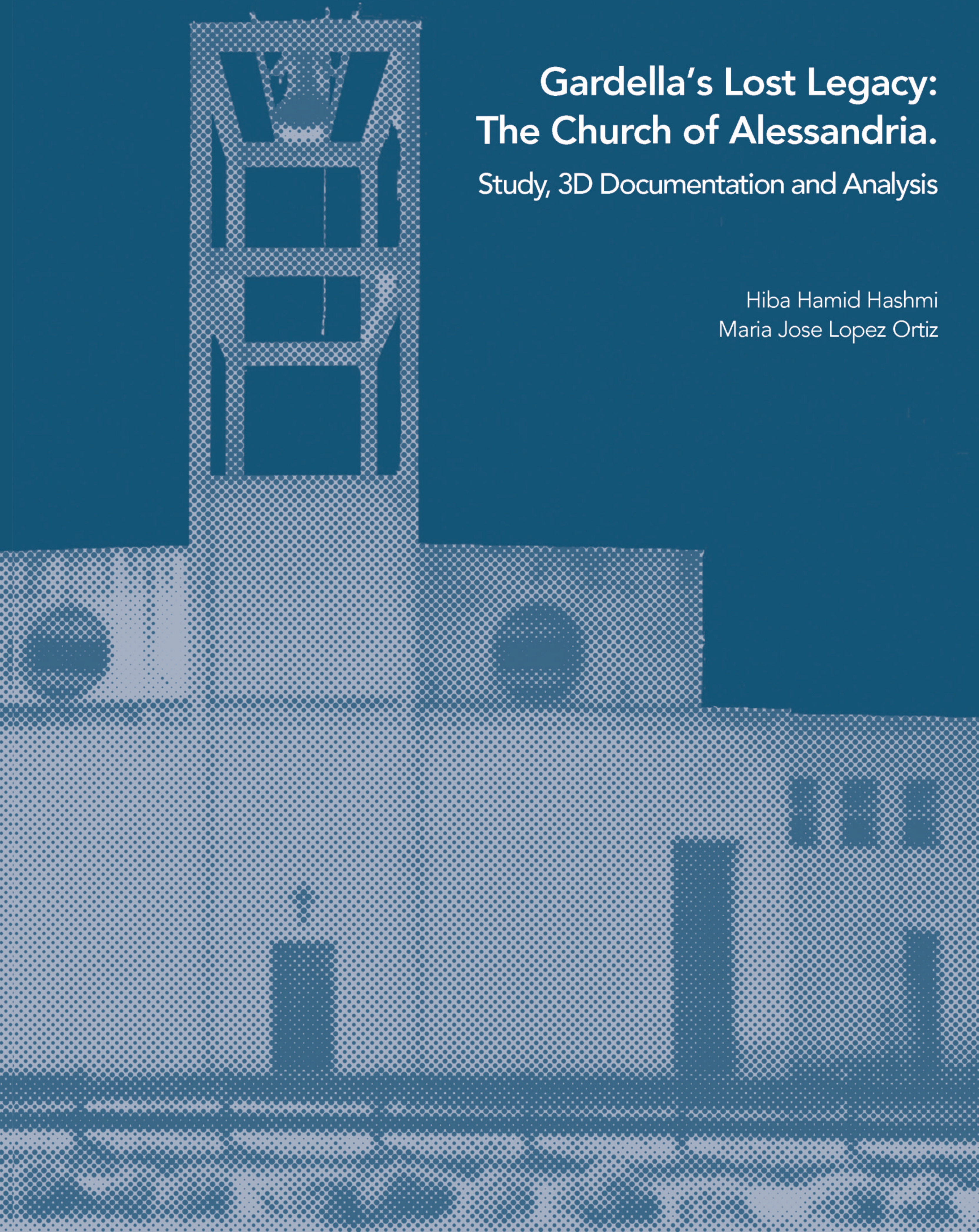

Politecnico di Torino

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Abstract

This thesis delves into the soul of Iganzio Gardella's church, a lost legacy nestled in the complex of Teresio Borsalino Rehabilitation Center (previously called the Sanatorium of Anti Tuberculosis Vittorio Emmanuele III) in Alessandria. More than an architectural artifact, the church embodies the confluence of modernist ideals and therapeutic intent, while remaining a place of great historical and cultural value for the people of Alessandria. A key example of Rationalism, the church is analyzed through the lens of historical exploration, advanced survey methods, digital documentation, restoration analysis, and concludes into envisioning a new life for this structure. As a beacon of Rationalist architecture, the church becomes a lens to reflect on the evolution of design, the narrative of decay, and the profound role of architecture in healing and community connection.

The research begins with a historical overview, situating the church within the urban and architectural trajectory of Alessandria and its transformation into a modern industrial and cultural hub. This section highlights the influence of the Borsalino family and their patronage of avant-garde architectural interventions through the family of Gardella. It links the sanatorium and the church to the city's historical and social identity.

The core of this thesis lies in the application of advanced survey methodologies to document the church's current state with precision and rigor. Combining topographic survey, LiDAR and Photogrammetry, the study captures the building's geometry, material conditions, and precise architectural details. The integration of these techniques forms a robust foundation for creating 2D architectural drawings with high precision and a comprehensive Historic Building Information Model (HBIM). The HBIM approach enables not only detailed documentation but also helps in documenting building's actual condition allowing for an evolution of building's condition while ensuring accuracy through Level of Accuracy (LOA) standards. The dual focus of documentation and accuracy establishes the model as a critical tool for both restoration planning, and the digitization of modernist heritage.

The degradation analysis and restoration solutions are informed by the documented data, focusing on the material and architectural degradation of the facades in line with the restoration practices for

20th century architecture. The proposed solutions emphasize maintaining the authenticity of Gardella's original design while addressing the challenges of preserving modernist materials and construction techniques.

The thesis concludes with a conceptual revitalization proposal, reimagining the church as a "Legacy Center". This adaptive reuse concept respects the historical integrity of the structure while introducing programs such as exhibitions, educational activities, and the central remains as a flexible space for multiple activities. These interventions are complemented by reconnecting the church with its therapeutic context within the rehabilitation center.

This research contributes to the fields of architectural conservation, digital documentation of heritage using traditional methods and their comparison with advanced methods such as Scan to BIM approach to create outputs with the highest level of accuracy possible. By integrating these methods into restoration workflows, this study provides a framework for balancing historical preservation with adaptive reuse in contemporary architectural practice.

OVERALL INDEX THESIS

Introduction

The Church in the Ex-Sanatorium of Borsalino in Alessandria stands as a lost legacy of Ignazio Gardella, marking the beginning of his independent architectural career. Following the passing of his father, Arnaldo Gardella, in 1928, the young architect took over the design and completion of the Sanatorium complex and proposed a new design for the church building, making it his first architectural contribution in Alessandria's context. This historical transition gives the building unique architectural and cultural significance, as it represents a bridge between two generations of architects and the early rationalist tendencies that would later define Gardella's career. Unlike his later works, which became widely recognized, studied and documented, this church has remained relatively obscure, despite its value as a foundational work in his evolution as an architect. The church was conceived as an integral or rather sculptural element within the Sanatorium complex, a specialized medical facility dedicated to the treatment of Tuberculosis which was a common healthcare building typology post World War I, commissioned by the philanthropist Teresio Borsalino. The structure followed the modernist approach of functional simplicity, reflecting the rationalist ideals of efficiency, clarity, and material logic. However, over time, the function of the Sanatorium changed, adapting to new medical needs and eventually being transformed into a Rehabilitation center. This shift left the church without its original purpose, leading to its progressive abandonment and material deterioration. The loss of active use and proper maintenance has contributed to its current state of neglect, making its documentation, analysis, and potential restoration an urgent necessity. Without intervention, the church risks being further forgotten, despite its potential to be reintegrated into the local, urban and social life of Alessandria.

The first part of this thesis focuses on the historical overview of early 20th century architectural movements in Italy, contextualizing the rationalist and modernist influences that shaped buildings like the Church in the Sanatorium of Borsalino. It explores the architectural and urban evolution of Alessandria in the 20th century, examining how political, economic, and social changes influenced the built environment of the city. Special attention is given to the Gardella family's architectural legacy, tracing their contributions to Alessandria's architectural transformation. By situating the church within this broader historical and urban framework, the thesis establishes its importance withing the architectural discourse of the period and highlights the necessity of its conservation.

The core of this thesis lies in the geomatic documentation and digital analysis of the church, using advanced techniques to create an accurate dataset for conservation / restoration planning. The study integrated both traditional and contemporary documentation methods, employing a combination of survey methods including terrestrial Laser Scanning, LiDAR and UAV photogrammetry. The datasets obtained have been processed to generate traditional architectonic drawings and advanced 3D documentation using Scan-to-BIM workflows to develop an HBIM (Historic Building Information Model). These methods combined serve as a key tool for analyzing the current state of conservation, structural and architectural details, and material degradation, supporting informed decision making for a project of restoration. The comparison of 2D and 3D documentation techniques and advanced 3D modeling methods provide insights into the strengths and limitations of different heritage recording approaches. Traditional methods, while widely used in historical preservation projects, often lack precision and efficiency especially in complex architectural geometries. In contrast, Scan-to-BIM workflows allow for detailed and data rich digital reconstruction, ensuring that the geometric and material characteristics of the structure are faithfully preserved. This thesis demonstrates the technical workflow of data production and presents ideas for future development in HBIM documentation while evaluating their application in a restoration project.

Beyond documentation, this study also examines the current state of conservation of the Church by examining the material degradation of the church's façade, identifying patterns of decay and structural vulnerabilities. Using the local norms for identifying types of decay, a detailed analysis has been conducted highlighting the weathering effects on the building's materials and construction elements. After analyzing all the possible types of degradations apparent on the facades, restoration solutions have been proposed ensuring that they align with the best practices in the conservation of early 20th century architectural structures, while exploring more innovative and sustainable solutions suitable for heritage preservation. The research then explores the broader regulatory and urban constraints affecting the site, particularly land use policies, heritage protection laws, and hydrogeological risks. The study of the Alessandria's Piano Regolatore (PRG) and the Piano di Assetto Idrogeologico (PAI) provides an understanding of the zoning restrictions, construction limitations, and legal framework governing interventions on the site. These insights ensure that any restoration proposal aligns with both historical preservation standards and modern urban policies while addressing site specific conditions and zonal bylaws.

As a final part of this thesis, a design proposal for a Legacy Center has been developed, aimed at celebrating the architectural contributions of the Gardella family while transforming the church into a social and community hub. This vision seeks to revitalize the structure as a multifunctional space, catering to the users of the rehabilitation center, regular visitors, and the general public. By integrating cultural exhibitions, social events, and public engagement activities, the project ensures that the church does not remain an isolated monument but becomes an active and meaningful part of Alessandria's contemporary landscape. The intervention respects the architectural and historical essence of the church while providing it with a new functional purpose, ensuring its long-term sustainability and continued relevance to the city's urban fabric.

Part I

Historial overview

Twentieth century architecture in Italy

1.1 Italy's Unification and the Changing Architectural Impressions

The unification of Italy, starting from 1861, considerably transformed its political and urban landscape. Not only did it play a role in architecture, governance and social hierarchies but also in forming a collective national identity. In addition to building a nation state, the agenda was to do so in the direction of "modern industrialization", following what was happening in its modernized neighbour Germany[1]. Before the unification, Italy was fragmented between the regions of north and south, which were dominated by foreign rulers, while the central parts under papal control. Post unification, the King Vittorio Emmanuele II of the House of Savoy, from Piedmont region, aimed to strengthen his rule by creating an ambitious plan to transform Turin as a national capital in 1860[2]. Later the capital was shifted to Florence for its central location in 1864, despite criticism for damaging its historic sites. In 1871, however, Rome was finally designated as a national capital, with its imperial and papal history, symbolizing national unity and modernization like other European powers[3].

Following the death of Vittorio Emmanuele II (1829-1878), the construction of the monument Il Vittoriano in Rome started, which included years of demolitions and a massive budget to demonstrate strength and power of the kingdom. The project was commissioned to the architect Giuseppe Sacconi whose project delivered the brief to include an equestrian statue with an architectural backdrop[4]. He drew upon Italian Art Nouveau (Stile Liberty), as well as Greek and Roman classical influences. The location of Il Vittoriano was also strategically chosen to be in the centre, overlooking the Capitoline hill. This was an attempt to emphasize the dominance of the new Italian state over the ancient Roman heritage[5]. The grandeur and power portrayed through architectural monuments was not only evident in this time, but had always been used in ecclesiastical, and palatial architecture. In Turin, however, the monumental aesthetics

1) Ghirardo, Diane Yvonne. 2013. *Italy: Modern Architectures in History*. London: Reaktion Books Ltd.
2) Duggan, Christopher. 2014. *A Concise History of Italy*. 2nd. New York: Cambridge University Press.
3) Ghirardo, Diane Yvonne, *op. cit.*, p. 15.
4) Savorra, Massimiliano. 2011. *Il Vittoriano. Dal concorso alla costruzione*. In *Architettare l'unità: architettura e istituzioni nelle città della nuova Italia*, 1861-1911, ed. by Fabio Mangone e Maria Grazia Tampieri, pp. 281-288. Naples: Paparo.
5) Ghirardo, Diane Yvonne, *op. cit.*, p. 13.

got challenged with the construction of the Mole Antonelliana, which lasted over twenty-seven years (1862-1889). Mole, which was initially intended to be a Jewish synagogue, became a municipal property in 1877 and dedicated to the museum of Risorgimento. The architecture of Mole gave a new identity to Turin to be modern and industrial by leveraging Antonelli's radical approach to masonry construction – an antiquated technique which became ambitious and innovative when combined with an iron frame structure. The 168 m high tower rejected the prevailing classical architectural aesthetics, while giving birth to a new era of architecture based on technical advancements in unified Italy[6].

With the goals to modernize, the leaders often disregarded the historic landscapes in the city center, as discussed in the case of Il Vittoriano and Mole Antonelliana, and prioritized monumentality to convey the strength of the nation. This phenomenon was true, however, only among the aristocrats and nobles, whereas the situation of the rural areas and hinterlands was starkly in contrast. They lacked infrastructure, sanitation, housing and utilities while being excluded from the decision-making process. This also led to the spread of diseases, like malaria and Tuberculosis in the poorer neighborhoods[7].

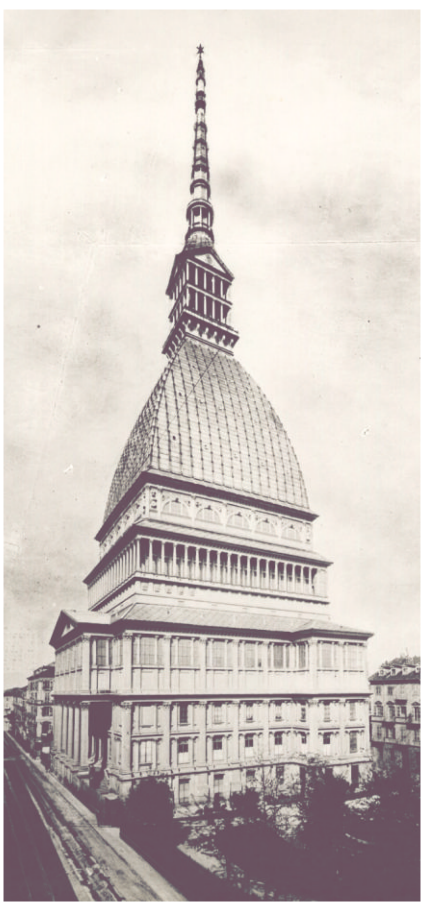

Fig. 1. Mole Antonelliana. Fondo Mario Gabinio, 1933 ca, B49/21. Fondazione Torino Musei - Archivio fotografico

1.2 Early 20th Century Architectural Movements

The emergence of twentieth century architectural movements in Italy, such as rationalist and modernist cannot be fully understood without discussing Futurism. In the early twentieth century, as Europe experienced a rise of avant-gardes, Italy saw the emergence of the Futurist movement founded by Filippo Tommaso Marinetti in 1909[8-9]. By 1914, Futurism began making its mark on architecture through the *Manifeto dell'architettura futurista* (The Futurist Architecture Manifesto), co-authored by Antonio Sant'Elia and Marinetti. The manifesto articulated to abandon historic preservation, classicism and the decorative architecture of the 19th century while introducing novel architectural elements such as the oblique line. The oblique-errant line was meant to challenge the dominance of the vertical and straight line. In addition, there was a focus on new materials like concrete, iron, and glass to forge a fresh synthesis of form, function and space[10]. The drawings exhibited by Sant'Elia in the exhibition of Città Nuova 1914, embraced new technologies to create an architecture of the future.

6) Volpiano, Mauro. 2004. *1862-1903. La Molte Antonelliana – Da sinagoga a museo nazionale dell'indipendenza italiana.* Turin: Archivio Storico Della Città di Torino.
7) Duggan, Christopher, *op. cit.*, pp. 150-151.
8) Billiani, Francesca & Pennacchietti, Laura. 2019. *Architecture and the Novel under the Italian Fascist Regime*. Machester: Palgrave Macmillan, Cham.
9) Ghirardo, Diane Yvonne, *op. cit.*, p. 33.
10) Billiani, Francesca & Pennacchietti, Laura, *op. cit.*, p. 69.

Around the same time, World War I started which lasted from 1914 to 1918. During this time, the political landscape of Italy was slowly changing with the rise of fascist movement, directed by Benito Mussolini. The Fascist movement was formed by a group of nationalist, interventionists, anarchists and veterans. By 1920s, there was a rise of a socialist movement and against them were the conservatives. In his stance, Mussolini sided with the conservatives, whose agendas were in line with the fascist nationalist ideologies, and since the conservatives were closer to the king, it helped Mussolini to rise in power. Finally, in 1922, he was appointed as a prime minister by the King[11]. The onset of WWI significantly affected the Futurist movement, as the war started a month after the futurist manifesto was published. Tragically, many futurists who participated in the war did not make a return and the movement did not gain vigor[12].

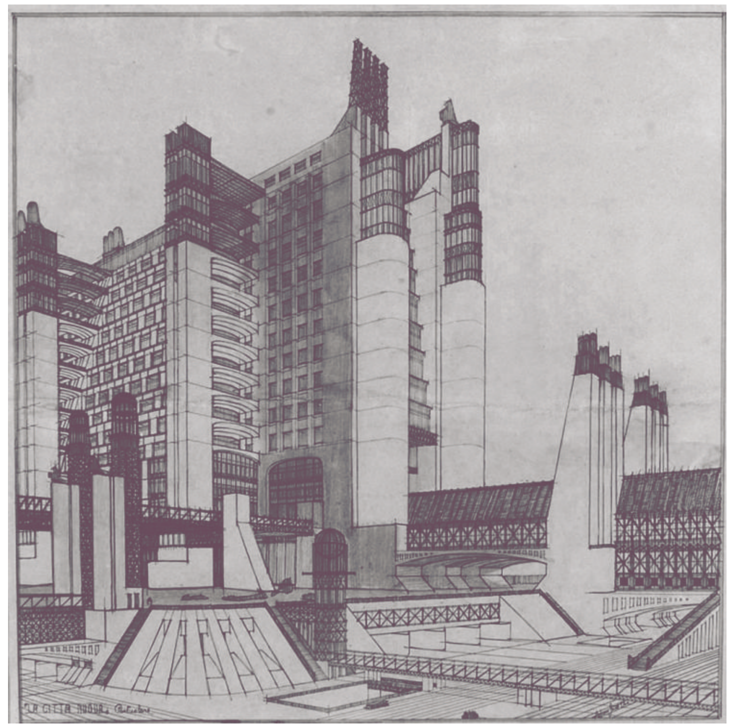

Fig. 2. *La Città Nuova* (The New City) "Casamenti con Ascensore", Antonio Sant'Elia 1914, Musei Civici di Como. Palazzo Volpi, Como.

In the wake of intense debates over Italy's participation in the WWI, the Italian intellectuals, gained new awareness of their political role. As Futurism glorified the war efforts, it positioned the intellectuals as key players on the political stage. The post war scenario included a divide between the emerging bourgeois and the proletariat. The intellectual elite significantly expanded its influence among the growing urban middle class who then were faced with the challenge in creating new forms of expression. This class sought to distance itself from avant-garde European movements, especially Futurism, which they viewed as alien to Italian sensibilities[13].

This context gave rise to Novecento, a widespread movement in the arts that gained traction as conservative yet modernist expression of Italian culture. This movement provided a reference point for a range of artists who embraces modernity while preserving traditional Italian values. The creator of Novecento, Margherita Sarfatti, defined Novecentisti as "the revolutionaries of the modern restoration". The ideology of this movement resonated with architects such as Giovanni Muzio, who called for a rejection of individualistic and chaotic modern architectural trends and return to principles of social harmony and stylistic unity rooted in tradition. With his breakthrough project, Ca'brutta, in Milan in the 1920s, Muzio attempted to reconfigure the aesthetics in a very controversial manner. The seven-story apartment block, the first in Milan to include a car park and central heating, used varied window patterns to break the rigidity of a grid-like layout and to make each flat unique. It's multi-faceted façade and severe geometry symbolized modernity, while the classical archway connecting two blocks nodded to Italian heritage. Though initially met with mixed reviews, its clean lines and structural clarity soon became emble-

11) Russo, Gianluca. 2020. *World War I and the Rise of Fascism in Italy*. Boston University - Department of Economics - The Institute for Economic Development Working Papers Series dp-341 (Boston University - Department of Economics).
12) Ghirardo, Diane Yvonne, *op. cit.*, pP. 33-34.
13) Regni, Bruno, e Marina Sennato. 1978. *L'architettura del Novecento e la "Scuola romana"*. Rassegna dell'Istituto di Architettura e di Urbanistica Roma n. 41-21, pp. 37-62.
14) Regni, Bruno, e Marina Senna, *ibidem*, pp. 37-38.
15) Sarfatti, Margherita. 1925. *Segni, colori e luci: note d'arte*. Bologna: Nicola Zanichelli, p. 127.

16) Billiani, Francesca & Pennacchietti, Laura, *op. cit.*, pp. 65-68.
17) Ghirardo, Diane Yvonne, *op. cit.*, pp. 66-68.
18) Brennan, AnnMarie. 2012. *The Big O.* AA Files, No. 65 111-118. https://www.jstor.org/stable/41762333.

matic of a new architectural direction[16]. Novecentisti did not aim to reinvent the tradition, but to reframe it in light of a prevailing theoretical push towards rationalization. This, in turn, fueled a strong social ambition to modernize society by promoting functional approaches to housing and construction.

1.3 Architecture during the Fascist Period

It must be noted that the architecture of the Fascist state of Italy (1922-1943) aimed to project the power, permanence and modernity of the regime while uniting italy's fragmented society. The building program of the regime was not only symbolic but also strategic to target the societal needs. The Fascist architectural Program included the construction of public buildings that symbolized national and Fascist power across Italian towns and cities, intentionally moving beyond the elite circles of the urban centers to reach all classes. These construction projects included schools, hospitals, courthouses, and government offices that visibly demonstrated the Fascist state's presence throughout Italy. The fascist regime under Mussolini sought to integrate the lower classes with a broader cultural and architectural agenda as a part of its political strategy. Projects such as land reclamation, the construction of autostrada, and low-cost housing aimed to integrate Italy's landless proletariat and rural classes into a national framework, attempting to replace local loyalties with a unified national allegiance[17]. This, in turn, created significant opportunities for architects and planners to engage in experimentation and innovation, fostering the coexistence of numerous schools of thoughts.

Around the 1920s, while there was an ongoing battle for a national hegemonic architectural style for a Fascist Italian state, a group of 7 architects from Politecnico di Milano, joined in as Gruppo 7, to create a movement of Rationalist Architecture. They published their first manifesto in La Rassegna Italiana in 1926, authored by Luigi Figini, Gino Pollini, Ubaldo Castagnoli later replaced by Adalberto Libera, Guido Frette, Sebastiano Larco, Carlo Raca and Giuseppe Terragni. They sought to create a revolutionary style for the Fascist regime, taking inspiration form Germany and Austria. They aimed to create a unified, rationalist style across various disciplines to cultivate a 'new society' through everyday aesthetic experiences[18]. The emphasis of rationalist architecture was on sleek, unadorned designs and extensive glazing. The first project as an example of rationalist architecture is the *Novocomum* apartments by Giuseppe Terragni in Como built between 1927-1929. Built on a trapezoidal plot, Novocomum is a composition of modern geometric forms with traditional housing functionality. Its linear, modular composition – marked by flat ro-

Fig. 3. *Novocomum* apartments by Giuseppe Terragni in Como, 1927-1929. Musei Civici di Como. Palazzo Volpi, Como.

19) Mras, George P. 1961. *Italian Fascist Architecture: Theory and Image*. Art Journal 21 (1) 7–12. doi:https://doi.org/10.1080/00043249.1961.10794176.

ofs, metal balconies, and use of circles, lines and triangles, established the principles of Italian Rationalism (Colombo s.d.). Later in 1932, Terragni was commissioned to design a Casa del Fascio in Como. His design completely diverged from classical architectural references, instead adhering to a strict logic and order through its geometric arrangement of rectangular forms. Despite its minimalist and modern design, *Casa del Fascio* symbolically reflects the Fascist ideals of discipline, public order, within a calm setting of Como[19]. (Mras 1961). The structured and minimalist aesthetics of rationalism became both a cultural symbol and a political tool, helping to establish a uniquely Italian modernist identity that would resonate in various public and private spaces, shaping Italian visual culture well beyond Fascist period.

Here, it is also worth mentioning the scenario of Turin, which

Fig. 4. *Casa del fascio* by Giuseppe Terragni in Como, 1932-1936. Courtesy by Danny Alexander Lettkemann Architekt.

was undergoing rapid transformations under the regime, in terms of industry, housing, and infrastructure development. One of the buildings which still stands as the odd one out in Piazza Castello, located at Via Roma, is La Torre Littoria (1933-34). It was a part of the urban renewal program of Via Roma. The building initially intended to house the Headquarters of the National Fascist Party but later the ownership went to Reale Mutua Assicurazioni and it served the purpose of an apartment and office building. The architect Armando Melis de Villa and engineer Giovanni Bernocco used an innovative construction method for the time including a metal load-bearing structure with modern materials, such as, glass blocks, clinker and linoleum which were unconventional for the time[20]. The building stands as an important example of Italian Rationalism, with its clear geometric form, emphasized functionality and the integration of modern materials. The building's deliberate contrast with its surrounding Baroque context underscored its rationalist ethos of rejecting historical ornamentation in Favor of modern expression.

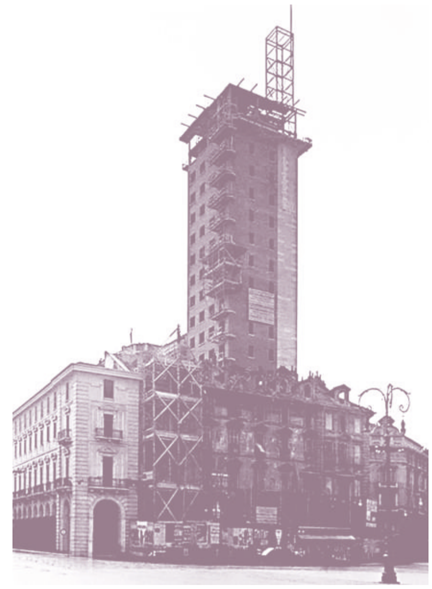

Fig. 5. *Torre Littoria*, by Armando Melis de Villa and Giovanni Bernocco in Turin, 1933-1934.

As apparent in the above-mentioned examples, the symbolic purpose of public buildings in Fascist Italy was as significant as their practical utility. Infact, this was the stance of Mussolini even in the development projects. The interesting factor about the architecture during the Fascist time is that it was not concentrating on one style like that in Germany.

The fascist government allowed for diverse architectural and artistic expressions. Mussolini and his followers believed that a new social order could arise through radical overthrow of established society, followed by governance that allowed for spontaneous and situational responses. Mussolini, in 1919, described a Fascists as "the gypsies of Italian politics" not bound to any fixed ideology[22]. This contradictory and "gypsy" ideology translated into the aesthetics theory, resulting in the blend of conservative, avant-garde and compromise designs leading to an eclectic architectural style[23]. The mix of ideologies was apparent even before, during and the post-World War II scenarios.

From 1932 onwards, a young emerging architect editor of Casabella, Giuseppe Pagano delved into an approach contrary to that of Terragni for the Italian Rationalist architecture. The young graduate of Politecnico di Torino, Pagano, approached architecture as an assembly of clean geometric forms based on moral principles, devoid of any ornamentation. While Terragni's view on architecture was of a social construct. He believed that architecture can be a social experiment where the daily life of individuals can inform the design of the buildings. In Pagano's views, it was important for the new architecture to differentiate itself from the past

20) Simona Talenti, Annarita Teodosio. 2020. *I grattacieli italiani. La trasposizione di una tipologia*. in *History of Engineering - Storia dell'Ingegneria. Proceedings of the 4th International Conference - Atti dell'8° Convegno Nazionale*. Napels. 895-904.
21) Ghirardo, Diane Yvonne, *op. cit.*, p. 72.
22) Schneider, Herbert W. 1928. *Making the Fascist State*. New York: Oxford University Press, p. 67.
23) Mras, George P., *op. cit.*

24) Billiani, Francesca & Pennacchietti, Laura, *op. cit.*, pp. 84, 188.
25) Ghirardo, Diane Yvonne, *op. cit.*, p. 80.
26) McLaren, Brian L. 2021. *Modern Architecture, Empire, and Race in Fascist Italy*. Vol. 36. Leiden: Brill Rodopi.
27) Billiani, Francesca & Pennacchietti, Laura, *op. cit.*, pp. 75-78.

rhetoric of aesthetics, and should emerge as anonymity, giving voice to the masses, while fulfilling the social and cultural goals of the Fascist regime. For him, the architecture had to embody the fascist morals. Whereas Terragni saw architecture as a representation of purity, order, and rationality of fascism. He wanted the architecture to have an educational role that helps the masses internalising the fascist ideals[24]. Despite the differences, both shared a common commitment to rationalist aesthetics and a collective role of architecture in serving political objectives.

In the same time, another school of thought emerged from Rome, with Marcello Piacentini, who became the regime's preferred architect and planner from 1935 onward. Having this power vested in him by the regime, he was responsible for some of the greatest public building and urban development projects, such as, the University of Rome and the planning of the EUR (E42) district in Rome in 1938 to host the 1942 Universal Exposition[25-26]. He was also responsible for the Master planning of Rome. Piacentini balanced modernist trends with traditional elements, designing the public buildings based on the hierarchy of their functions. He emphasized the importance of integrating international avant-garde movements with Italian tradition, aiming to position Italy at the forefront of architectural innovation while maintaining its cultural heritage[27]. The legacy of Piacentini was felt across Italy during and post-World War II period. Although, in the post war scenario, the architects rejected the idea of monumentality, but the ideas about the relationship between architecture and Italian tradition were still relevant.

1.4 Post World War II Scenarios

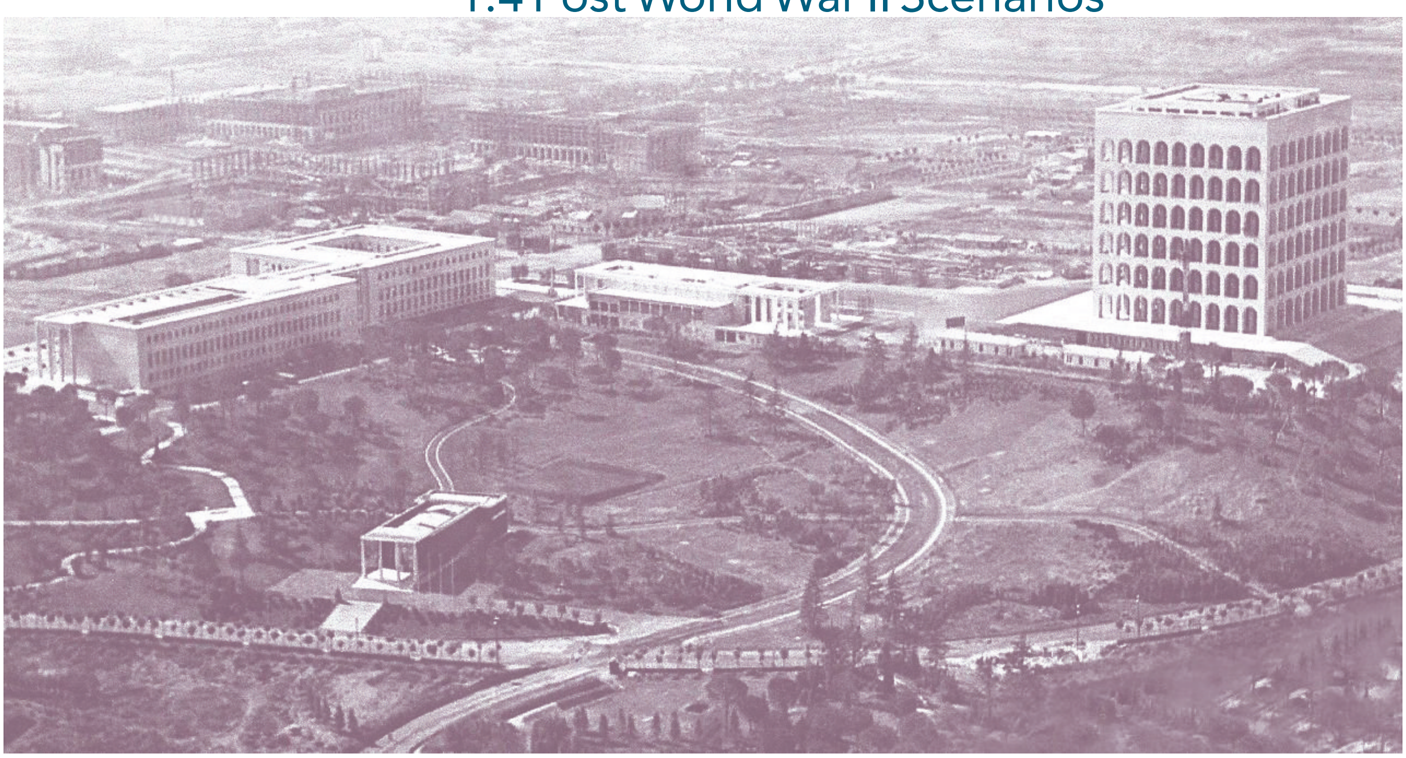
Fig. 6. *E42 Esposizione Universale 1942*, aereal photo of the site construction, 1940, Rome. Courtesy by Archivio Centrale dello Stato.

The second World War was also an end to the fascist regime, but it left its long-lasting impact, not just political but also in architecture and urban planning. In short, fascist Italy's urban and architectural policies were marked by both ambition and contradiction. They aimed to enforce social hierarchies and control urban populations while signalling country's alignment with European modernity. Ultimately, while the fascist architecture reflects the regime's propaganda objectives, it also stands as a testament to the complex relationship between power, cultural integration and architectural creativity in a politically charged era.

Many years post-World War II, the only acceptable style that merited was the Rationalist architecture, which was labelled "modern" by the critics and historians. Everything else was erased or dismissed by being considered irrelevant or mistake for having associations with fascism[28]. The post war period in Italy marked a critical phase of reconstruction and modernization, as the country sought to rebuild from the destructions of the war, while grappling with its recent fascist past. This era saw the emergence of architectural approaches that blended modernism with a sensitivity to Italian culture. Architects experimented with innovative designs rooted in functionalism and modernity, while addressing the challenges to recover the destructions caused by the war.

Since, rationalist ideology still prevailed in form of modernism, it faced a crisis diverging into two movements, as was happening during the pre-war time. The Milanese Movimento Studi Architettura (MSA) and the Roman founded Movimento per l'architettura Organica (APAO), both established in 1945[29]. In the issue 215 of March-April 1957, Earnesto Nathan Rogers of BBPR, in the editorial of Casabella-Continuatà, titled *Continuità o crisis?*, opened a debate about the relationship between historical continuity and revolutionary change in architecture[30]. According to Rogers, continuity represents a mutation within a tradition, a natural evolution grounded in historical context, whereas crises signify a rupture or an abrupt response to new factors – a revolution. Rogers advocated for a critical engagement with history, emphasizing its relevance in informing the contemporary designs[31]. Rogers emphasized the need for a critical investigation in the field of architecture that entails the integration of historical context into contemporary design, framing continuity as a progression of the past. This perspective shaped the approach to Italian architecture in the post-war period.

The MSA movement, originated in Milan was led by Franco Albini, who collaborated with figures like Ignazio Gardella, Ernesto Rogers and Giuseppe Samonà to shape architectural discourse of that time. In the 1950s, around the debate of continuity, Albini stressed on "tradition" as a reflection of "continuity of civilization", both in spirit and form, expressing it as, "historical continuity" and "continuous motion of life". This is the time when rationalism was reevaluated due to its inadequacy in

28) Ghirardo, Diane Yvonne, *op. cit.*, p. 70.
29) Fontana, Vincenzo. 2013. *Architettura italiana del scondo dopoguerra 1946-60.* Academia.edu. 25 May. Consultato il giorno 11 17, 2024. https://www.academia.edu/11419380/Italian_post_second_war_architecture_1945_60.
30) Rogers, Ernesto N. 1957. *Continuità O Crisi*. Casabella Continuità, March.
31) Castagnaro, Alessandro. 2010. *Ricordo di Rogers. Op.cit.* 137, January: 17-28.

Fig. 7. *Torre Velasca*, (1954-58) by Earnesto Rogers in association with BBPR, Milan. Courtesy by MIBAC, photo by Marco Introini.

italy's largely rural, artisanal construction context[32]. Albini, in his projects had the ability to blend tradition with modern needs, which was also reflected in the later projects of Ignazio Gardella where he explored the human scale and the traditional aesthetics.

The project of Torre Velasca (1954-58) by Earnesto Rogers in association with BBPR, was presented at the CIAM 11 (*Congrès Internationaux d'Architecture Moderne*) in 1959. Rogers represented Italy alongside architects such as, Ignazio Gardella and Giancarlo De Carlo. Rogers idea for the design of the Torre was based on a functionalist logic while addressing its medieval form as a contextual necessity, having more air and space for apartments above. He argued for evolving the relationship between architecture and history, moving beyond anti historical stance of early modernism. The project was met with criticism at the CIAM, for failing to respond to the contemporary societal needs[33]. However, this did spark a debate on a contextually rooted modernity.

1.5 Conclusion

The Italian architecture of the 20th century is a testament to the profound interplay between socio-political ideologies, technological advancements, and cultural heritage. Early in the century, Futurism emerged in form of radical movement that celebrated speed, movement, dynamism and industrialization, which was exemplified in the works of Antonio Sant'Elia's La Citta Nuova. As the political ideologies shifted, architecture became an instrument to the Fascist regime during the 1920s and 1930s which gave birth to the Rationalist Architectural discourse. The Rationalist architects, integrating the ideals of the Fascist regime, promoted modernist aesthetics that debated around the concepts of functionality and monumentality. While the structures built during the fascist regime glorified, they also originated debates on how architectural aesthetics and composition plays a role in expressing power and cultural identity[34].

Post World War II, the architecture in Italy faced dual challenges, the first of reconstruction and secondly the need to redefine its iden-

32) Chavardès, Benjamin. 2021. *From neoliberty to postmodernism*. In *Post-war Architecture between Italy and the UK*, a cura di Lorenzo Ciccarelli e Clare Melhuish, pp. 57-70. London: UCL Press, p. 72
33) Chavardès, Benjamin, *ibidem*, p. 64.
34) Etlin, Richard A. 1991. *Modernism in Italian Architecture, 1890-1940*. London: The MIT Press.

tity away from the shadows of fascism. The immediate post war period was characterized by functionalist approaches which aimed to address the shortage of housing and infrastructural damage[35]. It then evolved into the critical rethinking of modernism, as architects tried to reconcile the need for functional, and contemporary design with respect to the historical and cultural context. While rationalism (re invented) continued to play a dominant role, movements like MSA and APAO pushed for an architecture sensitive to tradition and complexities of Italian identity. The architects like, Rogers, Albini, Gardella, Zevi, and others laid a groundwork for their contemporaries and contributed to a broader discourse on relationship of modern architecture with history. In the latter half of the century, the debates around architecture transgressed into critical regionalism and post modernism. Architects and theorists of like Aldo Rossi and Carlo Scarpa were among the prominent figures, who attempted to reconnect with the vernacular techniques and historical context while challenging the rigidity of modernism[36-37].

In short, the brief analysis of Italian architecture of 20th century not only reflects the country's complex history, but also serves as a lens through which broader questions of identity, modernity, and tradition can be examined. The architects of this period have continuously tried to redefine the language of modernity and have left their legacy that continues to inspire the contemporary discourses of architecture and urbanism.

35) Ghirardo, Diane Yvonne, *op. cit.*, pp. 155-184.
36) Chavardès, Benjamin, *ibidem*, p. 59.
37) Ciccarelli, Lorenzo. 2021. *On the wave of the welfare state: Anglo-Italian town planning strategies in the post-war years.* In *Post-war Architecture between Italy and the UK*, a cura di Lorenzo Ciccarelli e Clare Melhuish, pp. 20-41. London: UCL Press, p. 36.

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38) Luino, Fabio. 2014. *A Flood Can Point Out Improper Land-Use Planning: The Case of Alessandria Town (Piedmont, Northern Italy)*, in *Engineering Geology for Society and Territory, vol. 5, part II, IAEG2014 (International Association for Engineering Geology and the Environment)*. Turin: Springer. 787-792. doi:10.1007/978-3-319-09048-1_153.
39) Subbrero, Giancarlo, and Paola Lombardo, . 2021. *L'economia della Provincia di Alessandria tra struttura e congiuntura. Dati statistici*. Alessandria: Provincia di Alessandria, Direzione Affari Istituzionali, Risorse Finanziarie e Strumentali, Servizio Provinciale di Statistica-CeDRES.
40) Dameri, Annalisa, and Roberto Livraghi. 2009. *Alessandria disegnata: città e cartografia tra XV e XVIII secolo*. Alessandria: Collegio Costruttori - ANCE Alessandria.
41) Dameri, Annalisa, and Roberto Livraghi, *ibidem*, pp. 4-5.
42) Garlandi, Roberto. 1989. *L' area urbana del cappellificio Borsalino: analisi delle preesistenze e proposta di intervento per una zona di Alessandria, Thesis Superviror: Luciano Re*. Thesis of Laurea, Faculty of Architecture, Politecnico di Torino, Turin.

2.1 Background and Context

The city of Alessandria, which is built in the marshy land between the rivers of Tanaro and Bormida got its name in 1168[38]. The city has an area of 203.57 square kilometres with a population of 93,876, which is 23% of the population of the province of Alessandria (406,831 inhabitants) as per 2024 ISTAT and Commune di Alessandria statistics. Apart from situating between the two rivers, it is also privileged for its geographical location to be in the most economically and socially developed Northwest part of Italy, the Piedmont region .In addition, its strategic location is between the crossroads of important highways, such as: Turin-Piacenza A21 and Genoa-Milan A7. Given its location, and connectivity, the region is known as the "integrated logistics hub"[39]. Alessandria, a city emerged as a fortified settlement, has its roots deeply embedded in Italy's medieval and early modern history, which makes it a compelling case study of architectural evolution and urban expansions shaped by strategic necessities and political agendas[40].

Alessandria's location has made it a contested site throughout the history, often serving as a defence stronghold or an outpost for expansionist campaigns. The central position of the city and its role in the regional conflicts date back to its early days, when it was under the Lombard influence and later integrated into the political and military frameworks of larger states and kingdoms[41]. The city's early role as a bastion of resistance defined her initial urban character, with walls, gates and strategic void spaces within its fortifications becoming symbolic for its medieval urban planning. In the medieval time, the fortress was absent, however, the city had a compact core with walls around which served as a defence strategy to resist sieges. The urban form of the city persisted to expand around the ancient Roman form where the Bergoglio neighbourhood was built even through the Renaissance[42]. During this time, Alessandria also served as a hub for local industrial activities such as wool dyeing and fulling, taking advantage of the Tanaro River. These old manufacturing efforts laid the foundation for the city's later industrial prominence, making Alessandria's economic backbone connected to its geography and infrastructure[43]. Ecclesiastical architecture played a pivotal role in the shaping of the city with church being the core of centrality. The Renaissance brought transformation not only in the architecture but also in urban planning. The building began to incorporate classical elements, proportions and ornamentation, while the streets became wider with the addition of public squares[44]. This is when the city's architecture began to balance functionality, with artistic impression which was overshadowed by later transformations.

The 16th century transition to the Spanish rule brought significant changes to Alessandria's urban fabric. The king Charles V established a protectorate over the State of Milan in 1525 and this marked a new era for strategic military development. The city's defence structure was reimagined, and a fortification was added at the Marengo Gate along with the addition of a covered bridge over the Tanaro River. This led to a total shift of Alessandria to a garrison town. In 1635, the defensive walls of Alessandria were redesigned by the engineer of the State of Milan, Francesco Prestino. The design prioritized military routes over civilian areas. This caused a neglect of civil infrastructure by reinforcing Alessandria's identity as a fortified military town rather than a commercial and cultural hub[45].

The Treaty of Utrecht in 1713 transferred Alessandria from Spanish to the Savoyard control, which marked a shift in political and military priorities. Alessandria, under the Savoy regime, integrated into a central administrative and fiscal framework, that included reduced noble and ecclesiastical privileges while building upon governance, education, and judicial system[46]. As previous rulers, the Savoy administration understood the strategic importance of the city for protecting the kingdom's Norther territories. This gave birth to the architectural projects aimed at fortifying and modernizing the city. At this time, the city was exposed to the Baroque architectural styles originating from Turin, the royal capital, influencing its urban and aesthetic evolution.

The main highlight of 18th century transformation is the construction of the Citadel. It was designed by Ignazio Bertola (1730-1732) in a hexagonal-elliptical form. For the construction of the fortress, the neighbourhood of Bergoglio was expropriated and demolished. This project displaced around 3000 residents, which required new structures and housing, reshaping the social, economic and urban fabric of the city. This is when the residents either moved to the city of Alessandria or to the countryside where they worked in the farms[47-48]. The design of the Citadel reflected military engineering principles of the time. The six bastions, interconnected by angular walls, provided a robust defence system. While its construction reinforced the protection of the garrison town, it also imposed restrictions on city's urban development, creating tensions between the military and civilian needs[49]. In addition to the Baroque influence in architecture, which was evident in structures like Palazzo Ghilini and Santa

43) Dameri, Annalisa, and Roberto Livraghi, *op. cit.*, pp. 14-15.
44) Garlandi, Roberto, *op. cit.*, pp. 30-34.
45) Dameri, Annalisa, and Roberto Livraghi, 2009, *op. cit.*, pp. 16-29.
46) Dameri, Annalisa, and Roberto Livarghi. 2005. *Il nuovo volto della città. Alessandria nel Settecento*. Alessandria: Rotary Club Alessandria, pp. XI-XII.
47) Dameri, Annalisa, and Roberto Livraghi, 2009, *op. cit.*, 62-67.
48) Dameri, Annalisa, and Roberto Livraghi, 2005, *op. cit.*, 21-40.
49) Ratti, Guido. 2019. *La Fortezza e il campo trincerato*. In *Alessandria: 850 anni di storia interno*, edited by Renzo Penna and Giancarlo Patrucco, pp. 71-86. Alessandria: Camera del Lavoro Alessandria.

Chiara Monastery, the demand for architecture extended beyond the traditional noble class and began to include a newly wealthy bourgeoise, which emerged through the Savoy policy of selling land and titles. This gave a boost to the economy and the demographics of the city rose[50]. This new social dynamic influenced the creation of public buildings and urban spaces that addressed broader civic needs. The transformation of the city was not limited to aesthetics but also involved functional improvements, such as better connectivity between key zones and enhancement in public infrastructure. These developments laid the groundwork for the 19th and 20th centuries evolution in Alessandria.

50) Dameri, Annalisa, and Roberto Livraghi, 2005, *op. cit.*, 14-15.

Fig. 8. *Plan of the City and Citadel of*, Quaglia, s.d., [Late XVIII century]. Sourse: AST, Corte, Carte topografiche dell'archivio segreto, Alessandria 25.A.I rosso.

2.2 The 19th Century: Industrialization and Urban Expansion

The 19th century marked Alessandria's transformation into an industrial and urban hub, driven by political unification, industrial growth, and infrastructural modernization. Emerging from its military-focused past, the city began to embrace broader economic and urban development while grappling with the legacies of its fortified history.

2.2.1 Political Reorganization and Early Urban Planning

Following the Napoleonic Wars, the Congress of Vienna (1815) restored Alessandria to the Kingdom of Sardinia. The Royal Decree of 1859 reorganized Italy's territories, positioning Alessandria as a major province in Piedmont alongside Turin, Cuneo, and Novara[51]. This integration catalysed urban planning efforts, beginning with Giovanni Garbarino's General Master Plan (1846), which proposed a ring road and streets to connect the city center to outlying areas. Antonio Rossetti's 1853 plan built on this, focusing on reorganizing streets, enhancing facades, and introducing new signage, though expansion was hindered by military land control[52].

Fig. 9. *Plan of Alessandria 1849* – In this plan the parts of ring road can be noticed and the location of the Station next to Strada Ferrata can also be seen. Source: Military Geographic Institute (Florence, Italy)

51) Cuccolo, Debora. 2005. *Alessandria tra Otto e Novecento: due ampliamenti urbani per la zona a sud della città, Thesis Supervisor: Annalisa Dameri*. Thesis of Laurea, Faculty of Architecture, Politecnico di Torino, Turin. p. 11.
52) Cuccolo, Debora. 2005, *ibidem*, pp. 6-7.

The development of the railway network during this time also influenced the city's urban organization. By 1851, the Turin-Genoa railway line positioned Alessandria as a vital node in northern Italy's transportation system, further integrated through subsequent connections to cities such as Milan and Savona. The railway station, designed by Alessandro Mazzucchetti (1852–1854), introduced public spaces and green areas near Porta Savona, fostering an early sense of urban modernization[53]. However, the design by Mazzucchetti was demolished in 1938, when the project of the new station building was approved. The new building was designed by the chief architect of the construction sector of Ferrovie dello Stato namely, Roberto Narducci. The new station building was operational in 1942. Interestingly, the new station building was built in rationalist style. These infrastructural advancements reinforced the city's role as a logistical hub, complementing broader urbanization efforts.

As military restrictions persisted, broader urban growth remained constrained until late in the century, when municipal acquisitions enabled new development (Dameri 2009). These shifts marked Alessandria's struggle to balance its military legacy with the demands of modernization and economic potential.

53) Cuccolo, Debora. 2005, *ibidem*, pp. 8-11.

Fig. 10. *Old Railway Station Building of Alessandria built between 1852-1854* – Architect: Alessandro Mazzucchetti. Source: Original (Picchio, Domenico, Alessandria, dal 1900 al 1940 attraverso le immagini d'epoca) – Author's source: (Amis ad Lisòndria - Tra Tani e Burmia 2014).

Fig. 11. *Railway Station building of Alessandria, built in 1942* – Architect: Roberto Narducci. Source: (Amis ad Lisòndria - Tra Tani e Burmia 2014).

2.2.2 Industrial Growth and the Borsalino Hat Factory

The rise of the Borsalino Hat Factory symbolized Alessandria's industrial emergence. Founded by Giuseppe Borsalino in 1857, the factory brought international acclaim to the city through its innovative approach to hat-making. Borsalino, trained in Paris, introduced advanced production techniques that revolutionized the industry in Alessandria, making the factory a beacon of industrial craftsmanship[54-55].

The factory's early success led to its relocation in 1871 to a larger site near the Carlo Alberto Canal, where it employed over 1,000 workers by 1896 and produced approximately 750,000 hats annually by 1900[56]. This exponential growth was not only a testament to Borsalino's entrepreneurial vision but also an indicator of the city's shift toward industrialization.

Beyond its economic impact, the Borsalino Hat Factory played a critical role in shaping Alessandria's urban landscape. Its expansion necessitated the rerouting of the Carlo Alberto Canal, creating space for new roads and industrial zones. Borsalino funded infrastructural improvements, such as bridges and the construction of Corso Teresio Borsalino, ensuring efficient connectivity for the factory and the surrounding area[57].

The factory also catalysed the transformation of southern Alessandria into a bustling industrial zone. Worker housing emerged in districts like Arzola and the Orti suburb, initially characterized by dense, un-

54) Subbrero, Giancarlo. 2000. *Fonti bibliografiche per la storia della "Borsalino Giuseppe e Fratello"*. In *Alessandria e Borsalino: Città Architettura Industria*, edited by Vera Comoli, Annalisa Dameri and Vilma Fasoli, 145-162. Alessandria: Cassa di risparmio di Alessandria SPA, pp. 152-153.
55) Ponzano, Cesare. 2019. *Alessandria "città manifatturiera": la Borsalino e il Sindacato*. In *Alessandria: 850 anni di Storia*, edited by Renzo Penna and Giancarlo Patrucco, pp. 106-109. Alessandria: Camera del Lavoro Alessandria.
56) Dameri, Annalisa. 2000. *Luoghi e architettture nella città dell'Ottocento*. In *Alessandria e Borsalino: Città Architettura Industria*, edited by Vera Comoli, Annalisa Dameri and Vilma Fasoli, 105-123. Alessandria: Cassa di risparmio di Alessandria SPA, pp. 105-106.
57) Dameri, Annalisa. 2000. *Ibidem*, p. 109.

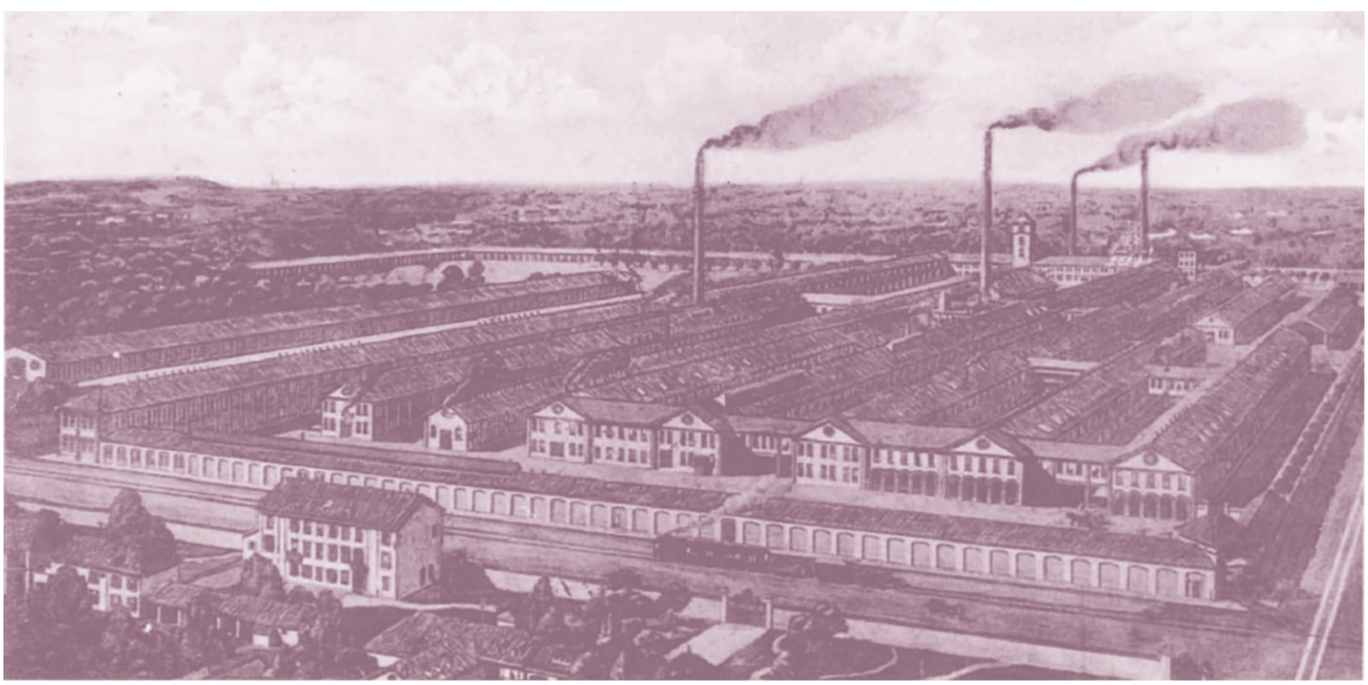


Fig. 12. *The Borsalino Factory in a late 19th century, in the city expansion area, near the Carlo Alberto canal.* Source: Comoli 2000.

Fig. 13. *The Entrance of the Borsalino Factory on Corso Cento Cannoni.* Source: Comoli 2000.

derdeveloped conditions. Over time, municipal investments—often supported by Borsalino—led to the construction of roads, schools, parks, and healthcare facilities. This blend of private and public efforts underscored the factory's role as a driving force behind Alessandria's urban modernization[58].

The railway network further enhanced the city's connectivity, enabling the efficient movement of goods and labour. Its proximity to the railway station made the factory's export operations seamless, facilitating the global distribution of Borsalino hats and embedding Alessandria firmly within Italy's industrial network[59].

The factory's influence extended beyond physical infrastructure. It shaped the city's social and cultural fabric, fostering a sense of industrial identity and pride. As Alessandria became synonymous with the Borsalino name, the factory's legacy continued to impact the city's architectural and industrial narrative well into the 20th century.

2.2.3 Urban Expansion Amid Military Constraints

Alessandria's military legacy posed persistent challenges to urban development. Fortifications restricted civilian construction, pushing expansion to peripheral areas like San Bernardino and Arzola. These districts became overcrowded and unsanitary, reflecting the city's struggle to accommodate its growing population and industrial workforce[60]. Urban renewal efforts sought to address these issues by demolishing slums and introducing improved infrastructure. The redevelopment of Arzola, for instance, replaced neglected housing with public facilities, including a psychiatric hospital designed by Arnaldo Gardella[61].

58) Cuccolo, Debora. 2005, *op. cit.*, p. 22.
59) Parodi, Nicola. 2019. *Alessandria, città ferroviaria*. In *Alessandria: 850 anni di Storia*, edited by Renzo Penna and Giancarlo Patrucco, 102-103. Alessandria: Camera del lavoro Alessandria.
60) Cuccolo, Debora. 2005, *op. cit.*, p. 12.
61) Dameri, Annalisa. 2000. *Ibidem*, p. 113.

By the late 19th century, the loosening of military control allowed for significant urban expansion. Municipal acquisitions of military land facilitated residential development in areas like Porta Marengo and the Orti suburb. Former fortifications were repurposed into public parks and boulevards, such as Spalti Marengo and Spalti Rovereto, providing both functional connectivity and aesthetic enhancements to the city[62]. These changes reflected a shift in urban planning priorities, emphasizing civilian needs over military servitudes.

62) Cuccolo, Debora. 2005, *op. cit.*, pp. 5-7.
63) Dameri, Annalisa. 2000. *Ibidem.*
64) Ponzano, Cesare. 2019, *op. cit.*
65) Ponzano, Cesare. 2019, *op. cit.*

2.2.4 Foundations for Modern Alessandria

The groundwork for the emergence of Alessandria as a modern and industrial urban centre was laid in the transformative era of the 19th century. While its history as a fortified military town imposed significant constraints on development, the city demonstrated remarkable resilience and adaptability. Alessandria balanced its historical legacy with the demands of urbanization through serious urban planning efforts, strategic negotiations, and industrial innovation. This transformation, deeply rooted in political, economic and social changed, provide essential context for understanding the city's 20th century trajectory and its architecture, including the works of Ignazio Gardella.

During the transformation process, the most essential part of the history was the repurposing and reclaiming of the military land which imposed limitations. The continuous efforts of Ludovico Straneo on the general regulatory plan, and subsequent developments like the creation of residential zones and public spaces, or the transformation of old bastions into roads, highlight Alessandria's capacity for reinvention[63]. These developments not only connect the historic centre to new industrial and residential zones, but also reflect a shift in priorities with urban planning increasingly catering to the civilian needs rather than being used as for military servitudes.

The rise of industry, characterized by the success of the Borsalino hat factory was a major driving force in this transition of Alessandria to a modern city. Giuseppe Borsalino's vision not only elevated the city's industrial reputation but also contributed to its urban development, as the factory's success compelled the growth of southern districts and inspired investments in infrastructure such as the sewage system and the repurposing of the canal as well as in welfare projects, such as schools, worker housing and hospitals[64]. The establishment of railways further reinforced Alessandria's integration into Italy's growing economy and industrial network, enhancing its role as a logistical and commercial hub[65].

The developments in the 19th century established a robust foundation for Alessandria's evolution in the 20th century. Moreover, the challenges and success of the 19th century continue to inform

66) Garlandi, Roberto. 1989, *op. cit.*

Alessandria's identity. The city's adaptability in the face of constraints, its ability to balance heritage with progress, and its commitment to civic improvement remain central to its narrative. This transition of Alessandria, from a fortified town to a thriving urban centre exemplifies the dynamic interplay of history, industry, and architecture that defines modern Italian cities.

2.3 Twentieth century Alessandria – Architecture and Urbanism

The architecture and urbanism of Alessandria in the 20th century reflect a profound transformation rooted in industrial expansion, sociopolitical change, and evolving design philosophies. The city's landscape was shaped by the interplay between its industrial heritage, Fascist modernization and rationalist ideologies mainly prevailing through the contributions of architects like Arnaldo and Ignazio Gardella. The efforts focused on retaining the historical core of the city, while developing new neighbourhoods to address the needs of growing population and infrastructural facilities to support the needs of the civilians. This is the period of intense restructuring, restoring and demolitions in a way to modernize the city.

2.3.1Unlocking New Urban Potential (1900s-1920s)

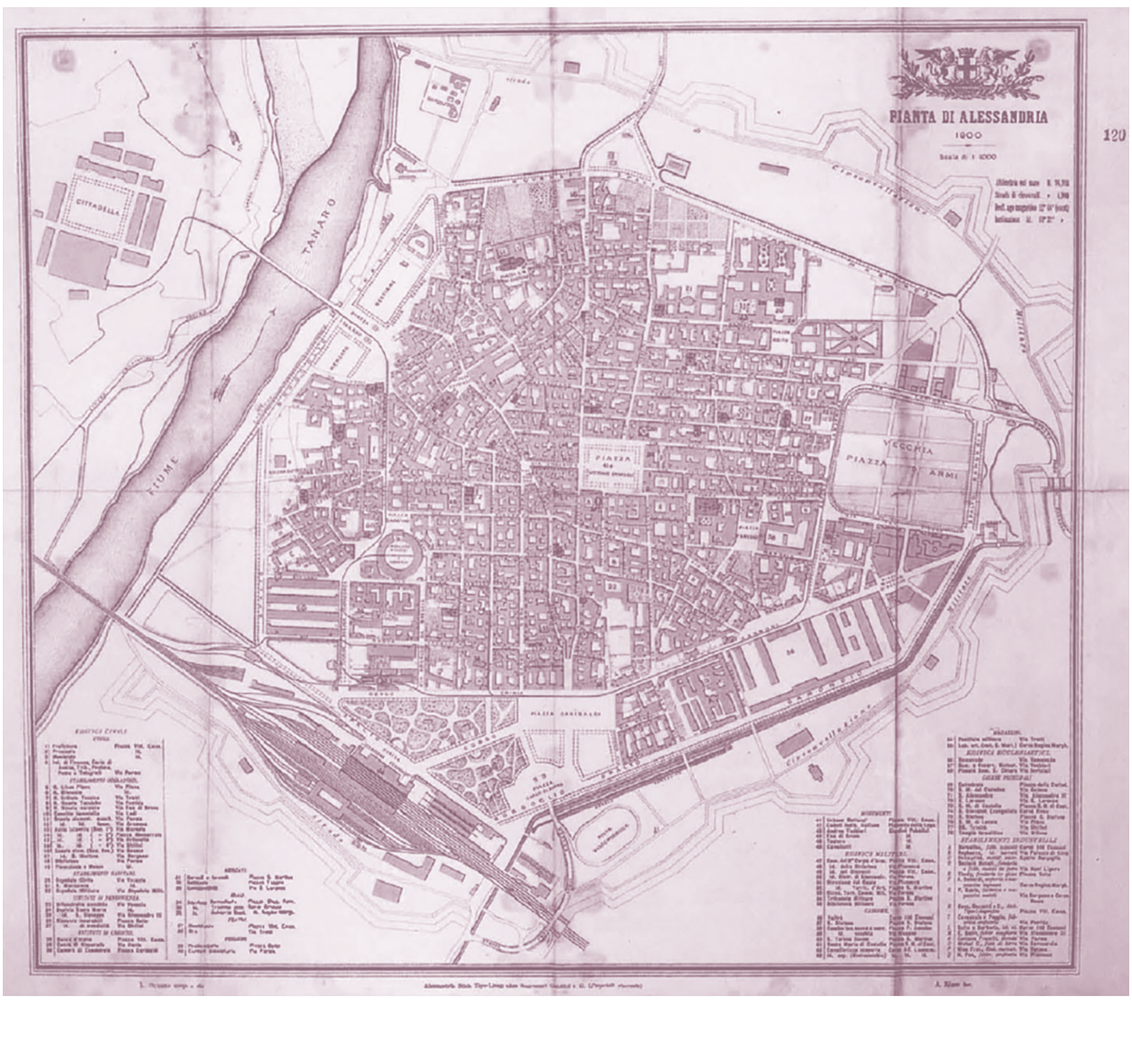
The pivotal development in the early 20th century was the dismantling of the fortified walls of many Italian cities, since the priorities shifted. The early developments came through the "Pizzichelli Act" in 1908, which facilitated the transfer of lands from the state to the municipality. These lands included parts of city's old fortifications, the former military parade ground "Piazza d'Armi", lands in the northeast of the penitentiary, riverfront strips along the Tanaro River, and connected roadways. As already mentioned, that the old bastions were being dismantled to allow for expansion in the southwest area[66].

The major developments in the early 20th century included the expansion of neighbourhoods that created Alessandria's growing working-class population. In the overcrowded districts like Marengo, the families were living in cramped conditions, often less than 70 cubic meters per household. The rents also became a significant burden for the families living in this situation. The purchase of 135 hectares of demilitarized land was pivotal for expanding residential areas. This is the beginning of the construction of the public housing projects with fixed rental costs. With the development cantered in the districts like Pista, Porta Marengo and Cristo, the demand for improvement in the railway's infrastructure and expansion of the ring road also increased, including the expansion of the Carlo Alberto Canal to the south[67].

In 1909, the Statue of the Autonomous body for Public Housing (Case Popolari) was approved, which allowed for the first timid attempts for the construction of worker housing near the offices of Thedy and Montel but the city saw more significant interventions during the socialist administration of Ernesto Pistoia from 1914 onwards. From the beginning of World War I, his contributions included the construction of schools and nurseries to help women to join the workforce in factories. Many unemployed people joined the workforce during this time to engage the demolition of the bastions, and the builders were imposed to reuse the

67) Fasoli, Vilma. 2000. *Da Piazzaforte Militare a città dell'industria e del commercio*, In *Alessandria e Borsalino: Città Architettura Industria*, edited by Vera Comoli, Annalisa Dameri and Vilma Fasoli, pp. 91-103. Alessandria: Cassa Ji Risparmio Ji Alessandria Spa, p. 92.
68) Fasoli, Vilma, 2000, pp. 93-94.

Fig. 14. *Figure: Plan of Alessandria 1900.* Original Source: ASAl, ASCAl, series IV, n. 2860 – Author's source: Comoli 2000.



brick reclaimed from the demolition sites[68].

Due to the seizure of power by the fascist squad in the 1920, the ongoing projects were halted, and no significant developments were carried out until 1927, when Ettore Mazzucco was appointed as a Podestà of Alessandria. This is when Teresio Borsalino contributed substantial funds for the construction of a modern aqueduct and sewage system, as per the 1913 designs of municipal office. Around the same time, the agreement between the Local Savings Bank and Borsalino, supported the construction of public housing in the Orti district (Via Rossini), the Pista district (Via Firenze and Piazza Mentana), and near Piazza Genova (Via Tortona), as

Fig. 15. *Plan of Alessandria 1909* – In this plan the newly proposed developments on the top of demolished fortifications can be seen. Original Source: ASAl, ASCAl, series IV, n. 3078 – Author's source: Comoli 2000.

69) Fasoli, Vilma, 2000, *op. cit.*, p. 94.

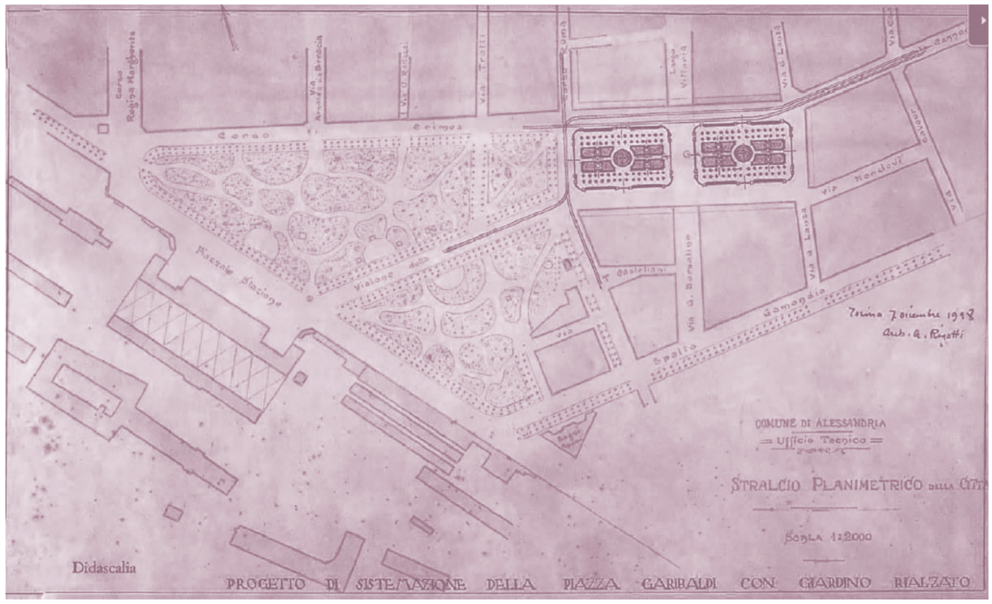


Fig. 16. *Project of the systemization of Piazza Garibaldi with raised Garden* – Architect Annibale Rigotti 1928. Original Source: ASAI, ASCAI, series III, n. 2276 – Author's source: (Comoli 2000).

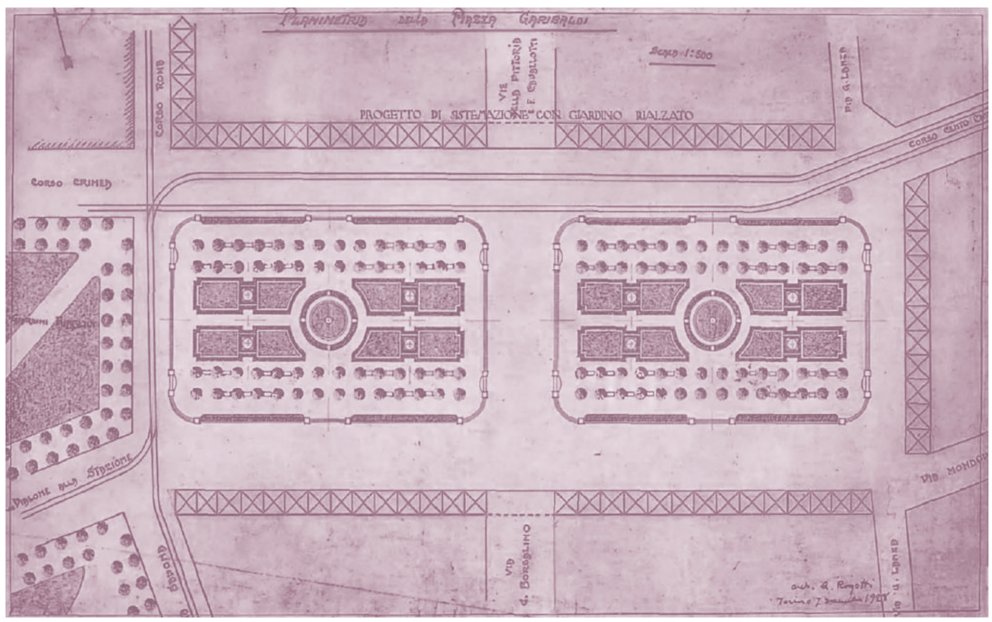


Fig. 17. *Proposed plan of Piazza Garibaldi with raised Garden* – Architect Annibale Rigotti 1928. Original Source: ASAI, ASCAI, series III, n. 2276 – Author's source: Comoli 2000.

outlined in the intervention plan od 1926[69].

Owing to being peripheral to the city centre, these neighbourhoods became the zones for migrants transferring from the rural to urban areas as the agriculture was impacted in the last decade[70]. Developed in the South of Alessandria, Cristo became a major residential hub for industrial workers. Its grid like layout, uniform housing, and proximity to factories spoke of a utilitarian approach to planning. The design of the district also constituted the development of communal spaces, such as local markets, and small public squares, with an idea to foster social cohesion. Cristo neighbourhood separated from the city by the railway station and bordered by railway lines to Cavallermaggione and Ovada, and as the Turin-Genoa line expanded, it reached the outskirts of Pista district. This is when the water network began to connect the southern districts[71]. The district of Pista was envisaged as a middle-class development, while Cristo district was characterized by low density rural development. Later the tree lined axis Corso XX Settembre was planned to form a connection between the new expansions and to the city centre. This was the beginning of the

70) *Ivi.*
71) *Ibidem*, p. 95.

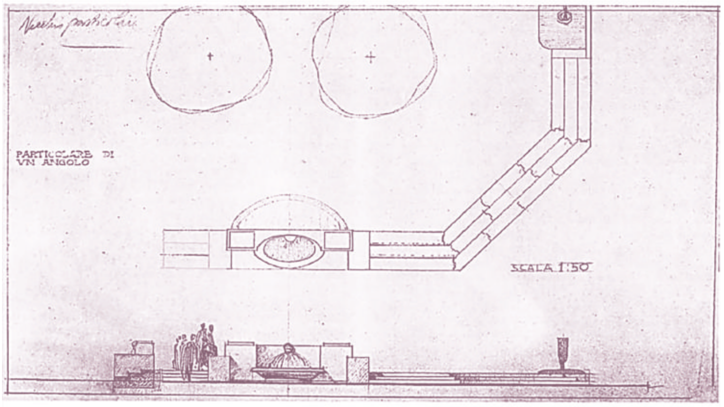


Fig. 18. *Corner solution with fountains and rigorous sculptural elements in Piazza Garibaldi* - project by Annibale Rigotti, 1928. Original Source: (ASAI, ASC AI, series III, No. 2276) – Author's source: Comoli 2000.

expansion beyond the city limits in Alessandria.

In 1927, there was an initiative by the local government to enhance the role of the porticoed square of Piazza Garibaldi, which was and still is a very significant piazza connecting the city centre to the railway station. The Architect Annibale Rigotti, in 1928, was commissioned to redesign the square. His proposal included gardens and leisure structures for the bourgeoisie and it aimed to enhance the square's decorum through an academically influenced design that reassured municipal expectations, however, the plan was never realized with no clear reasons for its non-implementation[72]. The piazza till today serves as a parking lot, and the proposal of Rigotti remains mainly undocumented, with some drawings available in the archives.

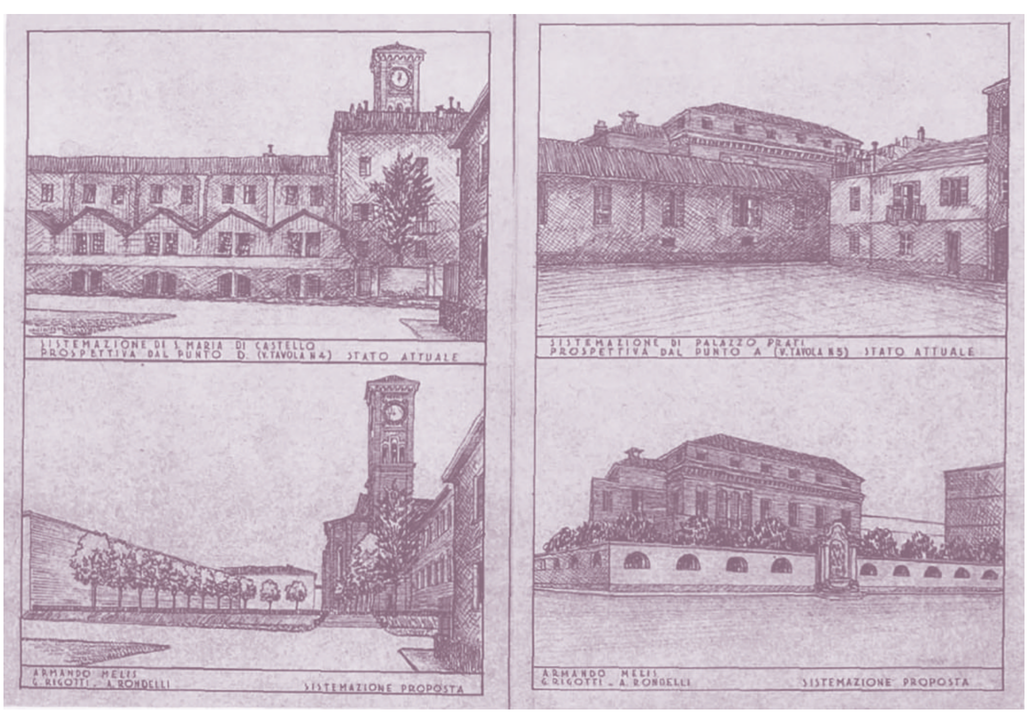
Rigotti contributed to some projects in Alessandria area, with his presence roughly from 1921 to 1930. His projects include the monument to the Fallen of WWI in Valenza, 1921, the Votive temple of Victory to the Queen of Peace on the hill of Castle of Tortona in 1922. In 1927, he signed a project for a kindergarten and in 1937[73], and in 1937, he participated in the competition of the Master Plan of the city with his son Engineer Giorgio Rigotti, and signed together with Armando Melis and Mario Rondelli[74].

72) *Ivi.*
73) *Ibidem*, p. 96.
74) Archival unit: Politecnico di Torino. 1941-1942. *Il '900 come non lo avevi mai visto.* Progetto per il risanamento della zona Tanaro di Alessandria. Turin: Unità archivistica, APRi, Archivi Professionali e della Ricerca - DIST. Accessed December 3, 2024. https://archivi.polodel900.it/scheda/oai:polito.it:2531_progetto-per-il-risanamento-della-zona-tanaro-di-alessandria.
75) *Ivi.*

2.3.2 The Masterplan of Alessandria 1937

As already discussed, by the end of 1920s, the signs of economic crisis were experienced in Alessandria, with its population facing unemployment. The municipal administration of Alessandria, to stop unemployment and to create a new face of the fascist regime, initiated a series of public works, taking advantage of the situation to resolve some of the persisting urban problems[75]. From 1927 to 1931, at least 5000 residential units were built, primarily on disused land. The municipality also invested in the creation of public green areas, the buildings representative of the regime and projects like social housing, schools and nurseries. These interventions structured urban functions into zones, such as, the

Fig. 19. *Armando Melis, Girorgio Rigotti, Aldo Rondelli 1937 - Arrangement of the area of S. Maria di Castello and Palazzo Prati.* Current state and proposed arrangement. Original source: (ASAI, ASCAI, Series IV, No. 3084) - Author's Source: Fasoli 2000.



Orti District, became a semi-rural district, hosting public services like a slaughterhouse, wholesale market, gasometer, cemetery, sports fields and a Tuberculosis sanatorium which was funded by Teresio Borsalino in 1935. In the south, the Cristo district, mainly became a residential district for factory workers and railway employees, contrasting the Pista neighbourhood for the bourgeois[76].

As a result of the WWI, the projects of the city's expansion, especially the organization of roads, redevelopment of quarters for hygiene purposes and mending of the peripheral urban fabrics were halted and the fascist ideals prevented the works to be continued in the same direction[77]. These issues called for the competition for Alessandria City's Masteplan in 1937, with clear guidelines to emphasize urban functionality, economic feasibility and integrating Alessandria within the national urban planning discourse. The proposal by the group of Armando Melis de Villa, Annibale and Giorgio Rigotti, Andrea Rondelli and Virgilio Testa was decided as a winning project in 1938.

Their proposal focused on three main aspects:

- The first being, Systematization of roads, since the traffic was one of the longstanding issues faced by the planners because in Alessandria many important roads and railway arteries converge, and it was necessary to sort them organically without diverting the traffic too much from the nucleus.
- The second aspect was Upgradation and Sanitization of neighbourhoods, especially between Piazza Tanaro and Piazza Santo Stefano that were the unhealthiest in the city. In that time, there was a high prevalence of Tuberculosis, up to 56 per 1000 people as per the data published in

76) Fasoli, Vilma, 2000, *op. cit.*, p. 96.
77) Archival unit, *op. cit.*

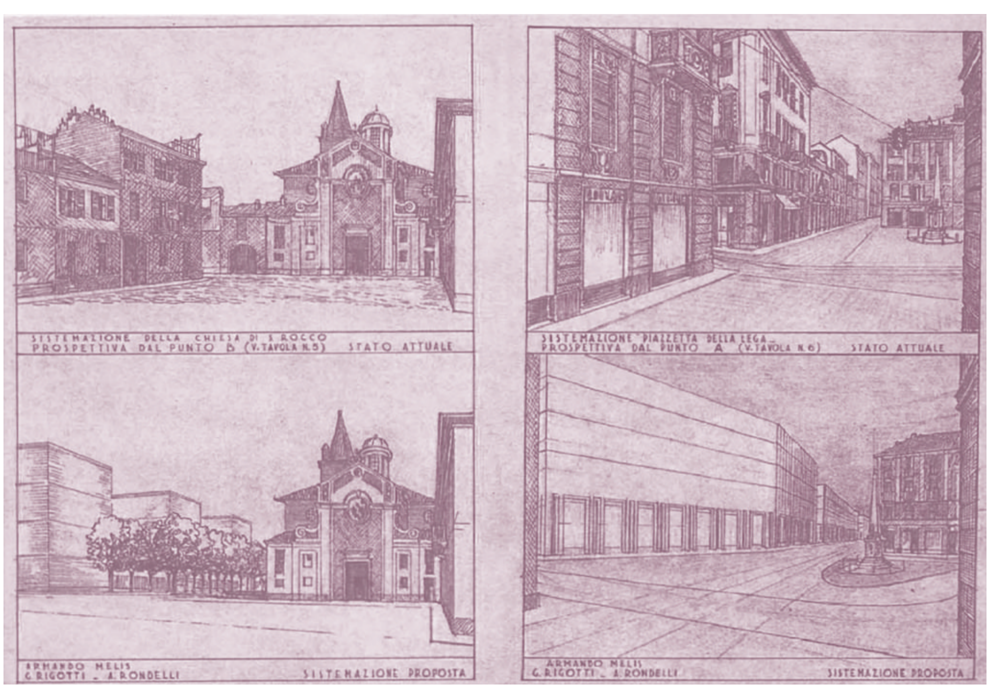


Fig. 20. *Armando Melis, Girorgio Rigotti, Aldo Rondelli 1937 - Arrangement of the Church of St. Rocco and Piazzetta della Lega. Current state and proposed arrangement.* Original source: (ASAI, ASCAI, Series IV, No. 3084) - Author's Source: Fasoli 2000.

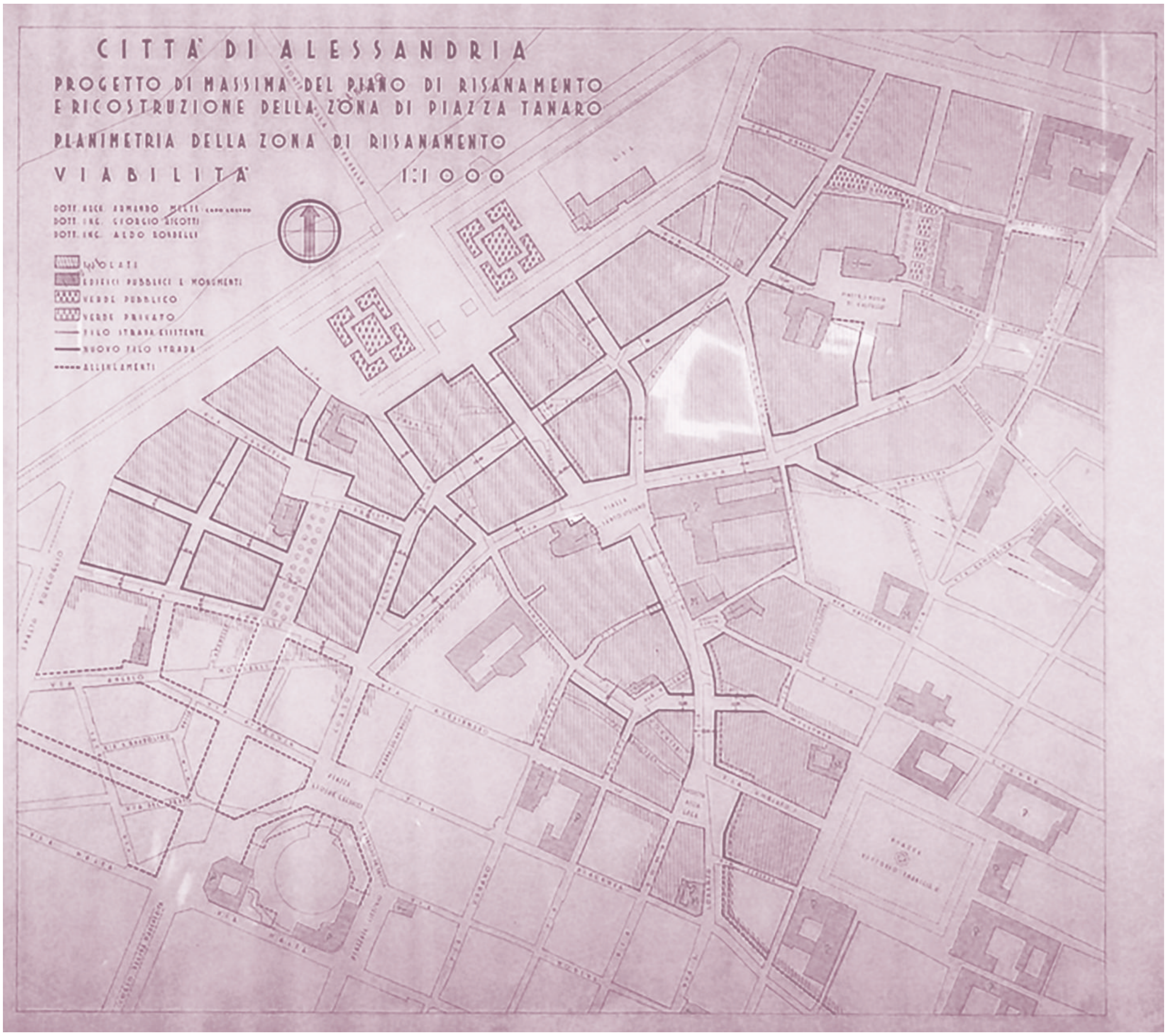


Fig. 21. *Armando Melis, Girorgio Rigotti, Aldo Rondelli - Plan of the Redevelopment of the Tanaro area of Alessandria 1937.* Source: Archival unit: https://archivi.polodel900.it/scheda/oai:polito.it:2531_progetto-per-ilrisanamento-della-zona-tanaro-dialessandria

1936, thanks to the Anti-Tuberculosis dispensary funded by Teresio Borsalino, the patients were getting the care needed. This is what underscored the urgency to address the poor living conditions in districts like Rovereto and San Rocco[78].

- The third aspect was the general Planning of Urban Expansion including the design of the city's aesthetics according to the regime's ideology and improving urban connectivity[79]. Overall, the focus of all the proposals were on hygiene, building density and preservation of the historical fabric. The proposal for new street. s, squares and promenades intended to highlight the historical landmarks while improving living conditions. The challenges were to balance visionary urban concepts with the economic realities of implementation costs.

78) Fasoli, Vilma, 2000, *op. cit.*, p. 99.
79) Archival unit, *op. cit.*

Following the competition, the municipality focused on redeveloping the northwest area along the Tanaro River, encompassing Piazza Biffi, Rovereto, Via Verona, Piazza Santo Stefano and Spalto Borgoglio. The reclaiming of the degraded neighbourhoods involved a series of "excessive and not always justified" demolitions. Within the historic bastions, zoning measures delineated areas for intensive residential buildings, hospital facilities and remaining industrial and military zones. Beyond the city walls, the plan of Melis, proposed the reorganization of vegetable garden district, establishing a food processing area featuring a slaughterhouse, and creating new livestock and fruit and vegetable markets. Meanwhile, the Cristo neighbourhood was foreseen as zone for public housing. New green areas were also imagined with proposals for new parks to the south of the cemetery[80].

Despite being a comprehensive proposal, the winning masterplan was not fully adopted by the municipality, leaving Alessandria without urban interventions for an extended period[81-82]. In 1939, the architect Armando Melis was asked by the municipality to draft the executive redevelopment project for the Santo Stefano area by creating a direct connection between Piazza Biffi and Piazza Santo Stefano, which included constructing four new blocks with unified architectural facades and porticos. Operating within the densely built area, the architect addressed the traffic issues by widening major arteries, which required demolition of several unhealthy building. In this plan, the main connections between Piazza Santo Stefano, Piazza della Lega, and Piazza Vittorio Emanuele were highlighted through road alignment and rationalization of Piazza della Lega[83].

A partial redevelopment plan for Piazza Biffi was approved in April 1940, but the ministry of public works demanded a more comprehensive general masterplan for the city. Eventually, the Mayor reassigned the task of drafting the comprehensive plan to the Municipal technical office, reliving Melis of his duties. In the meantime, the beginning of World War II and the ongoing political turmoil prevented the resolution on the masterplan for Alessandria until after the war[84]. After the WWII, in 1945, the efforts began on creating a new masterplan to address both reconstruction needs and future expansion. This is again when the city faced challenges in adapting to the post-war modern context, while pursuing long term urban renewal goals[85].

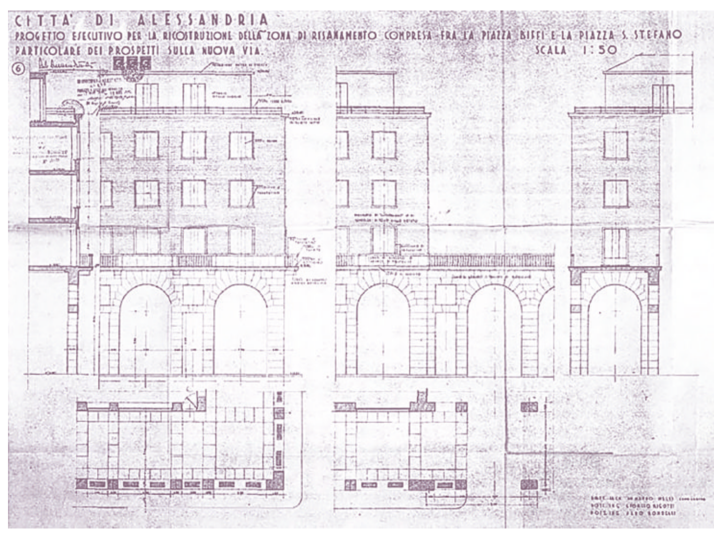


Fig. 22. Armando Melis, Giorgio Rigotti, Aldo Rondelli 1937 – *Executive project for the reconstruction of the redevelopment area between Piazza Biffi and Piazza S. Stefano*. Original Source: (ASAI, ASCAI, series IV. No. 3084) – Author's Source: (Fasoli 2000)

The biggest challenges post-World War II were not only those of reconstruction, but also the adaptation of a comprehensive regulatory framework guiding urban development. In 1958, the P.R.G. (General Regulatory Plan) was introduced, which formalized zoning patterns, em-

80) *Ibidem*.
81) Fasoli, Vilma, 2000, *op. cit.*, pp. 99-100.
82) Archival unit, *op. cit.*
83) *Ibidem*.
84) *Ibidem*.
85) Fasoli, Vilma, 2000, *op. cit.*, p. 100.

phasizing on residential development. This plan extended residential and industrial areas, particularly beyond the Carlo Alberto Canal near Borsalino factory. In 1966, the inadequacy of the 1958 P.R.G, led to the revision, that was finalized in 1972. According to this plan, the southwest area of the city continued to expand, especially the Cristo district experienced a boom in the construction of affordable housing, while the area over the canal of Borsalino factory did not change much despite the relocation of the industries to the designated industrial zones. The land was acquired in the outskirts of the city and the plan envisaged the creation of commercial, artisanal and industrial zones, in particular the zones D3 and D4. The P.R.G of 1988, focused on the development of the Borsalino area, as the factory was relocated from the urban centre to the D5 industrial zone in Spinetta Marengo. The abandoned sites and buildings were suggested to be used for residences, green areas, productive activities and a university. This is because the city had now the abandoned industrial heritage that needed to be transformed to new functions. Some of the industries were abandoned without relocation as the economy was shifting from manufacturing from service oriented. For example, the sugar refinery near Spinetta Marengo, ceased operations around 1978, and the Cristo district Brick Kiln was shut down in 1977, hence creating an abandoned site in the city[86].

The large scale abandoned industrial areas resulted in functional and environmental degradation, with negative consequences on the urban fabric and quality of life. That is when the city had to question the preservation of the historic industrial heritage while keeping up

Fig. 23. Armando Melis, Giorgio Rigotti, Aldo Rondelli – *Executive project for the reconstruction of the redevelopment area between Piazza Biffi and Piazza S. Stefano*. (ASAI, ASCAI, series IV. No. 3084) – Author's

86) Garlandi, Roberto. 1989, *op. cit.*

with the modernization trends.

2.4 The construction and Architectural trends – Pre and Post WWII

As the fascist regime, in 1929, was in search of consensus and was attempting to conduct counter-cyclical policies, they carried out a series of public works aimed at addressing unemployment and attempting to transform city's image in accordance with the new order. This is when the international economic crisis began with the 'great crash' of Wall Street in 1929, and as the world was facing a great depression, the repercussions were also faced in the city of Alessandria. Important architectural interventions were carried out in Alessandria in this period[87].

The 1930s in Alessandria, like other parts of Italy, were shaped by the architectural and urban policies of the fascist regime. In this period, there was a widespread adoption of Rationalist architecture in Alessandria, characterised by functional forms and monumental proportions. As already discussed earlier, the fascist government used architecture as a propaganda tool, commissioning public buildings and infrastructure projects that symbolized strength, efficiency and order. Many projects were realized in this period with a significant intent to celebrate the regime, for example, Casa Littoria (1932-1934) by the Architect Vittorio Tornielli, Case del Mutilato (1938-1940) by Architect Venzanzio Guerci, Laboratory of Hygiene and Prophylaxis (1937-1939) by Ignazio Gardella, the Sanatorium of Anti Tuberculosis (1930-1934) by Arnaldo and Ignazio Gardella and the Anti Tuberculosis Dispensary (1938) by Ignazio Gardella are some of the examples of the projects being done in the 30s. However, most of the works of this time have generally been forgotten or has been

87) Montanari, Guido. 1989. *Razionalismo dimenticato ad Alessandria: il Sanatorio Terresio Borsalino e il Dispensario antitubercolare, opere prime di Ignazio Gardella. Alessandria*: Excerpt from: Bollettino della Società Piemontese di Archeologia e Belle Arti, Nuova serie, v. 43. In cop.: Atti del convegno *Antichità ed arte nell'alessandrino*.
88) Montanari, Guido. 1989, *ibidem*, p. 492.

Fig. 24. *Casa Littoria/Casa del Fascio* – piazzale Turati Alessandria by Vittorio Tornielli 1932-1934. Source: https://www.artefascista.it/alessandria__fascismo_architett.htm

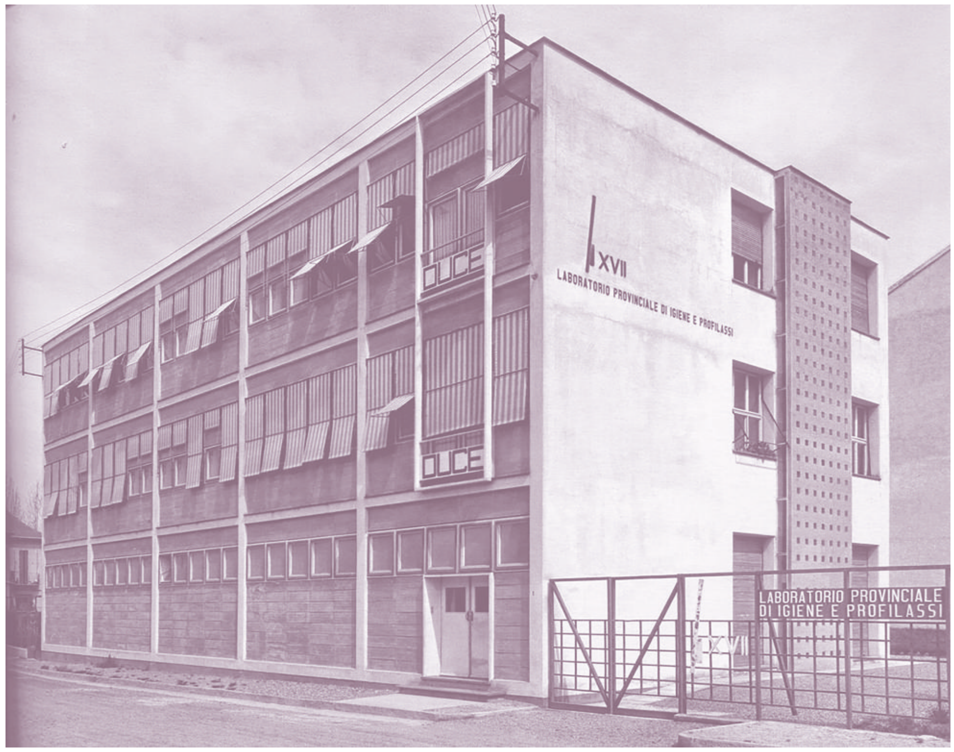


Fig. 25. *Provincial Laboratory of Hygiene and Prophylaxis* - Alessandria - Architect Ignazio Gardella 1937-39. Source: Stefano Vigolo (beniculturionline.it).

Fig. 26. *Present condition of Provincial Laboratory of Hygiene and Prophylaxis (1937-1939) by Ignazio Gardella.* Source: Flicker.com – Taken by: Xavier de Jauréguiberry on April 18, 2023.

confused with generalised "modernity" apart from some project by Ignazio Gardella[88].

The biggest contributions to create a modern identity for Alessandria were through the initiatives of the Borsalino Family, who commissioned most of their projects to the Milanese architects, the Gardella family. Their work reflects mid-20th century modern styles. The first project that Arnaldo Gardella was commissioned to by the Borsalino family was between 1923-1925, which was to realize the headquarters and the "Divine Providence" Institute of Mother Teresa Michel and its congregation. In this project, the architect highlighted a refined style but also referenced the Renaissance architectural culture. In the late 20s, Arnaldo was commissioned to design the "Sanatorium of Tuberculosis" (1929-1936) by Borsalino, but his death in 1928, marked the beginning of the architectural interventions of his son, Ignazio Gardella, who contributed in many projects realized in Alessandria afterwards[89]. Ignazio's first project was the small chapel inside the Sanatorium of Teresio Borsalino, where he followed the fascist design principles and introduced a modernist touch inspired by French Rationalism. The most surprising element of the design of the chapel was conceived as gender divided naves, which were meant to avoid the spread of the disease. The innovative layout of the chapel comprised of a unique parabolic shape, and a minimalist stylised bell tower. He also used a dual colour scheme to define the base and upper levels of the chapel, adding visual depth[90]. It remains one of the projects that Alessandria has yet to figure out how to enhance the value of. It will be discussed in detail further in the Chapter 2. The Case Study.

Another work that Ignazio took over after his father's death was the Casa di Riposo (Centro Anziani), at Corso Lamarmora, also funded by the Borsalino Family. It was an avant-gardist project for the residential complex criteria of that time, which included large halls, comfortable spa-

89) Ponzano, Cesare. 2019, *op. cit.*, p. 106.

90) Penna, Renzo. 2019. *Arnaldo e Ignazio Gardella: le figure chiave dell'architettura alessandrina*. In *Alessandria: 850 anni di Storia*, edited by Renzo Penna and Giancarlo Patrucco, pp. 110-114. Alessandria: Camera del Lavoro provinciale di Alessandria.

Fig. 27. *"Divine Providence" Institute of Mother Teresa Michel – Arnaldo Gardella (1923 – 1925)*. Source: Flickr.com – by Jacqueline Poggi – Taken on April 23, 2023.

Fig. 27. *"Divine Providence" Institute of Mother Teresa Michel – Arnaldo Gardella (1923 – 1925)*. Source: Flickr.com – by Jacqueline Poggi – Taken on April 23, 2023.

ces and modern services of a hotel. It included a Mensa room overlooking the garden, which was an innovative approach for the time, since the hygiene conditions of the city were not up to the mark. The Gardellian style in this complex is evident from the semicircular windows and the vertical cuts created by their juxtaposition on the façade[91].

The project that brought recognition to the work of Ignazio was the Anti-Tuberculosis Dispensary (1933-1937), which is now recognized as the Gardella Polyclinic. It became one of the significant architectural pieces of the time due to the juxtaposition of modern and innovative design elements with the traditional rural aesthetics. The use of glass bricks and the brickwork screen pattern on the façade evoked the sense of the traditional barns of Alessandria. This building was designed as a thoroughly functional organism yet managed to convey a warm aesthetic with well-lit interior spaces. The building endured damages during the war and was restored by Gardella himself in 1996, where he managed to achieve the original design perceived before he had to change it under the fascist regime[92].

Another pre-war significant project constructed in Alessandria is the Post Office building in Piazza della Libertà designed by the architect Franco Petrucci from 1939-1941. The style of the building is rationalist, as Petrucci was one of the leading figures of rationalism. The main façade of the building is covered in travertine while the lateral ones are in plaster work to imitate the stone texture. It is horizontally proportioned with ribbon windows to uniformly convey light into the work environments. The building is composed of four floors and a basement and formalistically a quadrangle which overlooks to Piazza Libertà and Via Mazzini (Città di Alessandria s.d.). Almost all the ground floor is designed as a public hall with an access through two lateral atriums and the interiors are of marble finishing. Even though the architect Petrucci was considered a promising architect while being promoted by the regime, this building

91) *Ibidem*, p. 110.
92) *Ibidem*, pp. 110-112.
93) Sapegno, Pierangelo. 2022. *La nostra grande bellezza: il razionalismo del Palazzo delle Poste di Alessandria*. Alessandria, August 10. Accessed December 5, 2024. https://tgposte.poste.it/2022/08/10/nel-palazzo-delle-poste-di-alessandria-la-filosofia-del-razionalismo-2/.

Fig. 28. *Anti tuberculosis Dispensary Alessandria, built in 1938 and restored in 1997 – Architect Ignazio Gardella*. Source: Archivio Storico Gardella in Archivio Opere Borsalino – Photograph taken in 1997 after restoration. https://www.archivioperborsalino.it/archivi/archivio-storico-gardella/

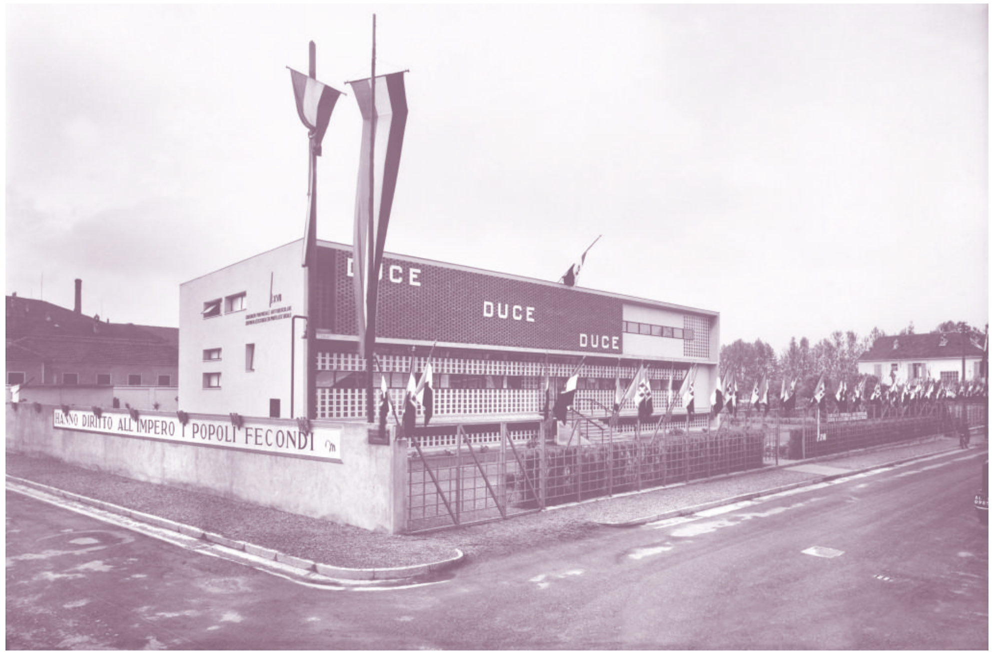


Fig. 29. *Post Office Building (1939-1941) – Architect Franco Petrucci and Artist Gino Severini*. Source: Flickr.com by Xavier de Jauréguiberry – taken on August 9, 2022

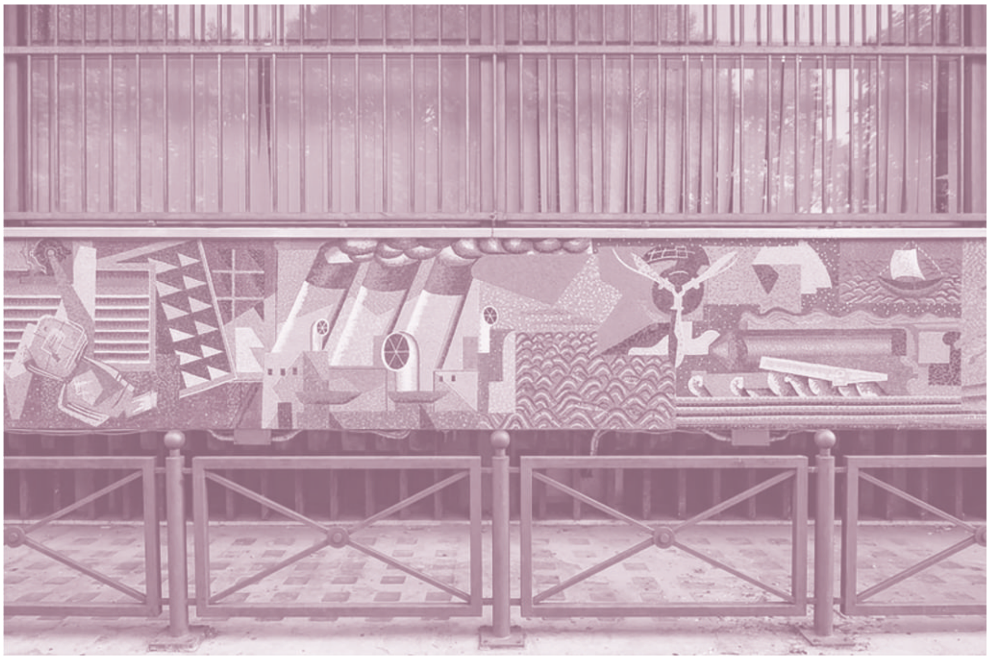


Fig. 30. *Figure: Post Office Building (1939-1941) – Architect Franco Petrucci and Artist Gino Severini.* Source: Flickr.com by Xavier de Jauréguiberry – taken on August 9, 2022

of his was met with little appreciation and a lot of controversies with the mayor calling it "the ugliest building of Piedmont"[93].

This is when a committee was formed comprising Marcello Piacentini, Armando Melis and the superintendent Vittorio Mesturina to evaluate the architectonic value of the building. Eventually the committee decided to accept this piece of architecture as a rationalist experiment but also insisting Petrucci to intervene with façade upgradation. It is when the artist Gino Severini was hired to enrich the "bare and poor façade" with mosaics[94]. The mosaic, located on the base band, is 37.8 m in length and 1.2m in height, realized between 1940-41. The mosaic depicts the continents such as Oceania and Asia on one side and Africa and America on the other side, while the central one is dedicated to the history of post office and telegraph. There is another smaller mosaic in the internal atrium of the building by Severini. Through this work, the artist aimed to illustrate the modern city, dominated by functional dynamism and increasing development of the modernization of services and transport[95].

In the post-World War II scenario, many buildings suffered the damage and there was a need for reconstruction and restoration of buildings. Central to the transformation was the Borsalino hat factory. The economic shifts after the war, the decline in demand and the lower production of hats led to the relocation of the factory to Spinetta Marengo in 1980. This led to the demolition of most of the complex, leaving few buildings to be preserved on the site. The previously occupied site created new urban voids which called for redevelopment, attracting architects like Ignazio and Jacopo Gardella. The only remaining identity of the Borsalino factory was it Chimney, the demolition of which, in 1987, symbolized the end of an era. The site remained a void until 1988, when Ignazio Gardella was employed to design the first Esselunga in Alessandria along with a residential complex to blend industrial heritage with modern needs[96]. The design of Esselunga remains a trademark of Ignazio Gardella's legacy to date. The whole site of the factory was repurposed into residential development, a university campus and community spaces. Despite these changes, the Borsalino brand, after bankruptcy in 2000s, was saved by an Italo-Swiss company Heares Equita. The company continues to produce high-quality hats till today, sustaining a legacy of craftsmanship and pride for Alessandria[97].

The career of Ignazio Gardella flourished in the postwar period, encompassing a range of projects that demonstrated his commitment to blend functionality with aesthetic sensitivity. In early 1950s,

94) *Ibidem.*
95) "Città Futura" di Alessandria. 2019. *"Il mosaico del Palazzo delle Poste di Gino Severini."* In *Alessandria: 850 anni di Storia*, edited by Renzo Penna and Giancarlo Patrucco, 114. Alessandria: Camera del Lavoro provinciale di Alessandria.
96) Dameri, Annalisa. 2007. *Alessandria 1950-2000: Da Gardella a Krier tra rinascita e rinascimento urbano.* In *Monferrato : lo scenario del Novecento*, edited by Valerio Castronovo and Enrico Lusso, 79-89. Alessandria: Cassa di Risparmio di Alessandria: Fondazione Cassa di Risparmio di Alessandria.
97) Ponzano, Cesare. 2019, *op. cit.*, p. 109.

Borsalino commissioned Ignazio Gardella to design the Employee housing near the Borsalino factory, where he was already involved in building post war damages. This project, with its distinctive curved façade and Klinker finishes, became one of Ignazio's defining works[98]. Inspired by modernist principles, he highlighted movement in architecture, a trait many aspired to bring to life in architecture, also hinting the futurist movement. His other notable projects included, the Hair Cutting Plant (1949-1956), and the technical institute ITIS A.Volta (1959-1967), a children's hospital (1964-1969) and transforming and upgrading Borsalino Shop at Corso Roma in 1956. Ignazio's later projects in the 80s, such as the supermarket and the residential complex on the former Borsalino site, showcased his ability to adapt industrial heritage to modern needs and the complex became a multi-generational architectural intervention[99].

Fig. 31. *State Technical and Industrial Institute ITIA – A Volta* by Ignazio Gardella (1959-1967). Source: Flickr.com by Xavier de Jauréguiberry taken on April 24, 2023.

In the later 80s, a large block freed up, opposite to Esselunga, on Corso Cento Cannoni, where the architect Paolo Portoghesi was invited to design a residential complex, now called Residential Park Borsalino. This building stands out in contrast to the rest of the surroundings because Portoghesi tried to incorporate his personal approach while revisiting some of the Baroque elements in this building. Some of the noteworthy elements are the balconies, with a tapered roof structure, and the variation of windows, which appear in the sense of verticality alongside the structure of balconies, making the façade and overall complex look lighter.

The urban renaissance in Alessandria can also be experienced in the small neighbourhood of Pista, not far from the interventions of Gardella and Portoghesi. The demolition of the Olva factory in Pista district invited the first project of the Luxembourgish architect Leon Krier in Italy[100]. Krier being one of the main theorists of "New Urbanism", sees urban villages as places to recover values of "human scale intimacy and vibrant street life". Krier rejects twentieth century architectural modernism and city planning and advocates a more traditional architecture that honours materials, techniques that celebrate a place's history and character. His aesthetic approach is to find the beauty in the classical orders which he believes are timeless and linked to the lifespan of humanity[101].

The project of "Borgo Città Nuova" in the Pista district was signed between Gabriele Tagliaventi and Léon Krier and built between 1995-2000. In this neighbourhood, the approach or Krier is very evident through the classical elements and vernacular architecture, in repetition of some fundamental and spatial construction types, the universal expression of human activities, work and pleasure altogether. In this project, Krier revisited the classical architectural archetypes and combining motifs

98) Dameri, Annalisa. 2007, *op. cit.*, p. 81.
99) *Ivi.*
100) *Ibidem, p. 87.*
101) Krier, Léon. 1998. *Architecture: Choice or Fate?*, Papadakis Publisher.
102) Dameri, Annalisa. 2007, *op. cit.*, p. 87.

Fig. 32 and 33. *Figures above and below: Residential Park Borsalino by Paolo Portoghesi 1987-1991.* Source: Flickr.com by Xavier de Jauréguiberry taken on April 18, 2023.

from the towns of Po Valley, more specifically Piedmonts' features[102]. In addition, he imagined a walkable neighbourhood by creating a civic and urban character of the neighbourhood by the geometric configuration of structures, avoiding the grid-layout, to control the traffic flow and keeping the human scale intact.

The courtyards, porticos, and alleyways echo the paths of a village within a city, a place closed within itself and in constant dialogue with its surroundings. The square opening onto Corso IV Novembre, dominated by a bank building with a disproportionately large column on the façade, acts as a self-referential monument marking the entrance into the urban space, while also setting the stage for an unusual area of habitation within a city with a metamorphic architectural history[103].

Throughout these decades, Alessandria's architectural and industrial evolution reflected a dynamic interplay between tradition and innovation. The legacy of Borsalino family, the Gardella architects, and subsequent urban planners and designers highlight the city's journey through a period of profound change. While many landmarks of the industrial past were lost, the enduring influence of this period continues to shape Alessandria's cultural and physical landscape, offering insights on how cities can be navigated between heritage and progress.

103) Dameri, Annalisa. 2007, *op. cit.*, pp. 87-88.

Fig. 34. *Borgo Città Nuova – View from Via Antonio Pachinotti*. Source: Flickr.com by Xavier de Jauréguiberry taken on April 18, 2023 April 18, 2023.

Fig. 35. *Figure: Borgo Città Nuova – Character of internal streets.* Source: Author – Taken on June 27, 2024.

Borsalino, a catalyst for economic growth and development

Borsalino non è un capello qualsiasi, è il capello. Ma è lontano della luci di Hollywood che questa storia ha inizio[104]

In 1857, Giuseppe Borsalino, an Italian entrepreneur founded the Borsalino factory. This industry was a trendsetting company, it bloomed in a period where "you couldn't think about going outside without a hat"[105]. It emerged as a small factory located in the center of Alessandria, with a daily production of 60 hats in 1861, and continued over time, until it was established itself as an award-winning firm. By 1871, the company increased its production to 300 hats daily with 130 employees, making the factory emigrate outside the city to facilitate future expansions. The popularity of Borsalino designs reached beyond Italian borders, even making their way to the Hollywood screen. The international market validation towards Borsalino in the last 20 years of the 19th century gave the company the boost to reach the industrial Olympus, with 1,250 employees and 750,000 hats produced, where approximately two thirds were exported[106].

Understanding the history of the Borsalino industry and its establishment in Alessandria allows the acknowledgment of both, the citizens' perspective on the industry's growth and the inverse. This means, as the company grew, so did the city. Understanding growth not only in terms of expansion, but in terms of development, due to the integration of different services which gave the citizens a better quality of life. In this way, it can be understood that Borsalino

104) "Borsalino is not just any hat, it is the hat. But it is far from the lights of Hollywood that this story begins" translation from Italian to English by author. From *Borsalino City* (2016). Directed by Enrica Viola. Italy: Istituto Luce Cinecittà.
105) "Non si poteva pensare di uscire senza il cappello", original quote from Erica Viola, 2016, *Ibidem*.
106) Annalisa Dameri, *La storia degli edifici, la memoria dei luoghi: le architetture dei Gardella in Alessandria*, La Tadeo DeArte 7, no. 8, 2021: in press (Translated by author).

Fig. 36. *Alain Delon and Jean Paul Belmondo in "Borsalino"*, 1970. Adel Productions, Marianne Productions.

107) Annalisa Dameri, 2021. *Ibidem*, p. 7.
108) Boidi, Sergio. 2009. Tre generazioni di architetti per una città, January, p. 151.
109) Marcello, Feola. 2023. *Alluvione 1994: questa mattina il ricordo delle vittime*. 11 6. Accessed 12 2024. https://alessandrianews.ilpiccolo.net/2023/11/06/alluvione-1994-questa-mattina-il-ricordo-delle-vittime/.
110) Annalisa Dameri, 2021, *op. cit.*

was not just an economic motor for Alessandria, but also a social one, making Giuseppe Borsalino an entrepreneur but also a philanthropist among the community; "this leads them to become the promoters and supporters of the urban growth of Alessandria in the first decades of the twentieth century"[107], converting this city into a modern and efficient one for its residents.

When Borsalino decided to shape the future of Alessandria, this city was a blank canvas, which lacked public infrastructure, this led Borsalino to finance major public works for 51,600,000 lire at that time over Alessandria[108]. Some of their projects had an industry connotation like the design of the factory itself, others were private commissions[109], such as villas, and others were more related to the improvement of the city like the aqueduct which was constructed between 1924-1927 after WWI.

Under the leadership of its founder Giuseppe, the Borsalino industry also proposed social and welfare initiatives such as donations in favour of the wounded of the Third War of Independence and the fallen of Africa. Besides these initiatives, he also put forward architectural constructions aiming at the welfare of the community, an example can be the children's hospital or the Educatorio Borsalino, a school that provided an education for the workers' children. In 1900, after Giuseppe's death, his son Teresio Borsalino (1867-1939) took over the company. Like his father, he was a philanthropist, which gave Alessandria economic and community-focused initiatives and projects, especially since in 1902 he entered to the municipal council representing the business aristocracy. Teresio's patronage and the achievements he realized increased after WWI.

Throughout the city, he proposed a series of buildings to meet the needs of the citizens. This involved working in both, the public and private sectors to provide structures related to industry, health, education, housing, and more. Many of these commissions were entrusted to Arnaldo Gardella and Luigi Martini. The relationship between the Borsalino family and Arnaldo Gardella began the same year Giuseppe Borsalino passed away, when Gardella won the contest for the expansion of the mental hospital. This event marked the start of a long collaboration between both parties.

"If the Borsalinos were the protagonists of the social and economic life of the first half of the century, and Alessandria the stage on which they moved, it was only through the projects and works signed by the two Gardellas that the desired and tenaciously pursued architectures would take shape"[110]. saying this, it is worth to highlight the projects initially commissioned to Arnaldo Gardella, such as the Hospice of Divine Providence (1923-1925).

This project started thanks to Mother Teresa Michel's work in Alessandria. In 1893, she initially established a school for the poor and disabled, and then expanded her work to include caring for the elderly, disabled, and beggars. She provided shelter and comfort to these people at her residence on Via dei Martiri. Subsequently, she purchased a property on Via Faà di Bruno to continue her mission. Later, Borsalino saw the inadequacy of the premises on Via Faà and decided to build the hospice. A building to serve as a shelter for the poor, with an initial investment of 50,000 lires and with an area of almost 17.000 square meters[111]. This project was able to provide administration rooms, laboratories, classrooms, dormitories, a church and a nursery, while hosting 500 people under its characterized twentieth-century neo-Romanesque style given by his architect Arnaldo Gardella.

By understanding the lack of public services in Alessandria at the time, as previously mentioned, Teresio Borsalino managed the creation of the aqueduct in 1924, which also prompted the consideration of a sewage system. This second project began in 1926, based on plans designed by the municipal technical office in 1914. The first section of the sewage system was completed in 1928, extending to 2,000 meters of ducts. At the time, this was recognized as "one of the greatest glories of the revered Senator Borsalino"[112]. Thanks to his contributions, the sewage system expanded between 1928 and 1936, ultimately reaching approximately 40,000 meters of ductwork. These two projects became a great example of how Borsalino invested in increasing the quality of life in Alessandria by modernizing the city.

Another example of Teresio Borsalino's commitment to the citizens of Alessandria were his efforts in tuberculosis treatment. It all started in 1912 when the Congregation of Charity highlighted the importance of having a dedicated unit for people with this disease. At that time, tuberculosis patients were sharing a department with other patients, this situation led to dangerous contagious conditions. In 1914, the idea was to provide a temporary tuberculosis department while waiting for the construction of a new unit. Unfortunately, due to the economic problems implicated by WWI (1914-1918), this initiative was set aside. Nevertheless, Teresio Borsalino did not forget the issue and gave funds to improve the environment in which these patients were currently hospitalized.

Tuberculosis was becoming a frequent problem among the hat factory workers. Therefore, in 1925, Senator Borsalino contributed again to the cause, providing funds for the construction of the Sanatorium Vittorio Emanuele III. In 1930, the design commissioned to Arnaldo Gardella (Later, his son Ignazio Gardella took his place) and Luigi Martini began its construction. Later, in 1935, the Sanatorium started their operations, becoming a building capable of hosting 216 beds, which benefits from seven auxiliary services, one of them being the church and where Teresio's efforts were reflected as the sanatorium gave priority admission to factory workers with more than three years of service.

An additional project worth highlighting is the rest home on Corso Lamarmora. While it is true that the building is primarily intended for the elderly, this project demonstrates Borsalino's concern for the entire city. He decided to undertake this work to provide employment for the unemployed. He remarked "The job crisis is serious, universal, and also

111) Guido, Barberis. 2000. *La famiglia Borsalino. La fabbrica e le opere*. In *Alessandria e Borsalino: Città, Architettura, Industria*, edited by Vera Comoli, Annalisa Dameri and Vilma Fasoli, pp. 55-90. Cassa di risparmio di Alessandria SPA.
112) *Ibidem*, p. 81.

spread to my factory, which plays no small part in the economic life of the city. For reasons of charity and civic duty, I have decided to personally fund the expansion of the rest home, which will come at some financial sacrifice. But I do it with happy heart because I'm fulfilling a duty as a Christian and as a citizen"[113]. Once again, Borsalino showed his commitment to the city.

Fig. 37. *Casa riposo Corso Lamarmora*.

The sanatorium, and the rest home are two of many projects that Borsalino assigned to the Gardellas (Arnaldo and Ignacio) and Luigi Martini. They became a key asset for the Borsalino family, and their bond strengthened over the years through different commissions the industry entrusted them with. Commissions for the city like, the modernization and expansion of the retirement home, the children's hospital; Private commissions, like a Villa in Santa Margherita Ligure for the Usuelli family (partners and cousins of the Borsalinos); Commission which helped and evoke the necessities and growth of the company, like the office building for the factory itself, "which represents the factory as a work temple, while the inside provides a mix between art deco and classic architecture"[114].

Even though after 1928, year where Arnaldo Gardella died. The report between these 2 protagonists in Alessandria (Borsalino and Gardella) didn't finish. The commissions that were first entrusted to Arnaldo trespass with the same truthfulness as to his son Ignazio Gardella. Some of the projects that passed through this transition were: Rest home in Corso Lamarmora, the mother house of divine providence and the Vittorio Emanuele III Sanatorium. These design projects were entrusted to a very young Gardella, whose architecture style had not yet matured, and who had not yet earned either his engineer or architect title.

The 1930s, being the pre-war period, could also be understood as Gardella's formation years. The Chapel-altar for the fallen in the Varinella war (1936) was designed, though not constructed until 2005. Through its formal synthesis it showed the reflections from Gardella over rural traditions; "two stone block walls support a reinforced concrete slab, while a brick grid, (…) serves as the backdrop tot eh simple altar. This grid is the real standout of this minimalist work, which introduces into the avant-garde lexicon the theme of the wall perforated by light"[115] this same

113) *Ivi*.
114) Boidi, Sergio. 2009. *Op. cit.*, p. 151.
115) *Ibidem*, p. 155.

Fig. 38. *Sanatorium Vittorio Emmanuele III.*

concept was replicated by Gardella in the Anti-Tuberculosis Dispensary of Alessandria (1936-38), the project which put Gardella on the map as one of the masters of Italian architecture in the twentieth century.

At the end of the thirties before the WWII stroke, Alessandria went through a time of grief after Teresio Borsalino passed way in 1939. By that time, his philanthropic achievements were well-known as he had left Alessandria with several projects. Providing a recap, the most notable were the aqueduct, the sewage network, and architectural projects carried out in collaboration with the Gardellas and Martini, such as the hospices for the poor and elderly, and the dispensary and sanatorium for the anti-tuberculosis, the last one having a church annexed to its services. And thus, the thirties concluded for Borsalino with a decline in their productivity and with the establishment of a new leader, to whom the factory is entrusted during a post-war period. Even though the philanthropist had no direct heir, the company continued under family leadership with Teresio Usuelli, the brother of Aura Usuelli, she was in fact the niece of Teresio Borsalino and the wife of Ignazio Gardella since 1933.

After the war, Ignazio Gardella was still the reference architect in Alessandria, and the city once again was able to receive the high-quality buildings designed by the architect. By this time his architecture style was already mature, a perfect combination between Italian traditional architecture and the modern movement according to Giuseppe Samona (Italian architect and urban planner)[116]. Projects such as the expansion of the children's hospital (1947-1973) and the industrial technical institute A. Volta (1959-1967) are some of them. Without losing the track between Ignazio and the Borsalino Industry; Teresio Usuelli, followed the same philanthropic steps of his predecessors, continued rewarding his employees, helping the city and tried to reborn the imaginary of the company which was damaged after the WWII[117], therefore, Usuelli entrusted Gardella with: the oversaw of the arrangement of a Borsalino shop in Corso Roma (1956); the reconstruction of Borsalino factory, which was seriously damaged during the air raids of 1944; the hair cutting building (1949-1956), which was a decision made during a directive meeting on April 12 of 1945, were they understood that having into account the technical, sanitary and hygiene components it was better to design a new building rather than refurbishment the existed one; and the house for the employees (1947-1952).

"Unfortunately, the story of Borsalino under Usuelli, as well as that of his successors, did not live up to the Senator: changes in fashion and taste, along with an unwillingness to diversify production, led the hat

116) *Ibidem*, p. 157.
117) Davio, Barbara. 1997. *La conservazione dell' architettura moderna : le opere di Ignazio Gardella in Alessandria - Thesis Supervisor: Luciano Re, Chiara Occelli.* Thesis of Laurea in Architecture.

Fig. 39. *Borslino Shop in corso Roma.*

118) Davio, Barbara. 1997, *ibidem*.

factory into an inexorable decline, resulting in the abandonment of the historic establishment"[118], therefore in the early eighties the factory relocate its production and at the end of the decade the factory went through the near-complete demolition of the factory. The physical spaces of Alessandria's collective memory are beginning to fade. Alongside the factory, we have the dispensary and the sanatorium for anti-tuberculosis, which have been vacant and uninhabited for many years, as medical treatments have finally succeeded in eradicating the disease.

The citizens of Alessandria had to confront reality that the Borsalino company would not return to its former glory. In the blink of an eye, any remaining hope disappeared on May 28, when the old factory chimney was brought down by the fire brigade. Globally, Borsalino was recognized as a renowned Italian luxury hat manufacturer, but for Alessandria, it represented much more: a symbol of the city, an economic lifeline for families, and a driver of community growth. Borsalino contributed to the quality of life for its citizens by funding various architectural projects, by proposing cultural and sports initiatives, by implementing social protection measurements such as birth benefits and daycare. The company established an industry-city model that understood and addressed the needs of its workers, therefore Alessandria citizens.

The chimney, a symbol in the Alessandria urban skyline was erased, but the memory of Borsalino's actions perdure, the same as the projects entrusted to the Gardellas. Thus, in Alessandria "remains the hair cutter, designed by Ignazio Gardella, stripped of its original context, and the office building, designed by his father Arnaldo in the twenties, destined to be restored and give a new function"[119]. As the office building, the dispensary and the sanatorium for anti-tuberculosis followed the same path. As already said, the aim is to restore the buildings and later introduce a new function, in the case of the dispensary the new function would be to become a polyclinic, while the Sanatorium was chosen to become a hospital for the rehabilitation of long-term patients. Unfortunately, the flood that occurred in the nineties delayed the projects and in the case of the Sanatorium, due to lack of funds, not all the annexed buildings in the complex have been restored, such as the church.

On November 6 of 1994, the Tanaro River causes significant flooding in the city. The extent of the impact varied based on proximity to the river and the orography of the area. The buildings designed by Gardella that were affected by the flood included: the Sanatorium Teresio Borsalino, the A. Volta technical institute, house on via Trotti, rest home on Corso Lamarmora, the Children hospital, the prophylaxis lab and the Anti-tuberculosis dispensary. The last three buildings marked the flood's boundary, while the Sanatorium, situated 350 meters from the river's left bank, suffered the most damage. The basement floors were completely flooded, the water high on the uppers floors was about 50 cm, while in the ground floor of the sanatorium, as well as in the annexed buildings including the church, the caretaker's house and the laundry the water reached approximately 137 cm high (Davio 1997).

After the flood, the project to repurpose the buildings could be resumed. In the case of the dispensary, which became a polyclinic, it is important to highlight that this project was commissioned to Ignazio Gardella. During the threshold of the 1990s he had the opportunity to work once again on his masterpiece. This time, he decided to incorporate a ramp into his design, adding an element which provided an asymmetrical composition to the facade. He revived his iconic building of Italian modern movement, removing it from its state of abandonment and providing (once again) a new space for the

119) Annalisa Dameri, 2021, *op. cit.*

Fig. 40. *Piazzetta della Lega flooded by Tanaro river.*

community. Working on the dispensatory would be his last commission in Alessandria, but his final project was working next to his son Jacopo Gardella (1935-2021) by providing new solutions for an Alessandria which is closing the twenty centuries.

When the Borsalino factory was demolished, Alessandria was left with an empty space in the urban trace. This area from a real estate perspective, was suitable for developing a residential and commercial zone. This event allowed different architects such as Paolo Portoghesi, Leon Krier and Jacopo Gardella, while also maintaining the traditional architect, Ignazio Gardella, to solve the new needs the city was undertaking. Ignazio and his son were commissioned to design an Esselunga supermarket and Agora complex (1984-1991), a residential and commercial project. This multifunctional project features a set of large windows that recall the openings of the old factory. Through this approach and other details. Such as materials, the design creates a link with tradition while simultaneously seeks innovation.

The architectural legacy of Gardella Family

4.1 The Dynasty of Gardella Family

120) Boidi, Sergio. 2009. *Op. cit.*, p. 150.

In life there are a variety of activities learned, by example from an early age some of them are used in daily life, such as walking or talking, while others are just achieved by experts. In this way is well known Ignazio Gardella, an engineer, a designer and a Master of Moden Italian architecture in the twentieth century. Born in 1905in Milan, Italy, and raised by a family of Genoese origin, Gardella´s future as a master of architecture was shaped form an early aged, owing to his family´s legacy in this field or architecture and engineering until the date of his death in 1999.

His grand-grandfather, named in the same way - Ignazio Gardella Sr. (1803-1867) – was an architect who worked in Genova and acquired some of his skills while studying under Carlo Barabino, a well-known Italian architect of the neoclassic period. The dynasty continuous with Jacopo Gardella (1845-1923) – the grandfather of Ignazio Gardella – with him the architectural ties with Piedmont began to form, although, it will be noted that these ties were not the first connection between the Gardella family with the region. In the eighteen century the mayor of Arquata – a province of Alessandria located in Piedmont – was the grandfather of Ignazio Sr. In this province, the Gardella family had a country residence. This set of events let Jacopo Gardella build a wooden bridge over the Scrivia torrent between Arquata and Varinella suburb in 1890[120].

In life there are a variety of activities learned, by example from an early age some of them are used in daily life, such as walking or talking, while others are just achieved by experts. In this way is

Fig. 41. *Ignazio as a kid, the father Arnaldo and his grandfather Jacopo* Source: memora.piemonte.it - Di generazione in generazione.

well known Ignazio Gardella, an engineer, a designer and a Master of Moden Italian architecture in the twentieth century. Born in 1905in Milan, Italy, and raised by a family of Genoese origin, Gardella´s future as a master of architecture was shaped form an early aged, owing to his family´s legacy in this field or architecture and engineering until the date of his death in 1999.

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121) *Ivi.*

As a poetic was of passing down the architectural torch within the family, later in 1912-1914, Arnaldo Gardella (1873-1928) – Jacopo's son – replaced this wooden bridge with a brick one. As the third generation maintaining the family legacy, Arnaldo Gardella, in partnership with

Fig. 42. *Wooden Bridge to Varinella by Senior Jacopo Gardella in 1890. Source: Chieketè – Associazione Storico Culturale Serra Vallese e dell'Oltregiogo*

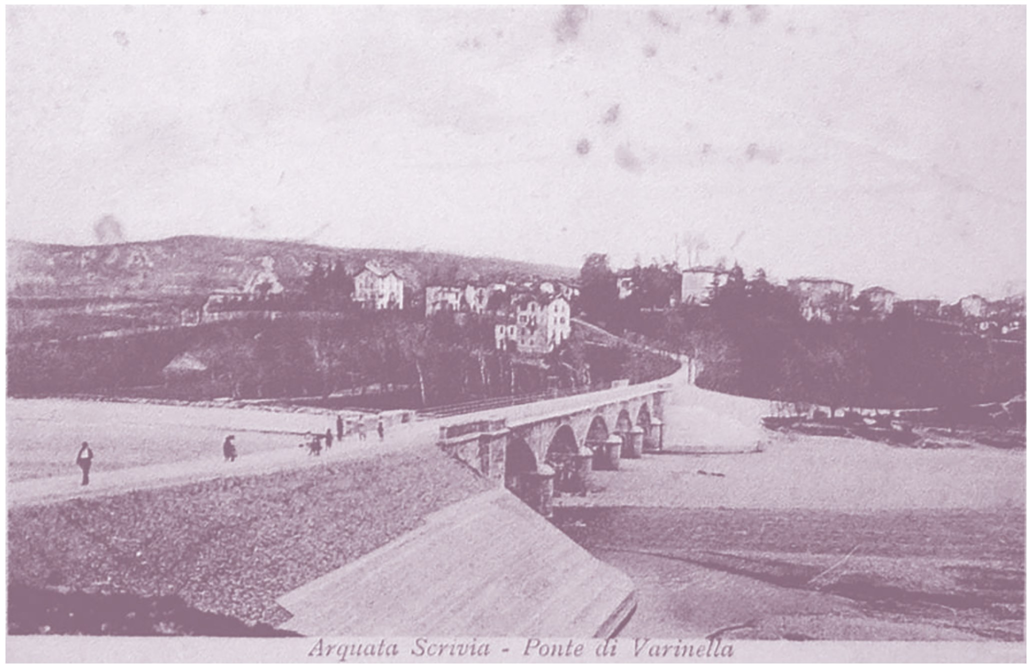


Fig. 43. *A brick bridge to Varinella designed by Arnaldo Gardella from 1912-1914.* Source: Chieketè – Associazione Storico Culturale Serra vallese e dell'Oltregiogo.

the engineer Luigi Martini, managed a Milanese studio which is well known in Alessandria for the projects they complete over this territory. "The relationship between the Gardella family and Alessandria became really close starting from 1900, the year in which Arnaldo won the competition for the expansion of the asylum"[122].

The projects designed by A. Gardella and L. Martini in Alessandria were primarily commissioned by Borsalino, the renowned hat factory that served as the city's economic and social motor. Besides providing employment, Borsalino also supported various social welfare initiatives. Among the notable works commissioned to Gardella and Martini were the Ospizio della Divina Provvidenza and the expansion of the Casa di riposo. Even after the death of A. Gardella in 1928, the rapport between the city and his family of architects did not end. In his twenties and before being able to finish his engineering studies, Ignazio Gardella – Arnaldo's son – was called upon to replace his father after his death. The tragic event had a positive outcome, where Ignazio Gardella had the opportunity to oversee unfinished projects while working alongside his father's partner, L. Martini; three years later, in 1932 Ignazio Gardella graduated in civil engineering at Polytechnic of Milan and in 1949 he graduated as an architect from the Faculty of Architecture at IUAV Venice.

122) *Ivi.*

Fig. 44. *Infant Hospital (Ospedale Infantile) by Ignazio Gardella.*

123) Annalisa Dameri, 2021, *op. cit.*, p. 8.
124) *Ibidem*, p. 3.

The objects that were undertaken in a first step by father (Arnaldo) in Alessandria and later subsequently directed by son, marking a new step in the responsibilities entrusted to Ignazio Gardella, were: Ospedale infantile "Cesare Arrigo" in 1932, rest hhouse in corso Lamarmora, Mother house of divine providence, and the "Sanatorium Vittorio Emanuele III", in this last project, the small church is annexed (1930-1931). Although the aforementioned projects are landmarks in Alessandria, none of them were responsible for putting "Ignazio Gardella on the map. It was in the thirties when Ignazio signed the anti-tuberculosis dispensary, the building that consecrated him among the masters of Italian architecture of the twentieth century"[123]. In front of it stands the Prophylaxis building. Both structures exhibit a strong urban connotation, but each of them understood it in a different way, in this way 2 buildings planned by the same architect but designed through different styles, showcased the skills Gardella had.

In simple words, commissioned by the Borsalino family, "Arnaldo Gardella and his son Ignazio designed in Alessandria some of the most emblematic architectures of the Italian twentieth century"[124] making this city an open-air museum. In here residents and visitors can enjoy two different languages, the transition projects between father and son, and the understanding of diverse needs through time and culture. In addition, people can observe how these architects focused principally on economic growth and social welfare. For example, the office building by Arnaldo Gardella enhanced the local economy; the housing for Borsalino employees by Ignazio Gardella addressed social needs. These examples still stand today, the first one has lost its original context and use, while the other continues to benefit itself with the boulevard in front of it.

Fig. 45. *Courtyard of the Ex-Borsalino Factory – currently a university residence and mixed-use complex. Building to the left was designed by Arnaldo Gardella in 1925, and to the right was designed by both Ignazio and Jacopo Gardella.* Source: Author – Taken on June 27, 2024.

In the 80s the decision to demolish a significant portion of Borsalino's industry building was made. The office part, designed by Arnaldo Gardella, remains to this day, though it is now used for different purposes. The resulting space became suitable for Jacopo Gardella (1935-2021) to work alongside his father, Ignazio Gardella. Together they designed the Agora, a residential and commercial complex. Thanks to these new projects where Jacopo Gardella was called, the people of Alessandria can appreciate three out of five Gardella's generations in the same space, "three generations of architects summoned at different times to address the presence (and absence) of one of the world's most important hat factories"[125]. In this way it is not possible to talk about Ignazio Gardella without addressing Alessandria and Borsalino. Borsalino as a creation motor, Gardella as the creation brain and Alessandria as the workshop where these two protagonists set up a plan for the city.

125) *Ibidem*, p. 10.

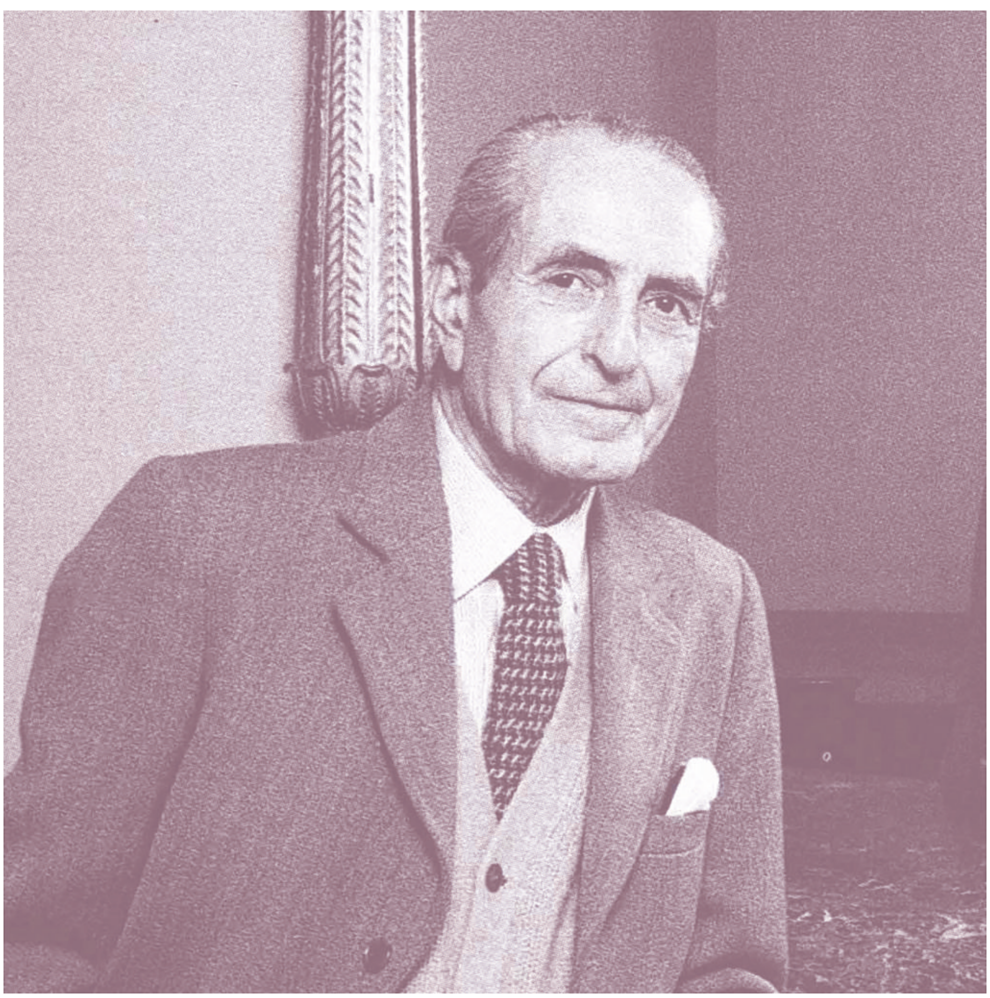
Fig. 46. *Agora complex Building.* Source: Flickr.com by Xavier de Jauréguiberry – Taken on April 18, 2023.

126) Davio, Barbara, 1997. *Op. cit.*
127) Boidi, Sergio. 2009. *Op. cit.*

4.2 Ignazio Gardella and His Architectural Ideology

Ignazio Gardella (1905–1999) represents a cornerstone in the evolution of Italian Rationalist architecture, a movement that sought to balance modernist ideals with the historical and cultural complexities of Italy. Born in Milan to a long line of architects, Gardella's practice was profoundly shaped by his lineage, early academic training, and subsequent professional experiences. His architectural philosophy emphasized the ethical dimensions of design—an approach that not only adhered to Rationalist ideals of functionality and simplicity but also sought to humanize and contextualize modernist architecture in ways that resonate profoundly with contemporary discourse.

Fig. 45. *Architect Ignazio Gardella.*



Gardella's Architectural Philosophy: Bridging Rationalism and Humanism

At the core of Gardella's ideology lay a commitment to reconciling Rationalism with the humanistic traditions of Italian architecture. While Rationalism in Italy was often perceived as an austere and somewhat dogmatic pursuit of pure forms, Gardella's work stands apart for its warmth, sensitivity, and contextual depth. His philosophy transcended the rigidity of Rationalist principles by incorporating elements of local tradition, material tactility, and historical resonance[126-127].

Educated at the Politecnico di Milano, Gardella graduated in engineering in 1931, a training that endowed him with a rigorous understanding of structural systems. His early exposure to the works of Giuseppe Terragni, the architectural debates in Casabella led by Pagano and Giolli, and his interactions with international figures such as Alvar Aalto further shaped his understanding of architecture as both technical and cultural practice. The influence of Aalto is evident in Gardella's nuanced use of materials and his focus on designing spaces that respond to human needs and environmental contexts[128].

Gardella's works often display an acute awareness of their surroundings, both in terms of their urban and socio-historical context. For Gardella, architecture was not merely an imposition on a site but an active participant in shaping the cultural and physical identity of a place. This contextual sensitivity is particularly evident in his works in Alessandria, where he engaged deeply with the urban and industrial fabric of the city. The Borsalino family, major patrons of Gardella's projects, provided him with a fertile ground to explore these ideas.

128) *Ibidem*, pp. 150-151.

Fig. 46. *The façade of Sanatorium showing rhythm, functionality and standardization.* Source: Source: Flickr.com by Gianluca Giordano – Taken on April 19, 2014.

129) *Ibidem*, p. 155.

Integration of Tradition and Innovation: Materiality and Contextualism

Gardella's ability to synthesize tradition and innovation is perhaps best exemplified by his projects in Alessandria, where he employed a vocabulary that merged the Rationalist ethos with the specificities of the locale. The Dispensario Antitubercolare (1938) is a paradigmatic example of this synthesis. The building's façade features a dynamic interplay of materials—brick, glass blocks, and concrete—organized within a rational grid that adheres to the principles of functionalist design while paying homage to the material traditions of the region. The use of brick grilles, inspired by local vernacular architecture, creates a subtle interplay of light and shadow, adding an almost lyrical quality to the structure. Raffaello Giolli's description of this approach as "lyrical modernism" aptly captures Gardella's ability to elevate functionalist architecture into the realm of cultural expression[129].

In the Sanatorium Vittorio Emanuele III, Gardella's reinterpretation of his father's earlier design reveals his commitment to harmonizing modernist principles with the demands of the program and site. The chapel within the complex, with its parabolic design and separation of spaces based on gender, reflects Gardella's sensitivity to both functional requirements and symbolic expression. The combination of minimalist detailing with traditional ecclesiastical elements creates a building that is at once contemporary and timeless.

Fig. 47. *Church by Ignazio Gardella in the Sanatorium of Teresio Borsalino.* Source: Flickr.com by Gianluca Giordano – Taken on June 1, 2014.

Gardella addresses the concept of proportions and rhythms by stating that:

> […] we seem to be able to recognize the topical stations of the design process: a conceptual incipit (and already rational in the election of the dominant geometric system); a complex intermediate phase of elaboration, on the double construction register: of the figures and the detailed measurements, and of the technologies and materials; a final stage of metric and material coordination, in which all elements of the construction are rearranged in a perfect figure, brought to completion. Elementary figures, proportions and rhythmic scansions are three technical principles that Gardella uses to put order in the jumble of design data[130].

Hence, his work is fundamentally simple, which constantly refers to the use of materials, proportionality and technology. This sense of simplicity gives the users a feeling of familiarity and liveability enhancing human experience.

Rationalism in Transition: The Role of Human Experience

One of Gardella's most significant contributions to 20th-century architecture was his redefinition of the role of human experience within the Rationalist framework. While Rationalism often emphasized the abstraction of form and the universality of design principles, Gardella grounded his work in the lived realities of users and communities. His residential projects, such as the Casa per Impiegati della Borsalino, illustrate this ethos. This project shows his post war adherence to Nordic-Empricism, which can be interpreted in terms of his friendship with Aalto in the 1930s[131]. Here, he introduced double-facing living spaces to maximize light and ventilation, ensuring that the functionalist principles of efficiency were complemented by considerations of comfort and well-being.

Similarly, the Taglieria del Pelo (1949–1956), an industrial building, demonstrates Gardella's ability to translate this human-centered approach into a typology traditionally associated with utilitarianism. The building's open-plan interiors, ample natural light, and carefully articulated façades reflect a sensitivity to the needs of workers, creating an environment that transcends mere functionality to foster a sense of dignity and community. As Boidi notes, this project underscores Gardella's belief in architecture's capacity to engage with the socio-economic dimensions of its context[132].

130) Porta, Marco, ed. 1985. *l'Architettura di Ignazio Gardella*. Milano: Etas Libri.
131) Boidi, Sergio. 2009. *Op. cit.*, p. 158.
132) *Ibidem*, p. 159.

Fig. 48. *Taglieria del Pelo Borsalino.* Source: FAI

Gardella's Legacy: A Modernism Rooted in Place

Gardella's architectural ideology is distinguished by its commitment to rooting modernism within the specificities of place and culture. His works in Alessandria, exemplify his ability to create architecture that is simultaneously functional, contextually resonant, and poetically expressive.

Gardella's legacy lies in his capacity to challenge and expand the boundaries of Rationalism, introducing a humanistic dimension that continues to inspire architects today. His work reminds us that architecture, at its best, is not only a response to functional demands but also a profound engagement with the cultural, social, and environmental dimensions of its time.

Conclusively, it can be said that Gardella's work emphasizes contextual sensitivity, material innovation, and displays a nuanced response to both cultural and functional needs. His work often transcended the often-rigid frameworks of modernism. His designs, from residential to industrial and healthcare buildings, demonstrate a profound commitment to harmonizing tradition with innovation, blending local identity with universal principles. His legacy continues to influence contemporary architecture, offering a timeless model of how design and thoughtfully engage with history, environment, and the human experience.

4.3 Prominent Projects of Gardella

Casa per impiegati della Borsalino

Teresio Borsalino's contribution to Alessandria extended beyond business encompassing projects aimed at enhancing the citizens' quality of life in domains such as health, housing and education. Among these initiatives, the "Casa per impiegati della Borsalino" stands out as a significant residential building designed by Ignazio Gardella. Initiated in 1947 and completed in 1952, this project underscored Gardella's exceptional ability to craft a timeless design adaptable to various family structures. Situated near the Borsalino factory and aligned with Teresio Borsalino main street, the building not only provided housing but also became a distinguished urban landmark, showcasing a harmonious blend of functionality and aesthetics. The final composition was achieved through a study of the needs and aims on different scales; therefore, the approach of this building would be divided into the following scales: relation with the city, common spaces, housing unit and the window.

Fig. 49. *North façade of the building facing Teresio Borsalino street.* Source: Source: Flickr.com by Xavier de Jauréguiberry – Taken on April 24, 2023

Building the city

Gardella's design for "la Casa per impiegati" was made through understanding the surrounding landscape as well as the cultural context. In this way each residential unit was influenced by the site's dual orientation, providing each unit with a view towards the city and to the countryside ensuring a poetic view, but also proper cross ventilation. Adhering to rationalism architectural principles, Gardella reimaged the traditional box, however, this box evolved to meet internal needs while also reflecting and understating on the external context.

"Breaking Gardella's Box" was made through a series of steps, each of them served for the functional and aesthetic purposes. These steps will be named by the authors as: fold, unfold, displace and hide, extraction and offset.

- **Fold**: The north façade features 4 planes; one parallel to the street, and other three folded "to enhance the irregular trade of the medieval city"[133] with rotation of -6° and 6°. Each plane represents a residential unit, and this step is also mirrored on the south façade,
- **Unfolded**: Applied on the south façade. Gardella interrupted the two vertices farthest from the building's central axis. This adjustment reduced the size of the planes and added a horizontal plane between them.
- **Displace and hide**: An outward offsetting of the horizontal planes on the south façade, allowing to locate hidden opening for ventilation and lighting or service areas without disrupting the composition of the main façade.
- **Extraction**: A volumetric adjustment across all the facades, creating terraces to provide a connection with the outdoors on the south while on the north façade this extraction created a new urban facade, giving the impression of three separate buildings instead of the traditional box.
- **Offset**: The roof strategy. A cantilever roof designed by the offset of the final footprint of the building, following a northern Italian architecture tradition. This final touch added a sense of lightness to the structure.

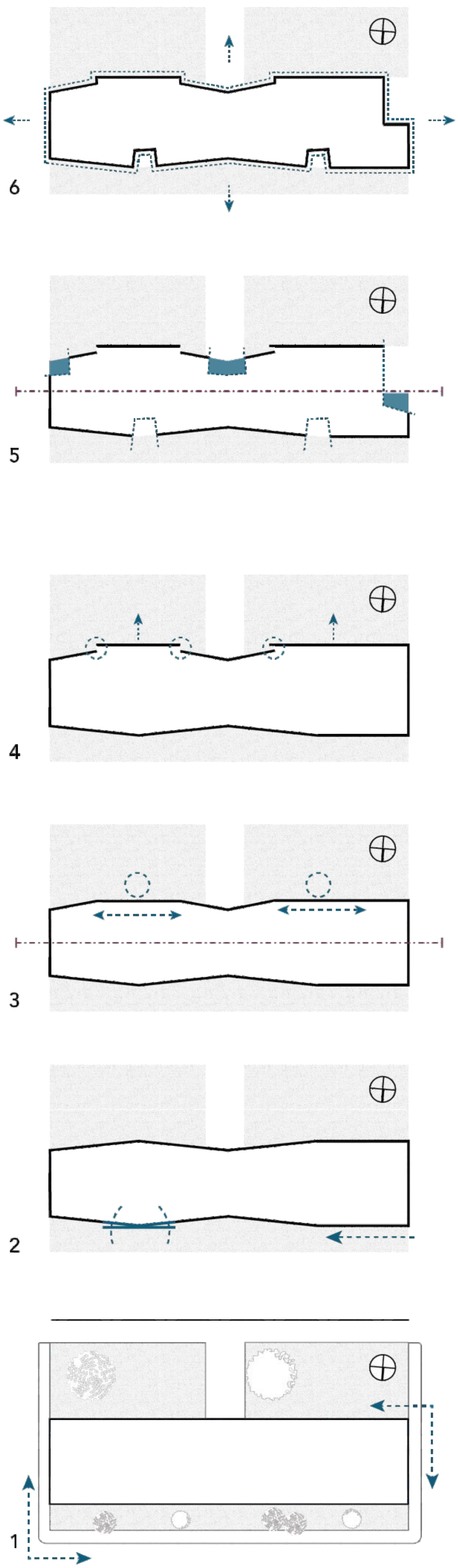


Fig. 50. *Showing the conceptual development of the project.* Source: Elaboration by the Authors.

133) Martinez, Carmen, and Rodrigo Pemjean. 2015. *De la Ciudad a la ventana Ignazio Gardella y las viviendas Borsalino en Alessandria. Cuadernos de proyectos arquitectonicos 5*, pp. 60-65. Translation by the authors.

Common spaces

The transition from the building urban environment to the interior of the building begins with two prominent positioned north-facing entrance. Each entrance is marked by a marquee that extends over the sidewalk, emphasizing the importance of planes in the overall design[134].

In the entrance, residents encounter an inclined ceiling with glass brick, which not only provided illumination but also guided the user towards the vertical circulation[135]. This core consists of a staircase and an elevator, connecting all eight floors, facilitating access to the 32 residential units (4 units per floor). Gardella's design for these shared spaces ensured functionality and ease of movement.

134) *Ivi.*
135) *Ivi.*

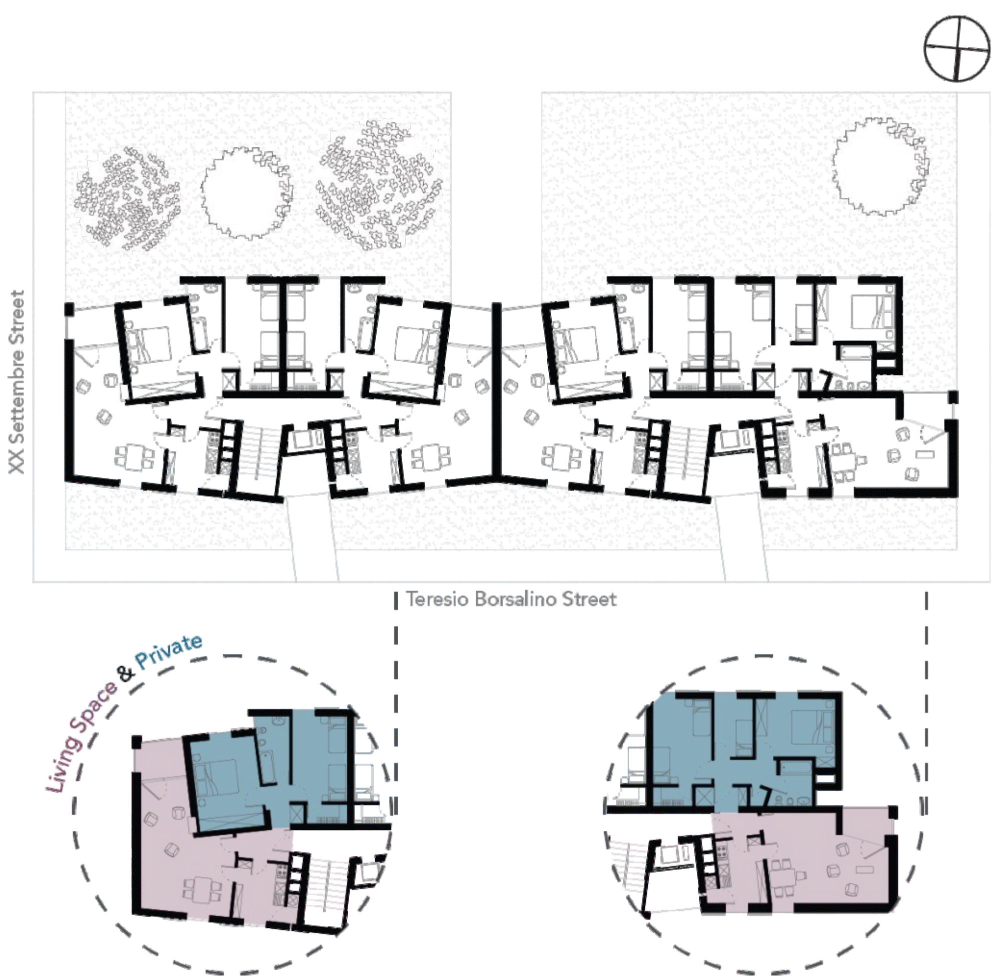
Fig. 51. *Principal Entrance.* Source: Emanuele Piccardo 2018 from *Atlante Architettura Contemporanea.*

The living space

Each floor of the building accommodates four residential units, where two different typologies can be found. Each unit is divided into private and public zones, where the social areas occupy a central role in the spatial hierarchy due to its dimensions. The living room is the only space that enjoys the perks of the bilateral façade, in this way, this space offers the residents a panoramic view on both sides, while in the north facade the residents enjoy the view through its floor-to-ceiling vertical windows, in the south they will enjoy the feeling of being outside through their terraces. The bilateral facade not only allows the user to enjoy different views but also contributes to a climate solution, which permits the residence to benefit from the cross-ventilation strategy. The private zones, compromising bedrooms and bathrooms, are thoughtfully oriented to ensure privacy and intimacy, which is why they are located towards the south, since the north façade faces the main street. This is elaborated in (Figure 52) below.

Gardella's innovative approach to the construction is evident in the continuous slab flooring system under the partitions (non-structural dividing walls). This methos ensures maximum flexibility over time, as changes in the layout requiring partial or full demolition of the dividing walls would not necessitate a change in the flooring. A small but significant detail about the flooring to add is that the heating system is embedded in the floor. This allowed Gardella to achieve places that feel clean without any visual disruption, enhancing a clear geometry following the rationalism parameters.

Fig. 52. *Plan showing the private and public space of each typology.* Source: Elaboration by the Authors.



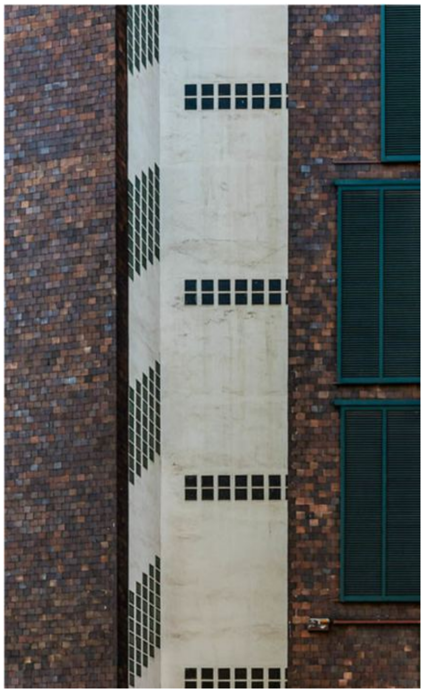
The window

The window module, a multifaceted element that balances functionality, flexibility and aesthetic appeal. Far more than a simple opening, the window plays a pivotal role in harmonizing the interior and exterior while providing practical benefits to the residents. Each module comprises three distinct layers, each designed with a specific purpose. The innermost layer features a curtain rail, offering residents privacy and shading options as required. The middle layer consists of a glass window from top to bottom, constructed from painted white Douglas fir, which provides uninterrupted views and contributes to the facade's harmonious rhythm. The outermost layer is a green Douglas fir shutter with a lattice design, mounted on a sliding mechanism; this shutter ensures privacy and climatic control while adding a dynamic visual element to the façade. In simple words this module was designed to adapt to each user, because it can regulate the amount of light and wind through the day, creating a flexible and dynamic interplay.

The innermost layer is the connection between the residents and the city, while the other layers reflect the connection between the building and the city, demonstrating once again how Gardella thought this building through the scales, and gave to the city a building which evokes flexibility through a module that also helps to emphasize the building's slenderness and verticality through the proportion of the module. Besides putting his attention on the main module, Gardella also proposed a secondary type of window, they are characterized by being glass bricks which are in areas like

Fig. 53. *Window module demonstrating their flexibility and rhythm feature.* Source: Emanuele Piccardo 2018 from *Atlante Architettura Contemporanea.*

Fig. 54. *Glass bricks.* Source: Flicker.com by Jacqueline Poggi – Taken on April 24, 2023.



the stairs and the bathroom. The glass bricks, with their ability to diffuse light while maintaining privacy, embody Gardella's innovative spirit and sensitivity to both utility and design harmony. The glass brick, being a single layer, does not provide the same efficiency as the 3 layers of the main module. For example, in winter the main module can close its glass layer to prevent wind entering and open the shutter allowing the light to pass, creating a greenhouse effect, while the glass brick will remain the same under this condition or any other.

Conclusion

On the street, everyone can notice the differences between us, particularly phenotypes differences such as height and facial features, which are the most immediately identifiable. However, there is another aspect that is noticeable but often overlooked, except perhaps by architects: the way we live. People walk the same street, but each person experiences it differently. This includes walking at different paces, seeking shade at different times and needing different amount of space to feel comfortable. Despite these differences, the city is ideally designed for everyone, as we all live in it.

In the same way, Gardella understood the design of the residential building, and his understanding has ensured that, even today, despite the social and urban changes that have occurred around this building, the house "La Casa per Impegnati" remains a relevant project whose use has not changed in the face of different paradigms.

Fig. 55. *South Façade view from Via Messina.* Source: Flicker.com by Jacqueline Poggi – Taken on April 24, 2023.

The reason is that Gardella understood he had a type of user "family". However, this macro user is characterized by their origins, evolutions and needs. In other words, his achievement was designing a building that reads the cultural landscape rather than the fleeting fashion, that shows its flexibility in the floor plan allowing to address housing problems for the XX family but also the XXI century family and finally he undresses the climatic perspective of the area ensuring a comfortable area for its users.

Antituberculosis Dispensary

At the age of 28, Gardella received his first dual commission in the public sector: the antituberculosis dispensary and the provincial laboratory of Hygiene and prophylaxis, both projects located in Alessandria and facing each other. Designed during the 1930s, these projects represent the evolution of Italian architecture in the interwar period. Even though both are in front of each other, each building has their one features in terms of design, constructive system, and materiality. The dispensary established Gardella as one of the great masters of the XX century in Italian architecture, earning recognition and publication in prominent magazine of the time such as Casabella and architecture d'Aujourd'hui.

Fig. 55. *South Façade view from Via Messina.* Source: Flicker.com by Jacqueline Poggi – Taken on April 24, 2023.

Gardella conceived a unique architecture grounded in constructive truths serving a program of needs as the ultimate driver of its architectural form. It was not surprising for Gardella to deviate from the norms of the time to make certain design decisions. A clear example of this is in the design of the floor plan. As Gardella himself stated: "In those years, there was a governmental dispensary model that envisaged an irrationally symmetrical distribution scheme with separate waiting rooms for men and women, because tuberculosis was considered a shameful and sexually stimulating disease. Since it was a dispensary, a place for diagnosis and not for cures like a sanatorium, there was no reason, and it was even counterproductive, to separate the waiting rooms. Therefore, I designed a single, large, very bright waiting space, common to both men and women, from which one could directly access the various spaces for medical consultations, as well as laboratory and radiology tests"[136].

In the same way as this architect was concerned with floor plan issues, his attention and advancements were also evident in the elevation and materials. Gardella's sectional façade design explains why the façade has a clean design without visual obstructions; the focus was on creating structural pillars that free the façade. As the master himself said in one of the interviews carried out by Monestiroli in 1995, "At that time, thinking about the structure independent of the enclosure was difficult, whereas today it is a normal occurrence". The relationship between structure and en-

136) Vitale, D. 1989. *Ignazio Gardella. Arquitectura.* Revista de COAM 259: pp. 11-19.

137) Visconti, Federica. 2013. *La "forma giusta" dell'architettura. Il dispensario antitubercolare di Ignazio Gardella.* 21: pp. 146-153.
138) Ros, Jordi. 2023. *El plano como representación del volumen: dispensario antituberculoso en Alessandria (1933-38).* DPA: documents de projectes d'arquitectura (25). https://raco.cat/index.php/DPA/article/view/259907.

closure varies on each floor. In the basement, the structure is absorbed by the enclosure walls. On the upper floors, various setbacks are observed in relation to the two longitudinal façades.

The façade design was based on interior needs, highlighting the importance of the light. ""Light, which was essentially entrusted with the treatment of tuberculosis, becomes the protagonist - filtered, distilled, diaphragmed - of the spaces of this building through its relationship with the different elements and materials used"[137]. The aim of the façade is to generously illuminate the interior spaces while simultaneously preserving the privacy of its inhabitants. This is achieved through two strategies: first, a translucent glass block wall; and second, a perforated brick wall. This creates the effect of a façade "woven with two different meshes"[138] (figure 56).

For the formal construction of the main façade, besides focusing on materiality, the façade was also concerned about the pedestrian access. The original design of the dispensary included an asymmetrical entrance, but it was eliminated under pressure coming from the local authorities and the ministerial regulations specific to tuberculosis care, which required a more conventional organization. For the architect's satisfaction, the dispensary took a new direction. After tuberculosis rates declined, the dispensary was abandoned; in order to save one of Alessandria's landmarks, the municipality proposed a new program, a polyclinic. The building's restoration process was entrusted to Ignazio Gardella in the 1990s. During this opportunity, the master was able to restore some of the eliminated elements, such as the asymmetrical ramp for the main entrance.

Fig. 56. *South Façade view from Via Messina.* Source: Flicker.com by Jacqueline Poggi – Taken on April 24, 2023.

The dispensary is a clear example of how any building can fall into abandonment. This icon of Italian architecture, despite its significance, experienced a period of neglect. Such neglect can occur for various reasons; in the case of the dispensary, it was due to a program that was no longer needed. However, any building can be adapted and thus rescued. By converting the dispensary into a polyclinic, its functional relevance within the city was restored, marking a milestone in reconciling Gardella's architectural legacy with the contemporary needs of the community.

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Part II

The case Study

The Church in the Sanatorium of Teresio Borsalino

The Church in the Sanatorium of Teresio Borsalino

The case study for this thesis is a small Church designed by Ignazio Gardella in the complex of the Sanatorium of Teresio Borsalino (currently called the Rehabilitation center of Presidio Borsalino). This chapter explores the historical development of the complex, the architectural features and styles, its current state of the art and the decay. It also discusses the significance of the church within the broader narrative of the 20th century and expands upon its current state of preservation. This is done with the help of first examining the geographic, urban and environmental context of Alessandria. Then it moves into a deeper study of the architectural evolution of the sanatorium, which enfolds into discussing the changing function of the sanatorium to a rehabilitation center and finally it delves into a detailed analysis of the Church itself. This chapter establishes a foundation for understanding the integration of the Church within the sanatorium complex and that of the Sanatorium itself within the city's surroundings.

1.1 Site and Context Study

The Sanatorium complex, located in Alessandria, stands as a remarkable example of 20th century architectural innovation intertwined with public health objectives. The complex embodies functionalist principles while addressing the pressing healthcare needs of its time. The protagonist of this thesis, the small Church of Ignazio Gardella, within the Sanatorium is an architectural gem that reflects the evolution of modernist religious design.

In this part, the overall context of the study area will be introduced in the form of maps, which will give an insight into the current situation of the city's structure, land use and land cover, its transport connectivity, existing and potential landmarks and finally its immediate context in the micro scale.

Geographic and Urban Context

The Sanatorium is situated within the district of Borgo Cittadella of Alessandria which was previously a part of Orti district. The location of the districts can be referred to in Figure 1. Alessandria city itself is located approximately 90 kilometers southeast of Turin and 70 kilometers northwest of Genoa, making it a well-connected node within the Piedmont region. As already mentioned in the previous chapter in part 2.1, the city's location at the confluence of the Tanaro and Bormida rivers made it an ideal location for military servitudes. The footprints of these fortifications can still be witnessed in the structure of the city and in the development of its urban fabric.

The urban structure of Alessandria, as depicted in Figure 2, reflects its medieval origins, with a radial network of streets emanating from the historic core. As it was mentioned with the historical maps in the previous chapter, the city centre was previously the overall city enclosed within the fortified walls which began to be demolished in late 18th and 19th centuries for the growth of the city. Spalto Marengo, Gamondio, and Borgoglio, as shown in Figure 2, are the examples of streets developed over the old bastions. This radial layout highlights its strategic importance during its early history which in further development of the city has seemed to fade away. If we notice the city's development pattern, it seems to have been expanding more to the southwest direction, which can be due to presence of two almost parallel rivers which creates a natural barrier in the development of the city across the river. A strange phenomenon is also the underdevelopment of the district of Borgo Cittadella, which remains separated from the rest of the city due to presence of the river between the main city and this district. This isolation can also be due to the lack of connectivity between both sides of the river. Even though, at present, there are four vehicular bridges, and a railway track connecting both sides, however, it lacks the connection at a human scale. This is one of the reasons why the Rehabilitation Centre of Teresio Borsalino still stands far from the city, without any developed pedestrian, bike route or public transport connectivity.

It is important to mention that the city of Alessandria has been taking steps towards the urban requalification of the city, with a focus on social, economic and environmental sustainability principles. The city of Alessandria presented a program of intervention in 2011, for the recovery of the historical urban fabrics by the name of Progetto Integrato di Sviluppo Urbano P.I.S.U. "da Borgo Roverto al quartiere Cittadella" (Integrated Project for Urban development – from Borgo Roverto to Citadel district). The upgradation of the Cittadella district is focused on the revival of the river and the connection of the citadel with the city center. As part of this project, the Bridge of Meier was built between 2012-2016, where the architect has imagined providing separate access for the cars and pedestrian and cyclists which is a great addition to the city's urban fabric and attractions. In addition, to develop the riverfront, a park called Parco Italia has been developed and there are further plans to develop the riverfront[1]. These interventions can be very important in the future development of the church into another function.

1) Pleba, Paola. 2016. *Phenomenology of Urban Renewal. The experience of Alessandria. Tools, actors, projects*. Architettura Memoria Contemporaneità, 89-94. doi:DOI: 10.13128/Techne-19339.

The maps in the next pages show the location of Alessandria within the region of Piedmont and the structure of the city in the area of interest.

Accessibility and Connectivity

The sanatorium is located approximately 3 kilometres northeast of Alessandria's city center. This proximity ensures convenient access to urban amenities while maintaining site's semi-isolated character which was essential in the past for the healthcare facility related to Tuberculosis. Figure 3 shows the network of transportation infrastructure which connects Alessandria to other major cities via railways and highways, including the motorway of A21 and A26. It can also be noted that there is only one bridge which can be crossed by foot and the site is directly connected to the public transport stop which can help in arriving to the city centre in 20-25min.

Natural and Environmental Context

The location of the sanatorium was deliberately chosen to be within the pine forest along the banks of Tanaro River emphasizing the integration of natural elements for therapeutic purposes. The current scenario of the sanatorium and the city's surroundings depict that more than 70% of the land of the city is dedicated to agriculture, farming and pastures. The area's high productivity is driven by the cultivation of cereals, fruits, vegetables, vineyards, and the raising of livestock such as poultry, sheep, pigs, goats and horses. Figure 4 depicts the comparison of agriculture, forest, pastures and green spaces within the area of interest.

Land Use and Surrounding Features

As indicated in the land use map , Figure 5, the city centre is dominated by commercial and residential buildings typologies, whereas the site of Borsalino is isolated with a few sheds and barns as well as single family houses in its surroundings. The most important typologies to notice are the Hospitals and the Places of worship, since that is the typology of the case study. While Figure 6, indicates key landmarks within the city centre and the vicinity. They include the existing landmarks such as citadel, Meier bridge, Post office building, piazzetta della lega etc, and some potential landmarks have been proposed based on their twentieth century architectural significance. These potential landmarks celebrate Alessandria's modern history and deserve to be appreciated in the same way.

Immediate Context of the Site.

The sanatorium complex is located at the conjunction of Strada Carlo Forlanini and Via dei Preti as shown in Figure 7. It is spread over nearly 96,000 square meters, with 5,325 square meters dedicated to buildings, 22,000 square meters for roads, and 67,675 square meters for green areas. The central building houses patient wards, diagnostic and treatment rooms and a range of services[2]. The auxiliary buildings include nurse's quarters, Director's Residence, a small Chapel, Laundry, garbage and other service buildings. At present, there is also a sensory garden in the facility and a gre-enhouse right behind the chapel building.

2) Montanari, Guido. 2000. *Il Sanatorio Teresio Borsalino di Gardella: Dalla Costruzione All'Attuale Recupero.* In *Alessandria e Borsalino: Città Architettura Industria*, edited by Vera Comoli, Annalisa Dameri and Vilma Fasoli, 125-144. Alessandria: Cassa Ji Risparmio Ji Alessandria Spa, p. 32.

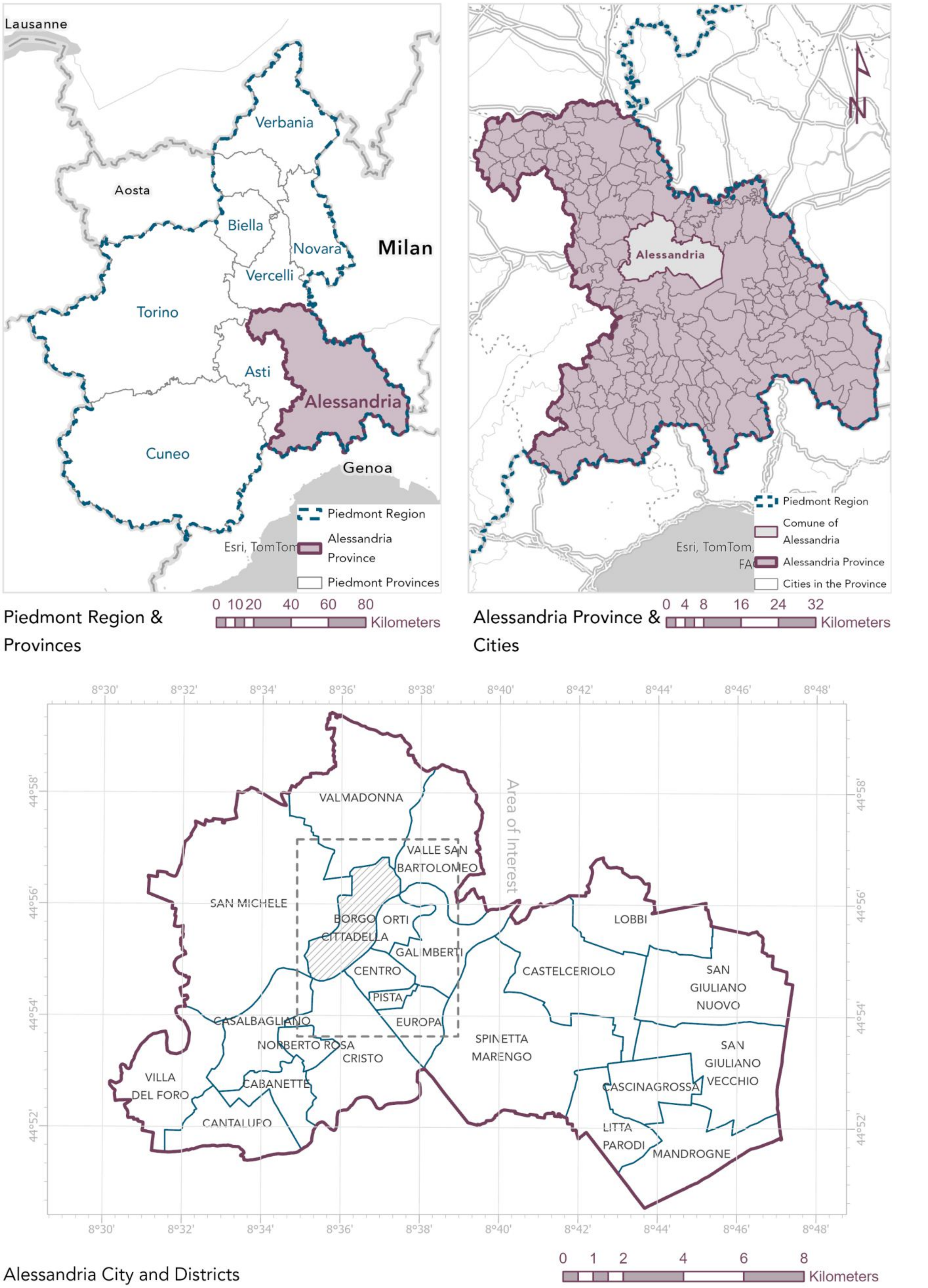


Fig. 1. Piedmont Region and Alessandria. Elaborations by authors, using ARCGIS Pro. Data from Geoportale Piemonte.

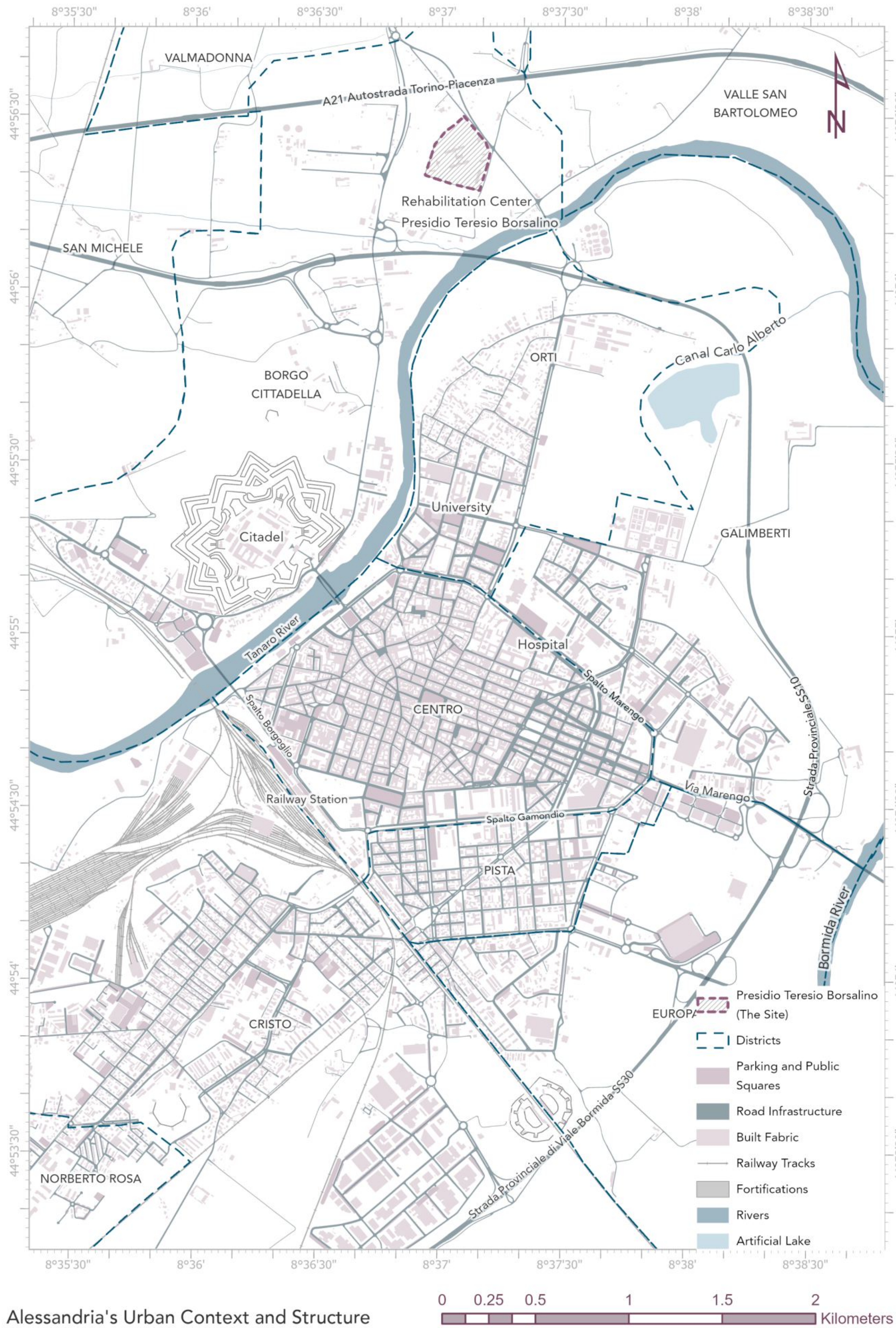


Fig. 2. Urban Context and Structure of Alessandria. Elaborations by authors, using ARCGIS Pro. Data from Geoportale Piemonte.

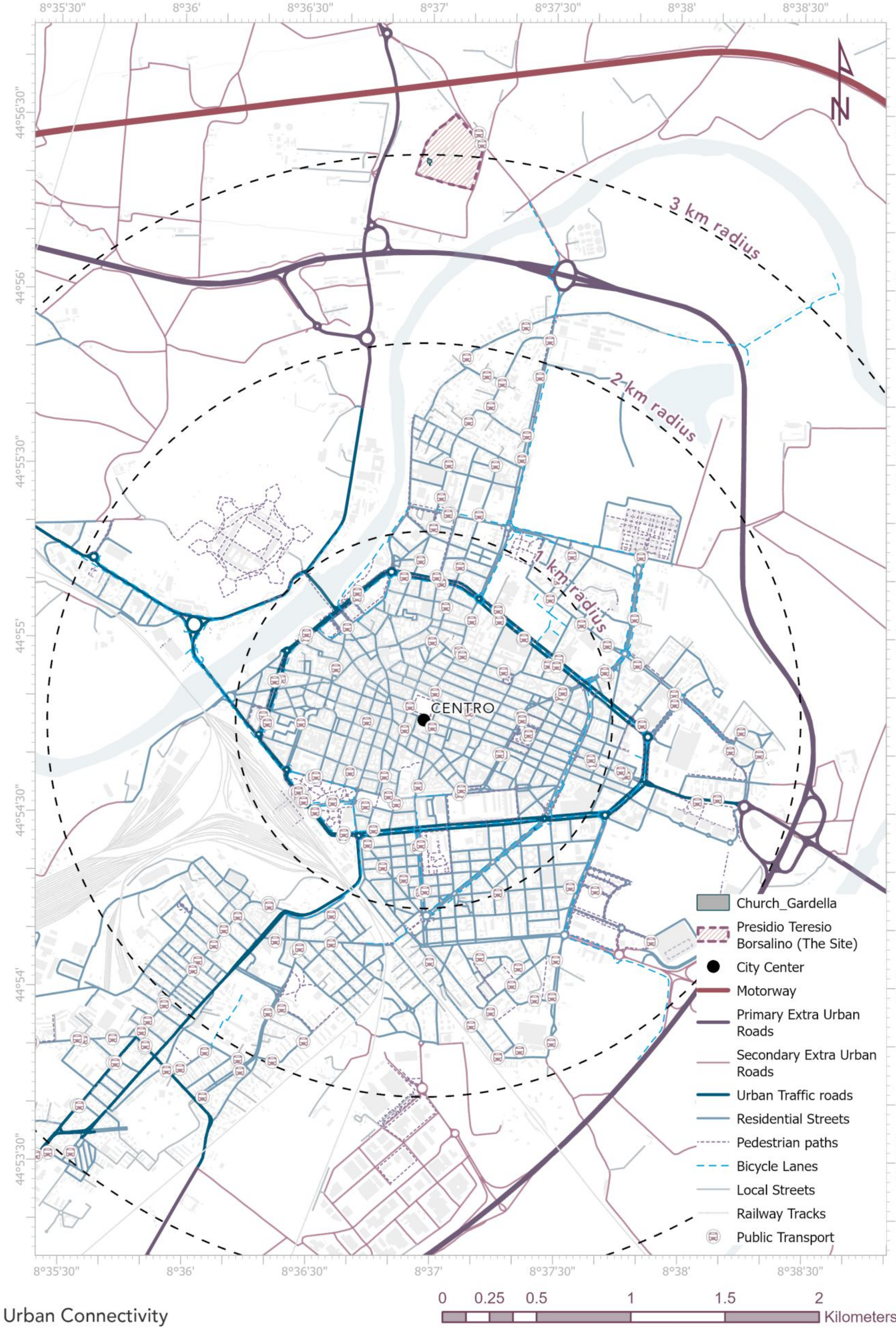


Fig. 3. Urban Connectivity of Alessandria. Elaborations by authors, using ARCGIS Pro. Data from Geoportale Piemonte.

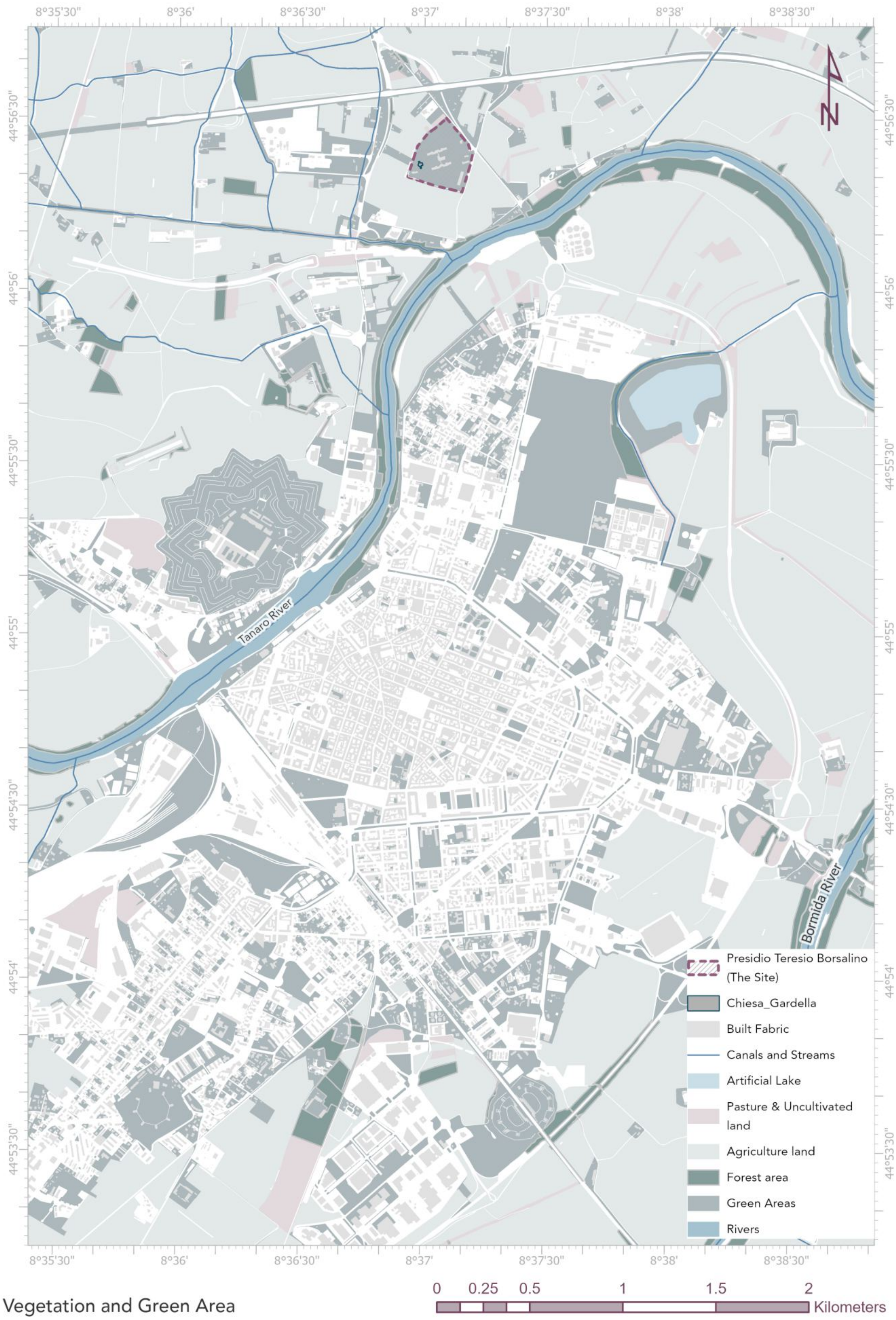


Fig. 4. Vegetation and Green Areas of Alessandria. Elaborations by authors, using ARCGIS Pro. Data from Geoportale Piemonte.

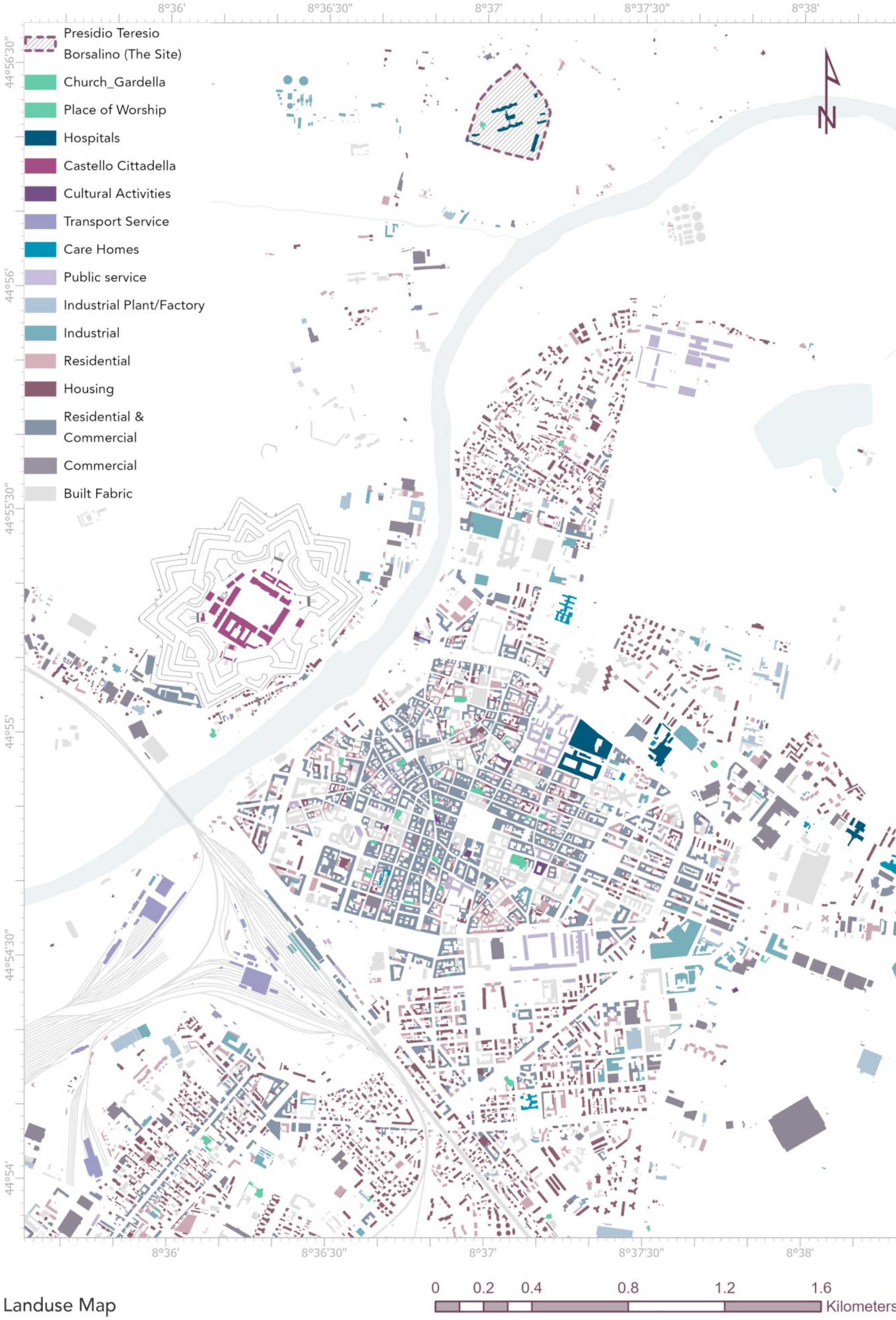


Fig. 5. Land Use Map of Alessandria. Elaborations by authors, using ARCGIS Pro. Data from Geoportale Piemonte.

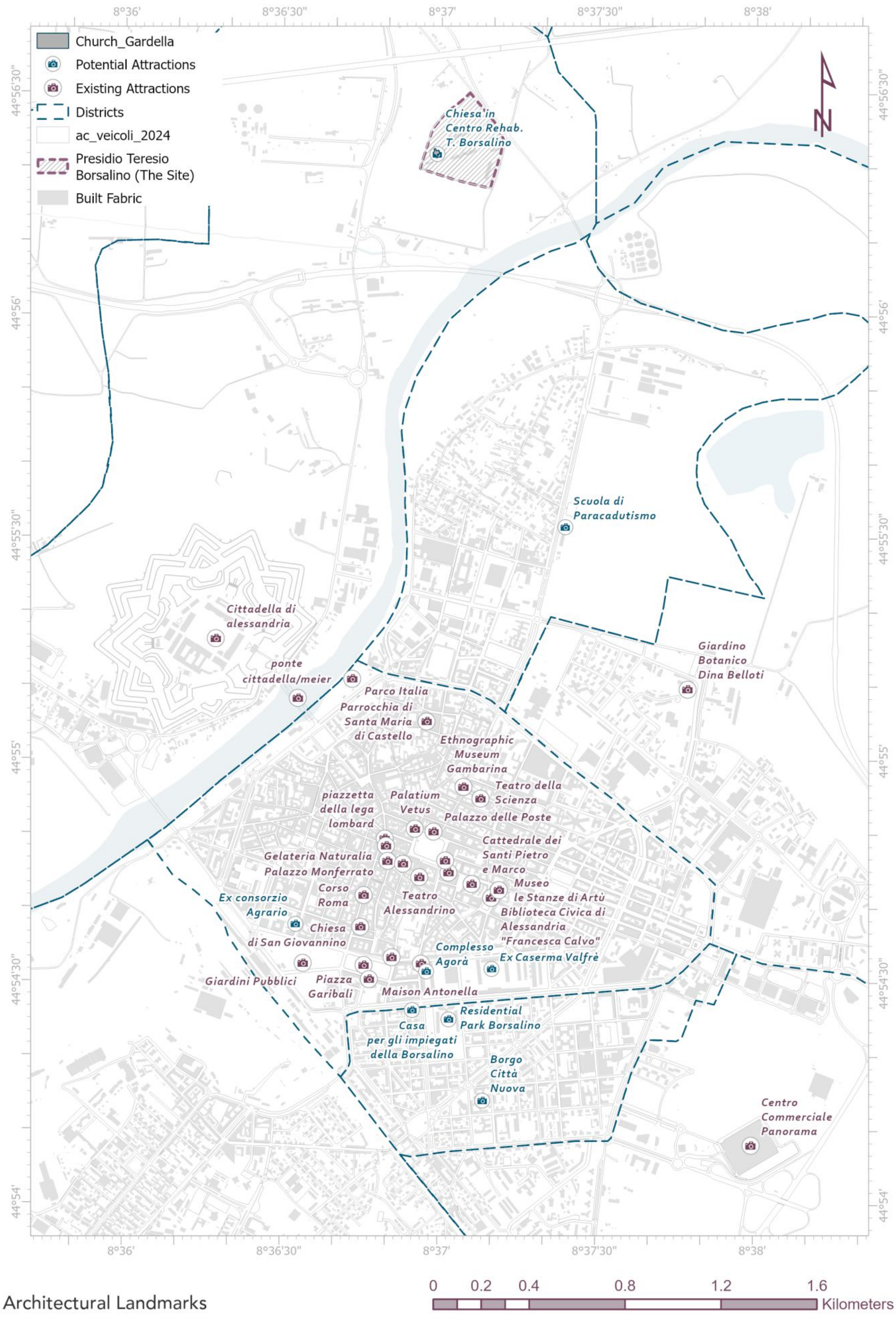
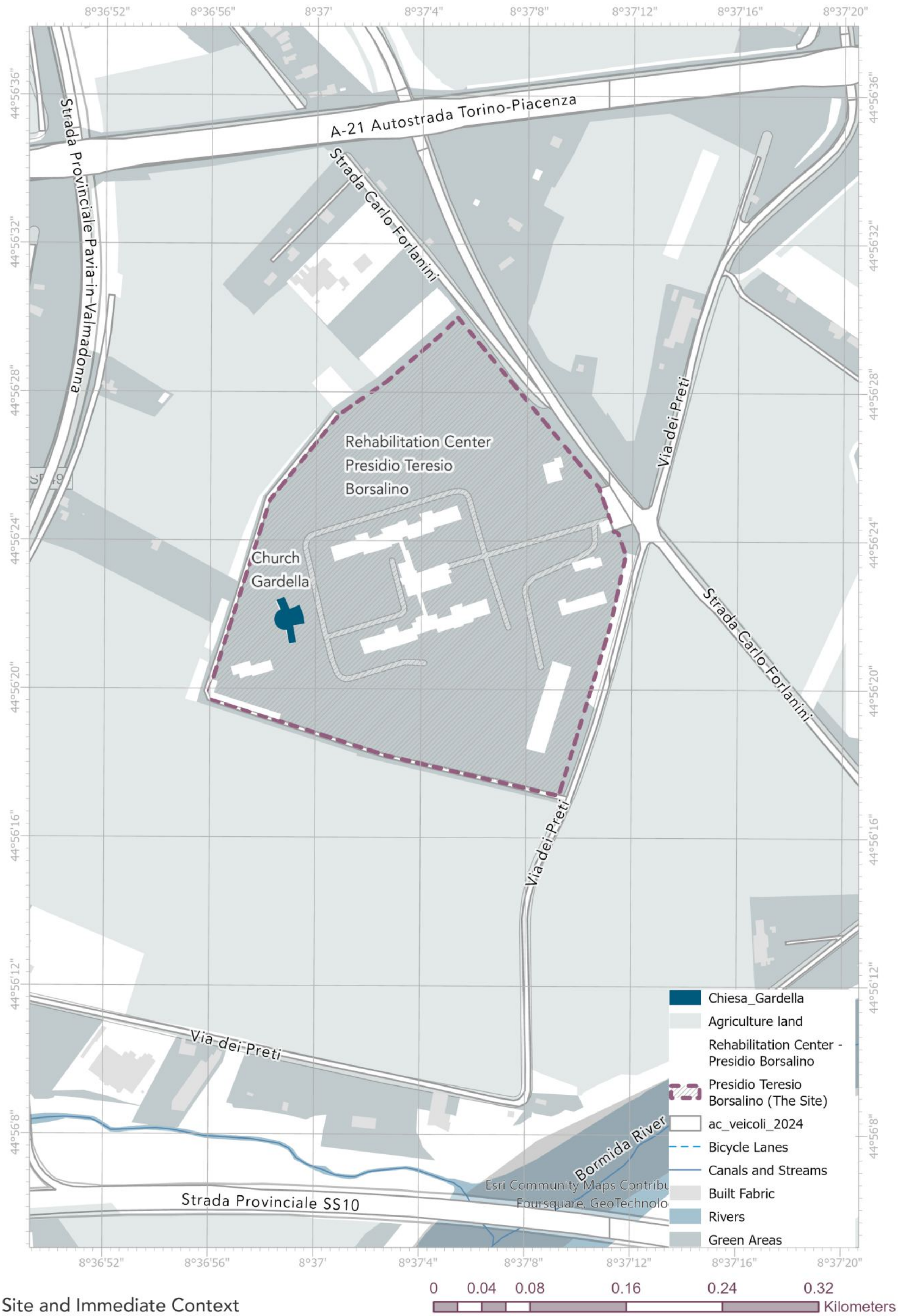


Fig. 6. Existing and Potential Landmarks of Alessandria. Elaborations by authors, using ARCGIS Pro. Data from Geoportale Piemonte.



Site and Immediate Context

Fig. 7. Site and Immediate Context of Alessandria. Elaborations by authors, using ARCGIS Pro. Data from Geoportale Piemonte.

The Sanatorium of Teresio Borsalino

The Sanatorium of Anti Tuberculosis of Teresio Borsalino, later dedicated to Vittorio Emmanuele III, exemplifies the convergence of architectural innovation and public health reforms in early 20th century Italy. This facility was a direct response to the devastating tuberculosis epidemic that plagued Europe at the time, with Italy among the worst affected. The establishment of the Provincial Anti-Tuberculosis Consortium in 1921, mandated by the Fascist government, marked a significant milestone in Italy's efforts to combat the disease. This consortium played a great role in addressing the crisis by creating specialized healthcare facilities, including the sanatorium[3].

In 1925, the project gained official approval when the Provincial Deputation allocated initial funds, and a public subscription campaign was launched to manage finances for the construction of the sanatorium. Senator Teresio Borsalino, an industrialist and a philanthropist, provided the crucial funding of ten million lire necessary to bring the ambitious project to fruition. The money from Borsalino helped in acquiring the land, the construction and the furniture and equipment for the hospital[4].

3) Davio, Barbara. 1997. *La conservazione dell' architettura moderna: le opere di Ignazio Gardella in Alessandria* - Thesis Supervisor: Luciano Re, Chiara Occelli. Thesis of Laurea, Torino: Faculty of Architecture, Politecnico di Torino.
4) Montanari, Guido. 2000, *Op. cit.*

Fig. 8. Presidio Borsalino – Currently a Rehabilitation centre. Source: arkitectureonweb.com – By Alessia Raponi May 06, 2019.
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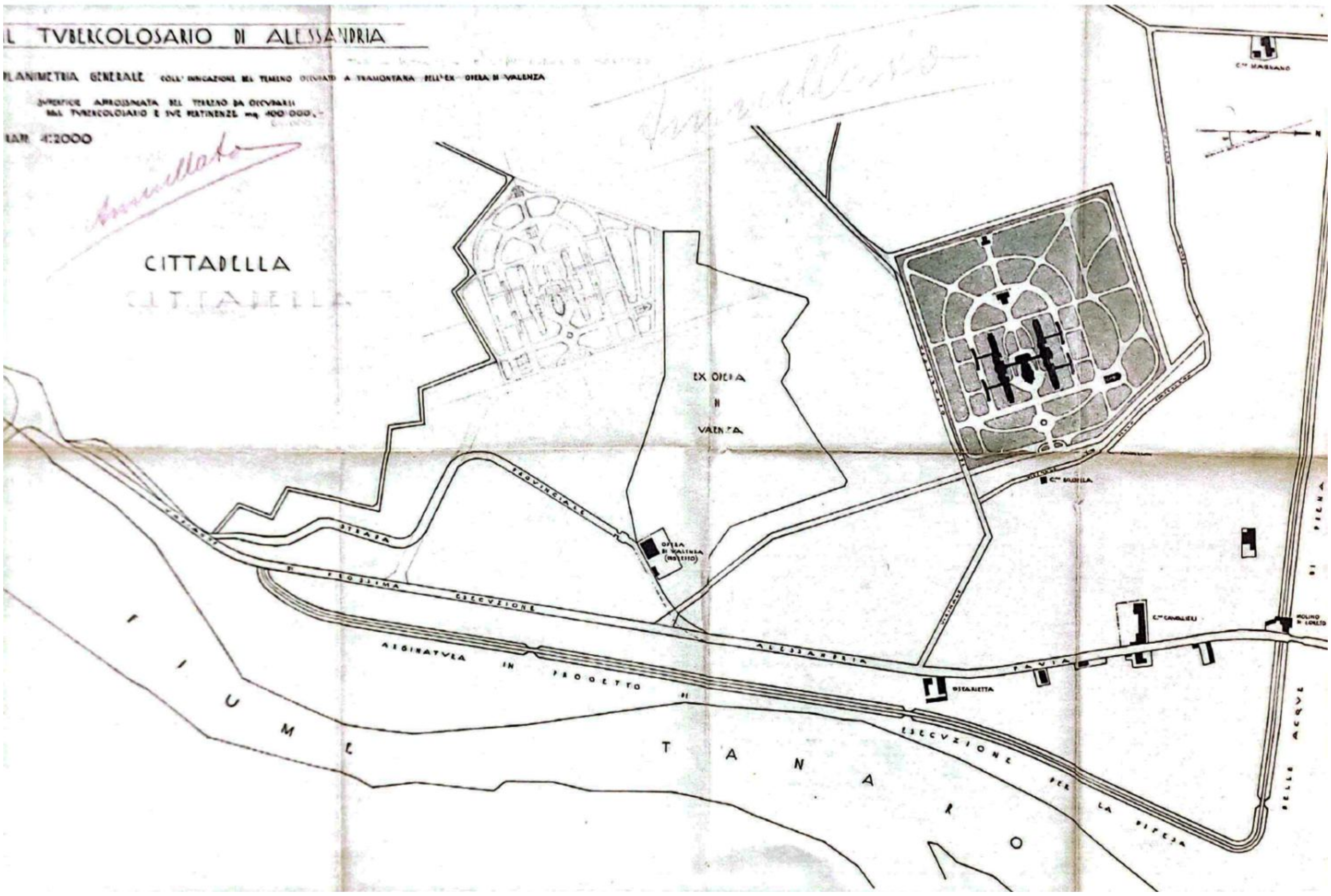
5) Montanari, Guido. 1989. *Razionalismo dimenticato ad Alessandria: il Sanatorio Terresio Borsalino e il Dispensario antitubercolare, opere prime di Ignazio Gardella*. Alessandria: Excerpt from: Bollettino della Società Piemontese di Archeologia e Belle Arti, Nuova serie, v. 43. In cop.: Atti del convegno *Antichità ed arte nell'alessandrino*.

This significant contribution ensured the complex could be completed to the highest standards of the era, reflecting both civic pride and the practical needs of the tuberculosis treatment.

The project was awarded to the engineers Arnaldo Gardella and his partner Luigi Martini, who opted for the "functionalist style" to design the Sanatorium[5]. However, in 1929, following the death of Arnaldo Gardella, the project was reimagined by Ignazio Gardella, who had recently graduated as an engineer from Polytechnic of Milan. Ignazio's involvement marked a significant departure from the traditional hospital designs of the earlier plan. He incorporated modernist principles, emphasizing the relationship between architecture, health and well-being, while also respecting the original layout designed by his father.

The original design prepared by engineers Arnaldo and Luigi in 1915, focused on a hospital for infectious diseases. However, due to material shortages and debates over location, construction did not commence until after World War I. The eventual selection of a pine-forested site along the Tanaro River in Alessandria aligned with contemporary medical theories advocating for the isolation of tuberculosis patients in natural, serene environments. The site located in the Orti district, which is now Borgo Cittadella, was perfect for the purpose of building as its selection was driven by practical considerations: its proximity to the urban center al-

Fig. 9. Entrance to the central pavilion from the west or rear façade. Source: Flickr.com by Jacqueline Poggi – Taken on April 23, 2023



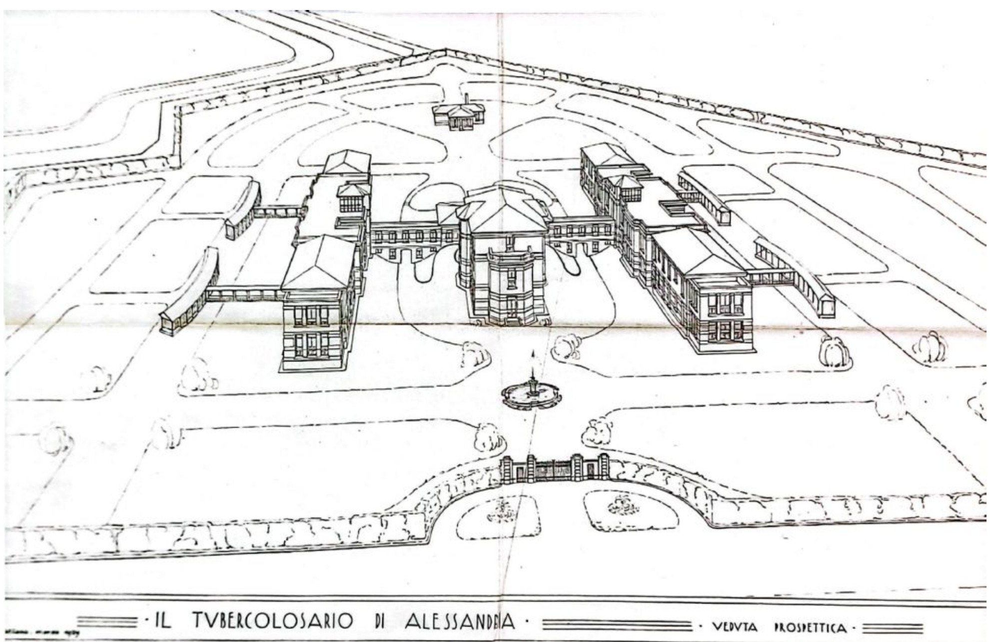


Fig. 10 (above). The first draft of the Sanatorium Anti Tuberculosis Alessandria (March 1929). Source: Archivio Gardella Oleggio[7].

Fig. 11 (left). The old Axonometric drawing of the sanatorium complex, which was later updated to a different layout by Ignazio Gardella and Luigi Martini. Here we can notice that the central building in located exactly in the center with a symmetrical layout and the church and the sanatorium building have a completely different architectural language to what was later realized in the 1930s. Source: Archivio Gardella Oleggio[8].

lowed easy access for medical staff, patient families, and supplies. Additionally, the area's location, being closer to the center, was intended to foster social interaction, providing patients with a sense of connection to the outside world. The design rejected the prevailing belief that high altitudes or coastal areas were essential for treating tuberculosis, instead focusing on the benefits of a nearby city that would provide ease of communication and care[6].

6) Montanari, Guido. 2000. *Op. cit.*, p. 130.
7) Di Franco, Andrea, Massimiliano Roca, and Guido Montanari, 2008. *I Gardella ad Alessandria, 1900-1996: architetture*. Alessandria, Palazzo del Monferrato: S.l.: s.n.
8) *Ivi*.

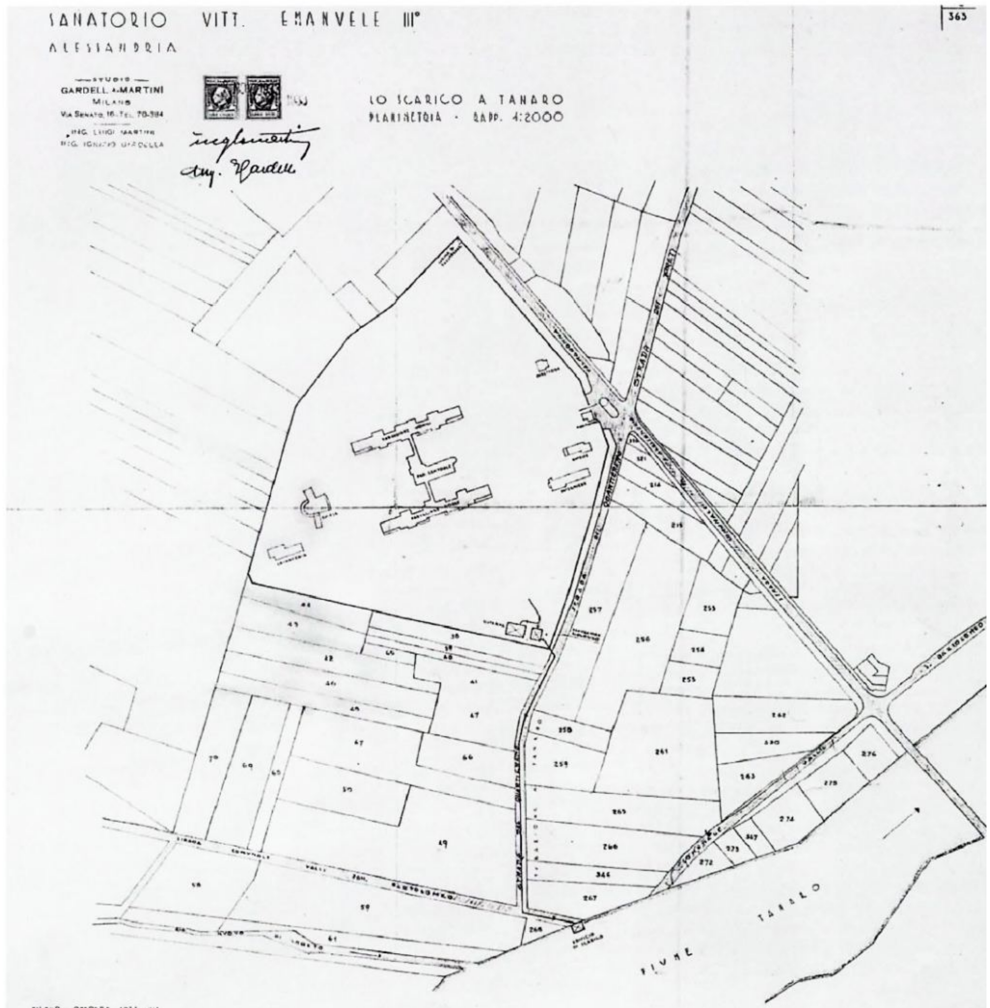


Fig. 12. Site Plan of the Sanatorium Complex - 1933. Original Source: Archivio edilizio del Comune di Alessandria – Author's Source[11].

Timeline of Construction

Construction of the Sanatorium began shortly after the approval in 1931. The provincial budget report from 1932 noted that the work progressed quickly. By October 1934, the building was almost complete, and the Sanatorium was officially operational by July 1935. The grand inauguration took place on October 4, 1936, with King Vittorio Emmanuele III in attendance. The facility became an important symbol of the local public administration's efforts, attracting attention of notable figures, including visits by Mussolini in 1939[9].

Architectural and Spatial Configuration

The design of the Sanatorium was influenced by functionalist and rationalist principles. The design of the building was initially designed as "H" shaped by Arnaldo Gardela. When Ignazio took charge of the project, he initially tried to change the design to "T" shape for better functionality, but he could not do that[10]. However, he managed to give the project his personal touch by independently designing a church in the premises and locating the church building in the premises in a way to intentionally break the symmetrical layout.

9) Montanari, Guido. 2000. *Op. cit.*, p. 131.
10) Montanari, Guido. 1989 *Op. cit.*, p. 496.
11) Montanari, Guido. 2000. *Op. cit.*, p. 127.

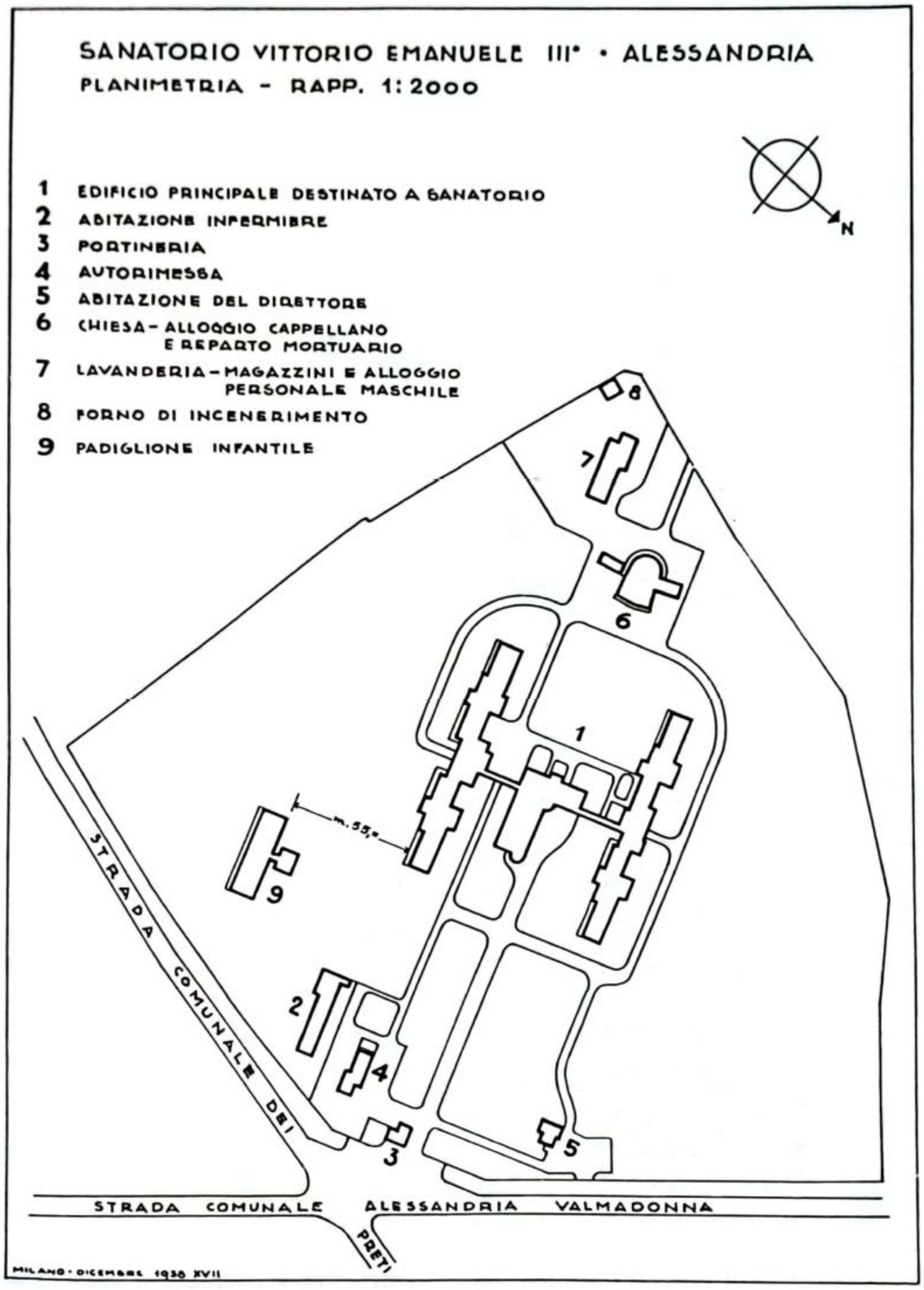


Fig. 13. Plan of Sanatorium Teresio Borsalino. Source: Thesis – Barbara Davio[14].

H Shaped Central Pavilion

The central building followed the original "H" shaped plan with two lateral wings divided into male and female sections and a connecting transverse section for common services. The lateral wings house patient wards and the central structure accommodates the administrative and treatment facilities. The central structure, asymmetrical in design, introduces visual dynamism and enhances functionality by facilitating efficient circulation[12]. The wings face to the south and east to allow for ample sunlight exposure in the patient rooms and each patient room opens directly onto the south terraces. This exposure to sunlight was central to the design for the heliotherapy treatment which was considered beneficial for the treatment of

12) Davio, Barbara. 1997. *Op. cit.*, p. 44.
13) Montanari, Guido. 2000. *Op. cit.*, p. 498.
14) Davio, Barbara. 1997. *Op. cit.*, p. 64.

15) *Ibidem*, p. 44.
16) Montanari, Guido. 2000. *Op. cit.*, p. 137.

tuberculosis[13]. These terraces are also equipped with blinds and built-in audio connections, that demonstrates Gardella's meticulous attention to detail and patient-centric design philosophy. The integration of natural light and fresh air into every aspect of the building reflects the influence of Alvar Alto's Paimio Sanatorium in Finland, a beautiful example of modernist healthcare architecture[15]. The inspiration is more obvious because Alto's design was based on T shaped layout as preferred by Ignazio in the beginning. In addition, the sizes of patient rooms vary to accommodate different stages of illness. Larger rooms with multiple beds are designated for early-stage patients, while smaller, private rooms cater to those in advanced stages of disease.

Fig. 14. The terraces for Heliotherapy – the steel parapet detonates the naval or engineered aesthetics of northern Europe, and the picture shows the retractable blinds for the terraces that are no longer present. Source: from Alexandria, 1938[16].

Fig. 15. 14-bed dormitory in the Sanatorium of Borsalino. Source: from Alexandria, 1938[18].

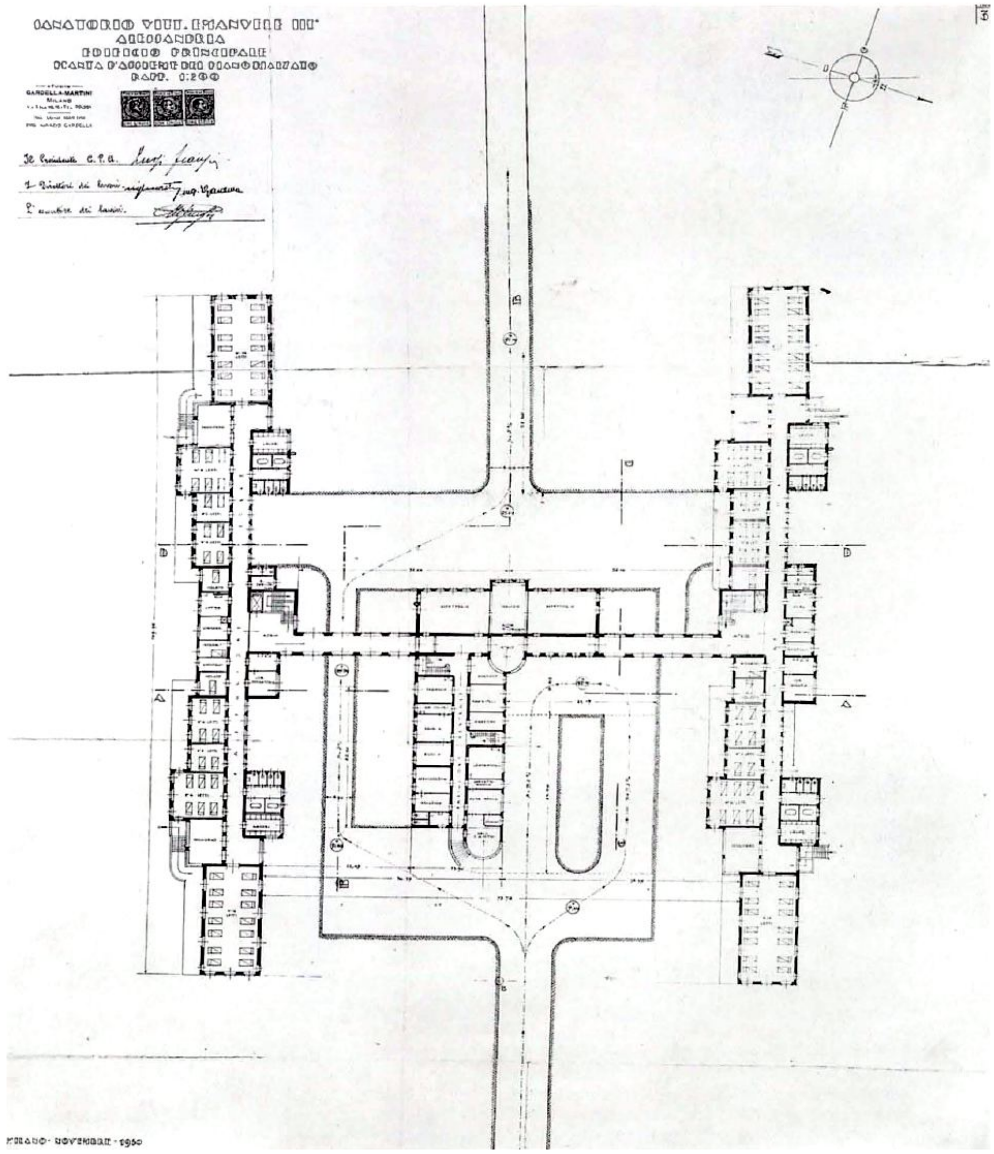
Central Section: Administration and Treatment

This asymmetrical central building is completely designed by Ignazio Gardella. This section of the building, as already mentioned, houses administrative functions and treatment rooms along with the communal facilities such as dining halls and lounges. The main entrance to the central pavilion features a curved façade and a projecting canopy, creating a welcoming yet modernist aesthetic. This area serves as a primary circulation hub, connecting the two lateral wings. The treatment areas in this section of the building include specialized rooms for radiology, inhalation therapy, and nebulization. These spaces were equipped with modern equipment for their time and were designed with hygiene and functionality in mind[17]. The centrality of the treatment areas was intentional for easy access of both patients and medical staff and their location was designed with hygiene principles in mind. Large dining halls and lounges were in this section to promote social interaction and psychological well-being among patients.

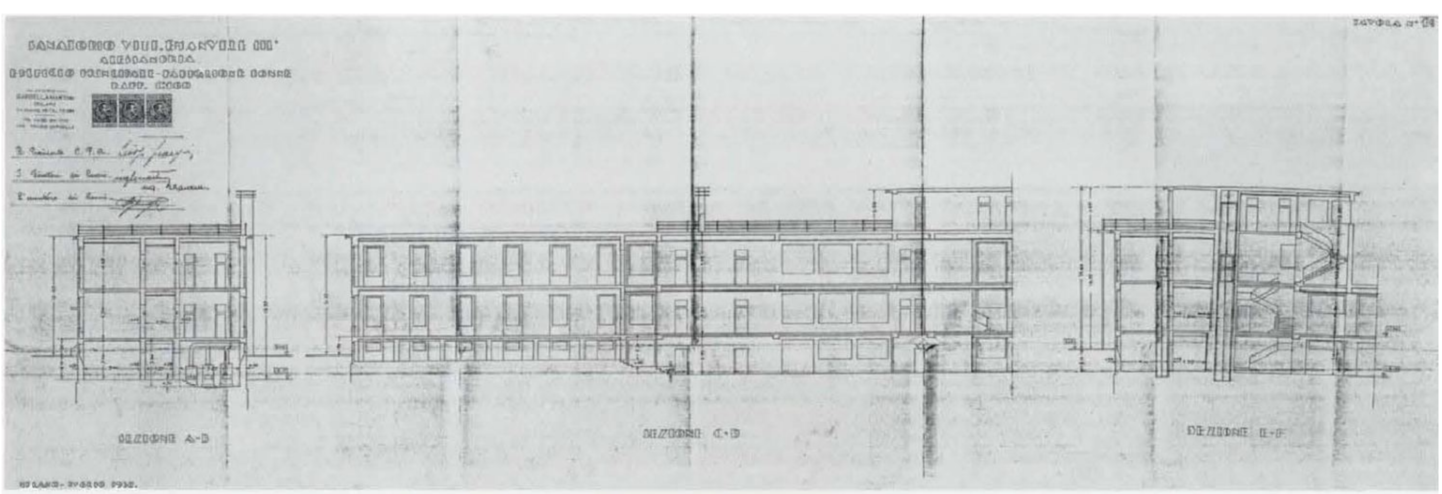
17) Davio, Barbara. 1997. *Op. cit.*, p. 47.
18) Montanari, Guido. 2000. *Op. cit.*, p. 137.

Fig. 16 (left). Ground floor plan of the Sanatorium. Source: Archivio edilizio del Comune di Alessandria[19].

Fig. 17 (down). Sections of the Pavilion Source: Archivio edilizio del Comune di Alessandria[20].



19) *Ibidem*, p. 128.
20) *Ibidem*, p. 130.



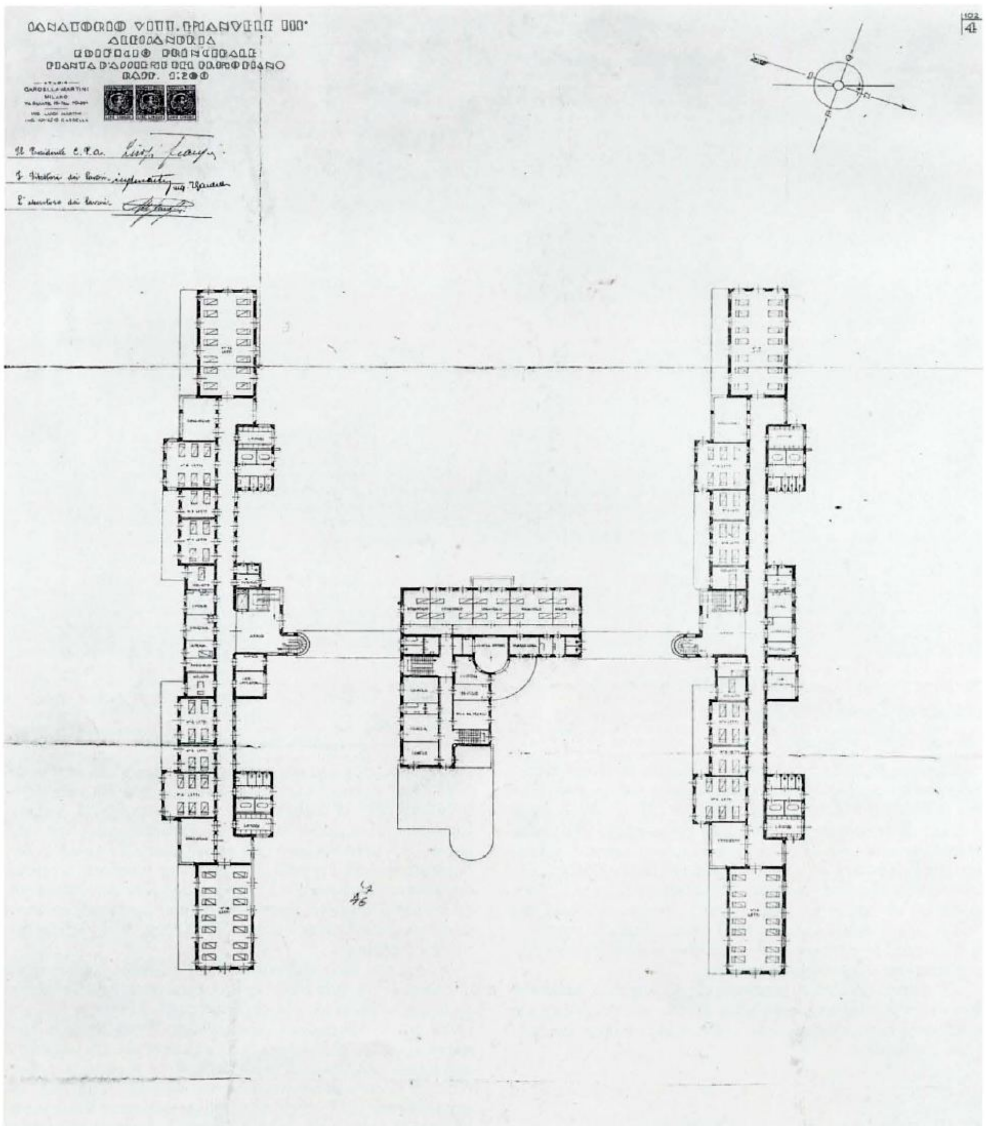


Fig. 18 (left). Ground floor plan of the Sanatorium. Source: Archivio edilizio del Comune di Alessandria[19].

Fig. 19 (down). Sections of the Pavilion. Source: Archivio edilizio del Comune di Alessandria[22].

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21) *Ibidem*, p. 129.
22) *Ibidem*, p. 130.

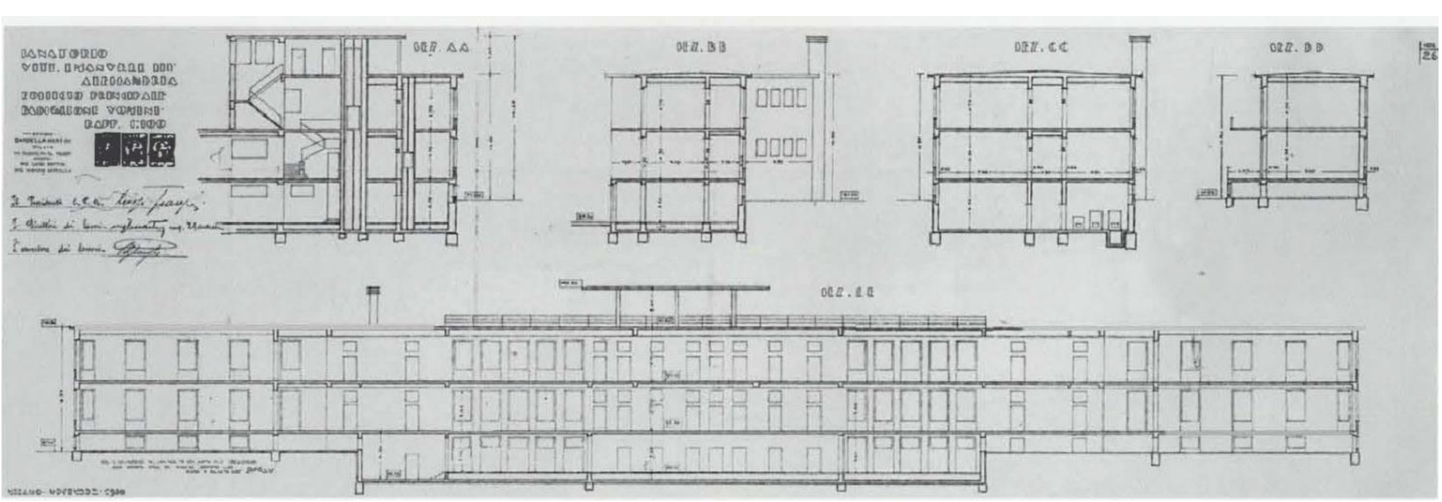


Fig. 20-21 (down-left). East Façade of Director Residence and Axonometric view showing the south façade, which is without columns in the drawing. Source: Drawings of Ignazio Gardella 1932 - Archivio Gardella Oleggio AGO G3.san.V.E[24].

Fig. 22 (down-right). Director's Residence in the Sanatorium complex – the residence was reimagined based on the principles of pilotis. A comparison can be seen between the realized version with respect to the early drawings in the pictures below. Source: Flickr.com by Jacqueline Poggi - Taken on April 23, 2023.

Auxiliary and Service Buildings

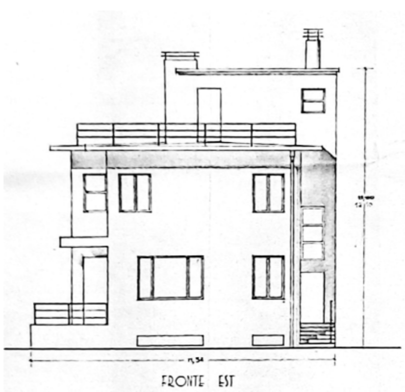
The complex includes several auxiliary and service buildings, such as the nurse's quarters, director's residence, concierge's lodge, a chapel and an incineration oven. These structures are seamlessly integrated into the site's natural landscape, emphasizing harmony between architecture and landscape. The use of wide internal roads and carefully planned landscaping enhances the sense of openness and serenity. Notably, the pine forest surrounding the complex was deliberately preserved to create a therapeutic atmosphere.

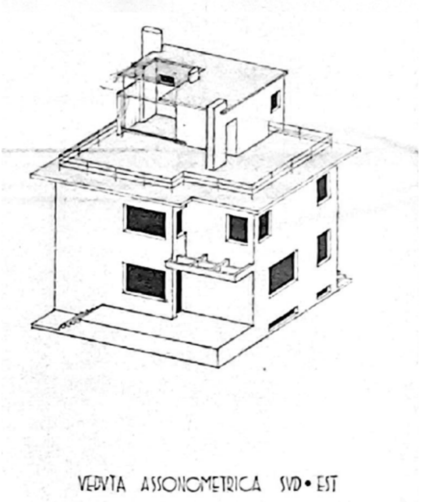
The director's residence, an understated structure, is one of the first buildings where Ignazio tried to design a theme of a single-family house. It consists of almost a square plan with four different facades, designed in correspondence with the entrance. On the ground floor, there are reinforced concrete columns which remind one of Pilotis by creating a portico space under the upper floor and this space serves as an entrance to the residence. The roof terrace also frames the landscape around which is another influence from the style of Le Corbusier in this building's character[23].

Housing of Nurses and the concierge's lodge are designed as separate buildings, ensuring the medical personnel have convenient access to the patients while maintaining their own living spaces. They are located close to the main entrance to the complex and seem to be intentionally farther from the patient areas to also limit exposure to the infectious disease. These buildings are now abandoned structures within the complex.

Additional buildings are provided in the complex for the laundry, storage and other essential services, and they are in proximity to the main building but are organized in a way to not interfere with the patient care areas. These service buildings support the daily functioning of the Sanatorium building and are still functional today.

23) *Ibidem*, p. 135.
24) Di Franco, Roca and Montanari, *Op. Cit.*, 2008.





The Chapel – (the Case Study of Thesis)

The small Chapel, a central element of the complex, is located near the mortuary. This project is very particular for its unusual combination of geometric solids and cylindrical and rectangular volumes. Its arrangement seems to be according to converging lines in form of a perspective. The chapel maintained a strict division between men and women, as was customary in tuberculosis care at the time, with separate entrance and internal naves[25]. The interior was illuminated by a circular skylight above the altar, while the exterior has a campanile (bell tower) designed in a modernist skeletal structure. This chapel is indeed a unique piece of architecture and will be studied in detail in the next chapter.

25) Montanari, Guido. 2000. *Op. cit.*, p. 135.

Materiality and Modernist Aesthetics

Architectural design of the sanatorium complex rejected the 19th century aesthetic decorations and was a result of collaboration between doctors, engineers and architects. In this project, they experimented with the techniques, materials and formal distribution of spaces. The main materials utilized were reinforced concrete, bricks and glass. The use of flat roofs, geometric volumes and large open spaces were among the innovative solutions

Fig. 23. The Chapel inside the Sanatorium by Ignazio Gardella. Source: FAI.

utilized in the design of the complex[26]. The element of thin concrete canopies, which was a recurring theme in Ignazio's later projects, added a sense of lightness to the otherwise monumental structure[27]. Gardella drew inspiration from northern European architecture, particularly the German rationalist school, as seen in the use of long, rectangular ribbon windows, angular openings and semi cylindrical staircases. The building's appearance also reflected industrial architecture, with a focus on efficiency and simplicity, and rejecting ornamentation[28].

Post-War History, Flooding and Decline

In the post-war period, the sanatorium complex, which was previously named after Vittorio Emmanuele III was renamed after Teresio Borsalino, and it continued to function as a sanatorium until 1978. As in the post-war time, there was a widespread adoption of pharmacological treatments for tuberculosis and there was a decline in the disease, the typology of sanatorium buildings began to diminish from public consciousness, leaving their architectural significance underexplored. The rise in new healthcare reforms led to the conversion of this facility into a pneumology centre, operated by the Local Health Unit (ASL)[29]. With the diminished need for isolation and long-term care, the building's function changes, and the maintenance of the complex suffered. During this period, technical modifications, including the expansion of director's residence and the installation of fibrocement roof in the 1980s, altered the original character of the structure.

Fig. 24 (top). Cylindrical Staircase – Current state of the building. Source: arkitectureonweb.com – By Alessia Raponi May 06, 2019.

Fig. 25 (down-right). Southern Terraces – The retractable blinds no longer exist on the terraces. Source: arkitectureonweb.com – By Alessia Raponi May 06, 2019.

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26) *Ibidem*, p. 126.
27) Davio, Barbara. 1997. *Op. cit.*, p. 45.
28) Montanari, Guido. 2000. *Op. cit.*, p. 132.
29) *Ibidem*, p. 136.

The complex was severely impacted by the flooding of November 6, 1994, when the Tanaro River inundated the area, submerging the buildings by over a meter. This caused significant damage to both the structure and its systems, such as water infiltration, broken windows, and other damage to the fittings and installations. The flood exacerbated the already deteriorating facility, which had suffered neglect from it underuse[30].

30) *Ivi*.
31) *Ibidem*, p. 138.
32) Raponi, Alessia. 2019. *Fotografia per ricordare l'Architettura Italiana. Un monumento alla Nostra storia*. 06 May. Accessed 12 10, 2024. arkitectureonweb.com/it/-/news/borsalino.

Rehabilitation and New Purpose

The increased awareness of the architectural value of the sanatorium, particularly in its historical and cultural context, led to a shift in the early 1990s. In 1997, the new owner, the SS. Antonio and Biagio and Cesare Arrigo" Hospital, proposed converting the complex into a multidisciplinary rehabilitation centre. This plan, which followed a proposal by the architect Claudio Pesce in 1994, aimed to integrate the historic structure while adapting to modern healthcare needs. The rehabilitation included the transformation of the central building into a care and rehabilitation centre for patients with brain injuries. Smaller auxiliary buildings were repurposed for complementary functions, such as the chapel for religious services, the director's house for administration, the nurse's house for visitors, and the former laundry building for technological installations[31]. The renovation works began in 2002 and were completed in 2006, transforming the facility into a new Multifunctional Rehabilitation Centre that includes about a hundred rooms, clinics, medical rooms, meeting rooms, gym and two swimming pools[32].

Even after efforts to rehabilitate the facility, most of the structures remain abandoned, including the Chapel. The main complex is still functional, however, unfortunately, the church building faces neglect and shows clear signs of degradation, such as, deteriorating façade, overgrown vegetation, and water damage, all of which underscore the challenges of preserving such historically significant sites.

The Case Study: Church on the Sanatorium grounds

From tradition to modernism

Over the years, architecture has been able to reflect society's desires, thoughts, and constructional advancements, and within this dynamic, religious architecture has played an important role in it. Architects have ensured that society has become habituated to seeing dazzling architectural works that are impossible to overlook whether due to their dimensions or ornamentation style; these buildings captured everyone's attention. This dynamic follows a chronological line of nearly a millennium, starting for example, with the Gothic movement (1100-1500 AD), exemplified by the Cathedral of Notre Dame in Paris, followed by the Renaissance (1400-1600) with St. Peter's Basilica in the Vatican, continuing with the Baroque (1600-1750) as seen in the Santa Maria della Salute church in Venice, followed by Rococo (1730-1760) with the church of Santa Maria Maddalena in Rome, succeeded by the Neoclassical (1750-1850) with La Madeleine in Paris, and finally reaching the XIX century with Historicism, which is a style that searches the interpretation or architectural styles from the past such as gothic, renaissance, baroque, etc. Despite each of these churches belonging to a diverse movement, where each of them possesses its own characteristics, a common point between all of them is that each movement finds its way to attribute decorative elements to the buildings, whether dramatic like Baroque, subtle with pastel colors like Rococo, or sober and sculpture like Neoclassicism. Even the early movements of the XX century displayed a tendency towards ornamentation, as exemplified by Art Nouveau with La Sagrada Familia.

Rationalism, a movement that emerged in the first half of the XX century, unlike the previous currents, is characterized by its simplicity, adopting clean lines and simple geometric forms – elements that starkly contrast with the complex decorations of the traditional churches. For this reason, the introduction of this movement in religious architecture represents a notable shift from the ornamental traditions that had dominated for centuries. Other characteristics of rationalism that are important to highlight include its functionality, as buildings must efficiently fulfill their purpose; the rational use of materials, which have an industrial nature – such as concrete, steel, or glass – expressed in an honest manner; and a search for the integration with the natural context, valuing natural light and exterior views.

Unsurprisingly, the churches of this movement reinterpreted the typical cruciform plan of religious architecture and transformed it to meet the needs of modern society. Under this context, various projects can be cited as examples, such as the church of San Giovanni Battista in Mogno, designed by Mario Botta (modern architecture with rationalist influences), where a rectangular space is embedded in, an ellipse façade, or – to highlight the case study – Gardella's church located in the ex-Sanatorium Vittorio Emanuele III – nowadays Teresio Borsalino Rehabilitation center – where its design is characterized by the incorporation of a curved façade (figure 28), which, through the application of smooth white plaster on the walls, allows a seamless and fluid transition between the curved and the straight wall Altering the traditional plan to fulfill the desired function, reducing almost to zero the decorative elements and emphasizing a pure design through its geometrical forms, represented a radical change in the way sacred spaces are conceived.

Consequently, this new movement not only transformed the aesthetics of churches but also reflected a new way of thinking about the role and functionality of spaces dedicated to worship, aligning them with the needs and sensibilities of modern society.

Fig. 26 (top). Church of San Giovanni Battista in Mogno. Source: (Ticino Tourism n.d.).

Fig. 27 (down-left). Church of Ignazio Gardella. Source: (Fondo Ambiente (FAI) n.d.).

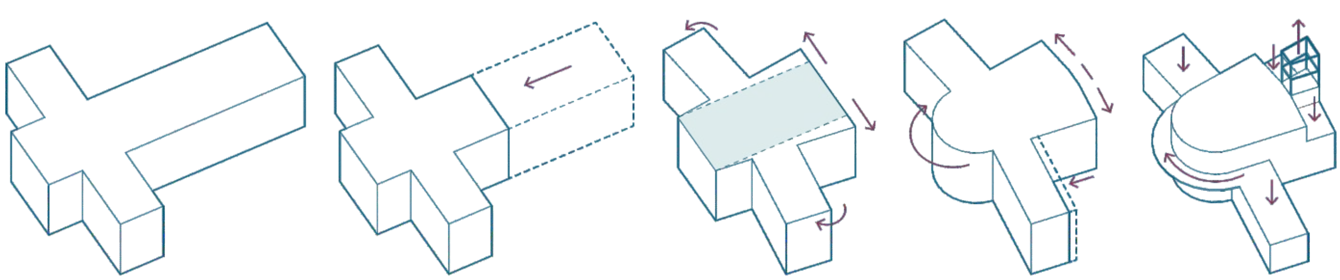


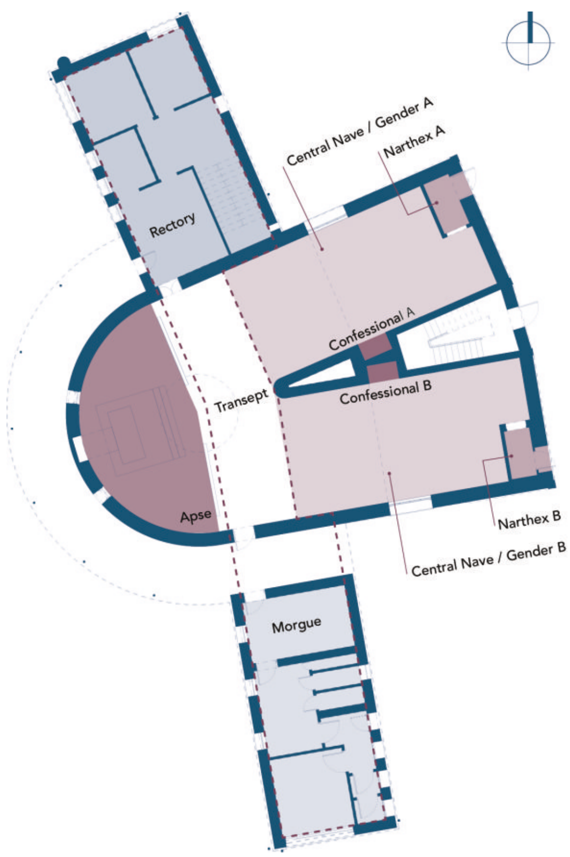
Fig. 28 (down). Changes in geometry that led the Latina cross into Gardella's church imposing in its last step a curved wall. Source: by the author.

Fig. 29 (down-left). Ground plan with classification of spaces. Source: By the authors Right

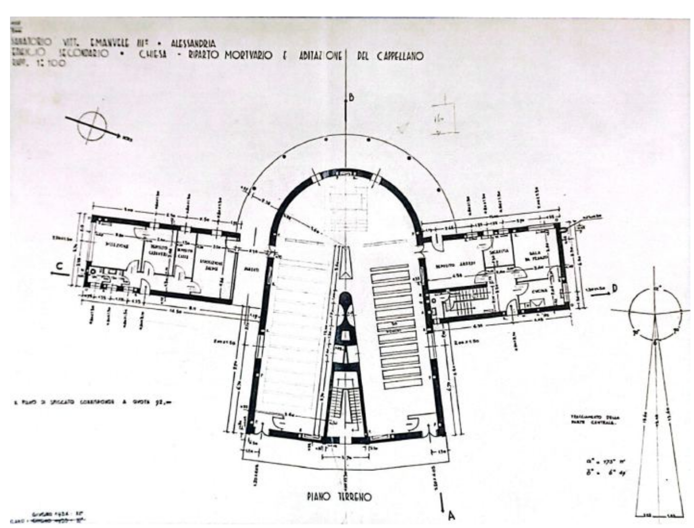
Fig. 30 (down-right). Hand-drawn plan by Gardella 1934. Source: Archivio Gardella Oleggio AGO G3.san.V.E[30].

Sacred space reimagined through Gardella's architectural language.

By reinterpreting the traditional floor plan, it becomes evident that Gardella's design represents an evolution of the Latin cross as seen in Figure 3. Therefore, by incorporating the parabola movement, Gardella deviates from tradition while demonstrating how he learned from the past. In the same way, as the building's footprint has changed, the spaces inside the church, such as the nave, the apse, the ambulatory, and others, have also experienced changes in their geometric composition (as shown in Figure 29) but their use evoked the same meaning. The central nave is understood as the main part of the church, this space extends from the main entrance to the altar. In other words, this space is where faithful congregate during religious services; spatially, it is characterized as a single and uninterrupted area. However, in Gardella's church, this architectural concept is altered, because instead of having a central path leading to the altar, there is a double-height wall, which divides the central nave into two trapezoidal spaces of equal side as seen in Figure 30.



The rationalist architect sought to respond to the needs of modern man. For this reason, Gardella had to divide the central nave. It is important to remember that this church is located in the Vittorio Emanuele III Sanatorium, a center dedicated to the care of patients with tuberculosis. As a result of its location, the church had to follow the regulations created for the combat and treatment of



this disease. One of these regulations was the necessity of having a clear separation between men and women in institutions where pulmonary diseases were being treated, which led to the design of this dividing wall[31]. Even though this element changed a long-standing tradition, Gardella managed to integrate it in such a way that it felt like this element naturally belonged to be there. To reduce the imposition of the wall, Gardella employed geometric strategies to his advantage: firstly, the tip of this wall is curved, on one hand, this created a sinuous movement, on the other hand, it replicated the same geometry as the wall in front of it (the apse wall); secondly, as the faithful enter their designated nave, this wall directs their gaze straight to the altar, the religious nucleus and main purpose of the church; thirdly, this wall is parallel to the perimeter wall and due to the dimension of the space between them, each area feels like an independent space to attend the mass rather than a large space that is divided; lastly, the wall does not create a geometric interruption, basically because its placement helps to create symmetry, which is originated from an axial line that start from the center of the circular opening above the altar (Figure 31).

30) Di Franco, Roca and Montanari, *Op. Cit.*, 2008.
31) Montanari, Guido. 1989. *Op. cit.*
32) Davio, Barbara. 1997. *Op. cit.*
33) Boidi, Sergio. 1997. *Gardella dimenticato. La chiesetta del sanatorio Borsalino ad Alessandria*, Ananke.

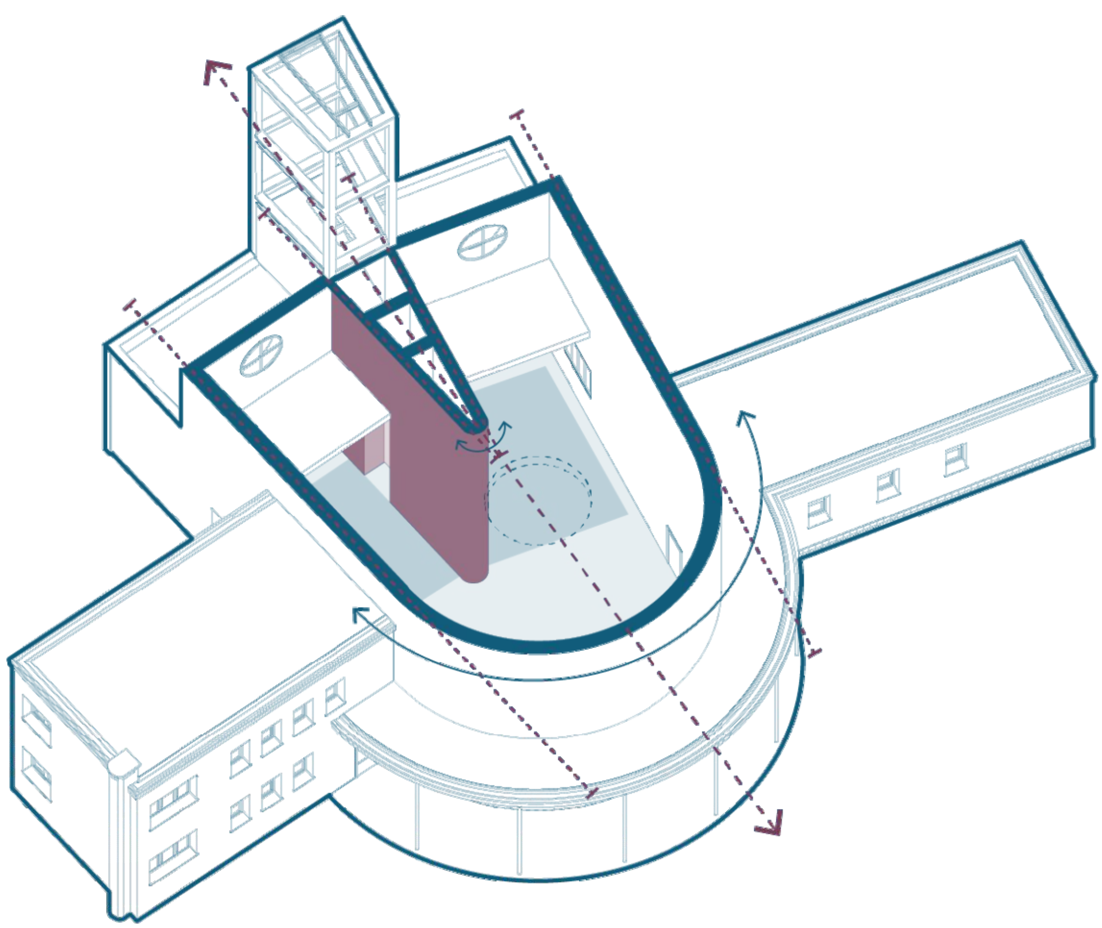
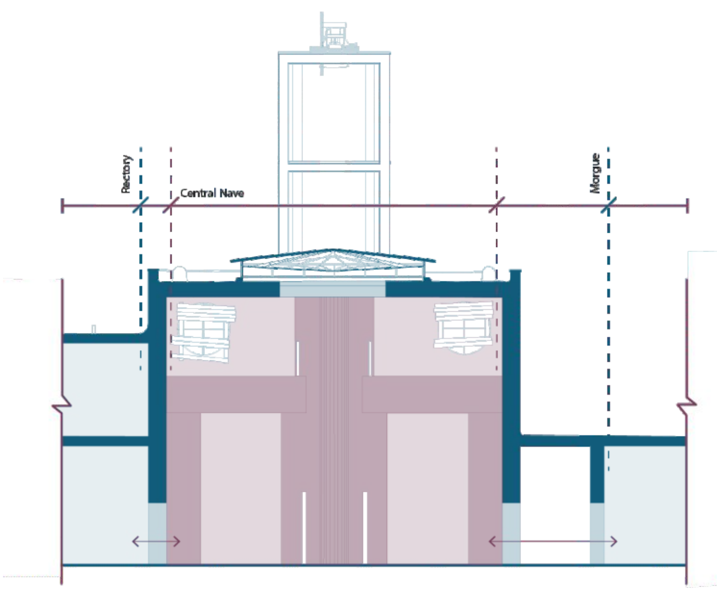


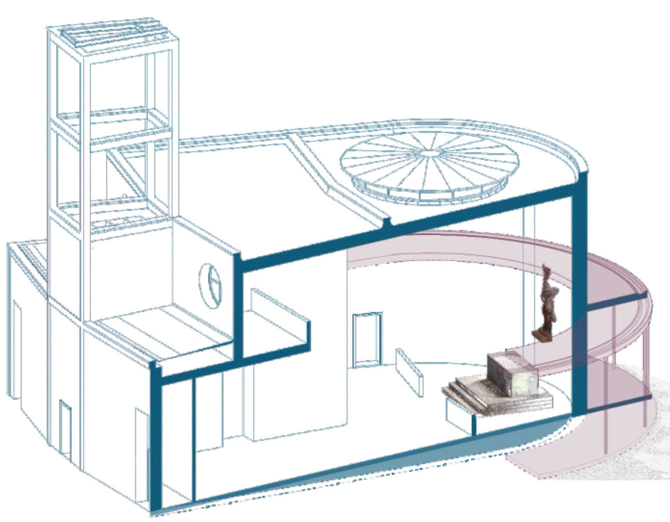
Fig. 31. Divisor wall inside the central nave of the church and its features. Source: By the authors.

Fig. 32 (top). Central Nave in contrast with the activities of the transept. Source: By the authors.
Fig. 33 (down). Hierarchy of the apse and its relationship with the ambulatory. Source: By the authors.

Traditionally, Gothic and Romanesque churches feature a transept that intersects with the central nave, forming the characteristic Latin cross shape. In Gardella's design, however, this intersection creates a "deformed cross", as the transept, rather than being perpendicular, is inclined towards the altar as is seen in Figure 30. Gardella not only altered the formal geometry of this space but also redefined functions and relationships with the altar. Unlike traditional transepts that seamlessly integrate with the central nave and accommodate religious activities, such as chapels or lateral alter for prayers, Gardella's transept is disconnected and proposed change in the religious program. The north wing, serving as the priest's quarters, is separated from the nave by a single wall, while the south wing, housing the morgue, is separated from the main altar by a corridor as shown in figure 32. The reason why the transepts changed its religious connotation is because this building acts as an extension of the Sanatorium needs, in other words, "the creation of these parts was certainly dictated by the desire to make the sanatorium complex as autonomous as possible"[32]. This spatial organization reflects a deliberate departure from conventional ecclesiastical layouts.



The apse retains its traditional function as the most sacred nucleus of the church, housing the altar. As illustrated in figure 33, its hierarchy is emphasized by its elevation above the level of the nave, and double highness of the area. In Gardella's design, the apse is surrounded by a corridor, which works as an equivalent of an ambulatory. Traditionally, the ambulatory allows the faithful to move without disrupting the liturgy, in this way it doesn't serve as a part of the sacred space but as its protective boundary for the apse and for the passerby as they walk beneath it. Gardella's approach diverges from tradition, because even though he is projecting the apse outwards, and is connecting both wings of the church, the ambulatory created is not inside of the building, instead is directly engaged with the external context. This reinterpretation does not diminish the significance of the ambulatory's tangential relationship to the central nucleus, instead, it extends the spatial boundary of the sacred structure beyond the physical perimeter wall, tracing an intangible line of connection with the surrounding environment, where a form of osmosis with the context occurs[33].



The ambulatory presents another contradiction considering the new practices. Although the portico is characterized by being supported by six columns – emphasizing a construction system that moves away from traditional load-bearing walls – these columns are so slender that, as a result "it does not appear that they are capable of supporting the slab above them, suggesting the function is primarily ornamental"[34]. The use of these columns solely for aesthetic purposes contradicts the statement that "form follows the function", in other words, it defies the core principles of rationalist theory. A symbolic rather than a functional interpretation offers a plausible explanation for this design choice. Symbolically, the ambulatory can be seen as a protective element for the apse; by creating an external ambulatory, Gardella needed to design an element that would enclose the space to preserve its protective function while ensuring its connection to the exterior was not disrupted. By arranging the columns in this specific manner, Gardella created an imaginary curved plane that defines the limits of the ambulatory. In doing so, he gave the space a dual character: providing shelter for the apse while maintaining its connection with the surrounding environment.

34) *Ibidem.*
35) Davio, Barbara. 1997. *Op. cit.*
36) Magagna , Alessandro. 2023. https://fondoambiente.it/news/al-via-i-lavori-di-messa-in-sicurezza-della-chiesa-di-ignazio-gardella-ad-alessandria. Settembre. https://fondoambiente.it/news/al-via-i-lavori-di-messa-in-sicurezza-della-chiesa-di-ignazio-gardella-ad-alessandria.

Fig. 34. West façade. Source: Magagna, Alessandro, FAI[36].

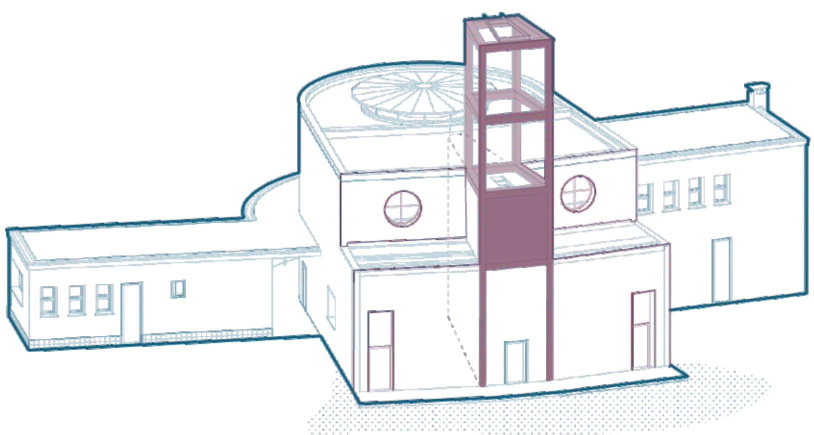
The modifications on the ambulatory and ground-floor plan are not the only elements that reflect a deviation from tradition. These changes made by Gardella in the plan are also reflected in the alterations to the façade. A clear example of this is the division of the central nave, which is emphasized also in the exterior. The congregation gathers outside on a marked section of the pavement, where a change in texture delineates the space. However, when each gender group is going to enter, the church does not feature a shared narthex. Instead, separated entrances are provided for men and women, reflecting a deliberate departure from conventional spatial arrangements. In this context "the main façade results in an inversion of the classical scheme: it no longer consists of a principal door flanked by two smaller lateral doors and a rose window. Instead, it features a central door accompanied by two lateral main doors, crowned by two rose windows"[35] while the center can continue with its hierarchical structure by raising the bell tower (Figure 9). Thus, although this church may initially appear as a simple volumetric structure devoid of ornamentation, it reveals a considered geometric composition. This design deviates from traditional models, demonstrating a different level of complexity.

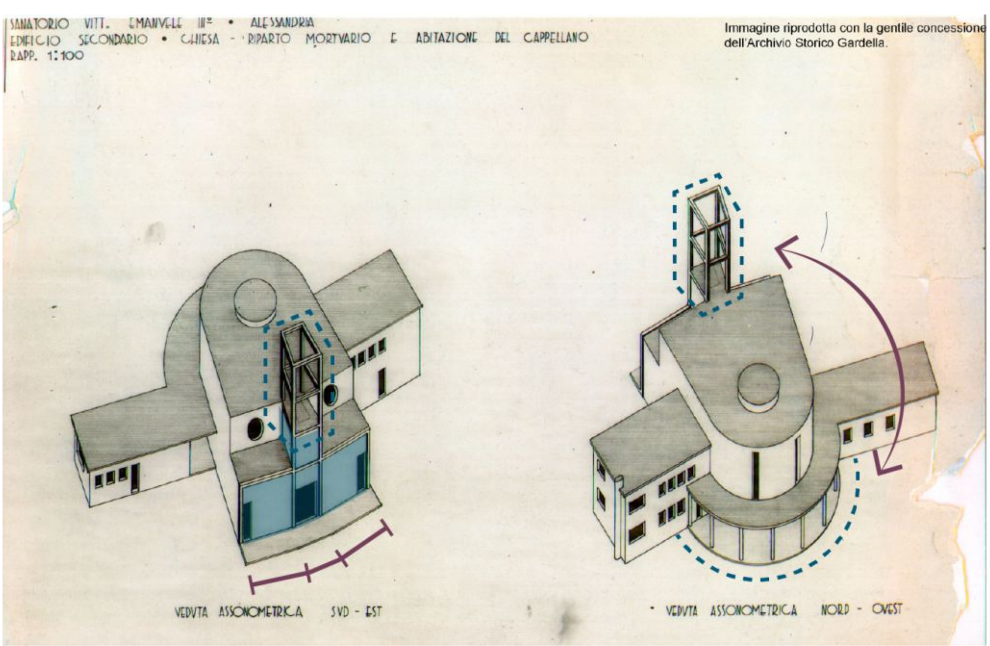
37) Boidi, Sergio. 1997. *Op. cit.*
38) Montanari, Guido. 1989. *Op. cit.*
39) Di Franco, Roca and Montanari, *Op. Cit.*, 2008.

Fig. 36. Inversion of the classical scheme in the main façade. Source: By the authors.

Fig. 37. South-east axonometry highlighting the trilithic structure and folded façade. Nord-West axonometry highlights the relationship between both tectonics systems[39].

The main façade at the east, devoid of ornamentation and featuring three entrances, is not a continuous plane. Instead, it is folded into three parts, creating a slight convexity. This design reflects a sensitivity towards approaches that deviate from strictly stereotomic tendencies. "A comparable example can be observed in the employee housing project"[37], where a single block is fragmented to appear as three distinct volumes (See Part 1, section 4.3). An orthogonal grid system of columns and beams defines these three planes. In this way, architects integrate the technological advancements of the period. Although this church appears to rely on traditional load-bearing walls from structural support, the main façade reveals an innovative construction system: reinforced concrete. This trilithic system is used to elevate the hollow bell tower, which as Montanari says, "contrasts with the solidity of the façade and suggests a vertical impetus. This upward movement is immediately tempted by the balanced proportions of the overall composition"[38].

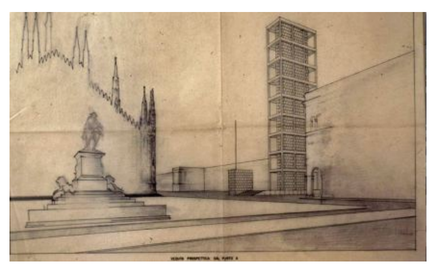




The bell tower can be understood today as a precedent for the tower in Piazza del Duomo in Milan, a project designed in 1934 by the architect but never constructed. The bell tower at Gardella's church is composed of a vertical arrangement of three volumes. The first of these is a completely solid mass, while the other two form a skeletal structure that, when observed, allows the sky to be seen through it, imparting a theatrical and spiritual quality to the façade. This purist opening justifies the tower's height, allowing the bell tower to be visible from the opposite façade (west), establishing a relationship between the architectural elements. Specifically, it creates a visual connection between the structure of the bell tower and the columns that support the ambulatory, resulting in a visual balance based on a more tectonic character. However, while the bell tower's structure is certainly load-bearing, the load-bearing function of the columns in the ambulatory is open to debate.

"Heliotherapy was used empirically from ancient medicine until the XX century to treat multiple diseases, including tuberculosis (…) furthermore, experimental studies have proven that vitamin D improves defense against M. tuberculosis"[40], because of this, the small church establishes a connection with its surroundings through various strategies, as the implementation of light and proper ventilation was crucial in this context. Gardella incorporated different openings to facilitate these conditions. However, he achieved this task in a unique way, as the openings also contribute to the theatricality expected in a sacred space. This light scenography is not immediately apparent when people enter the church, as they must first pass through a transitional space, the narthex, which is characterized by its dark ambiance. In this way, the contrast of light within the church is intensified. Gardella introduces 4 sources of light in the central nave.

The first light source consists of two circular openings in the upper part of the eastern façade. On the one hand, these could be reminiscent of the traditional rose windows; on the other hand, they could work as two oculi, like the typical opening found in nearby rural buildings[41]. These two oculi act as projectors, gradually dispersing light as it reaches the ground floor. However, from the ground floor, these oculi are partially concealed by a parapet that is in front of them. Nevertheless, these parapets also contribute to the theatrically, as they possess an opening with a cross shape where light floods in from the oculi above.



40) Quiros Blanco, A, A Arranz Sanz, and J.A. Garrote Adrados. 2009. *Luz solar, vitamina D y tuberculosis*. Boletín de Pediatría, pp. 220-226.
41) Boidi, Sergio. 1997. *Op. cit.*

Fig. 40 (top). Bell Tower in Gardella's church (top) as a precedent of the tower in Piazza del Duomo in Milan (Fig. 41 down). Source: By the authors 2024 (top) and Universita di Parma, centro studi e archivio della comunicazione n.d. (down).

42) *Ibidem*.
43) Dameri, Annalisa, and Paolo Mellano. 2022. *Recuperare il moderno. Una "fragile" opera di Ignazio Gardella - Recovering the modern. A "fragile" work of Ignazio Gardella*. Edited by H. Varum, A. Furtado and J. Melo. Xth REUSO Documentation, Restoration and Reuse of Heritage. Porto: Intervento presentato al convegno Xth REUSO Documentation, Restoration and Reuse of Heritage. pp. 497-507.

The second variation of light is in the opposite direction (western facade), behind the altar. These are two top-to-bottom windows. This configuration creates a rupture in the building's curved plane generating a dynamic play of solids and voids. The position of these windows creates a sensation where the spiritual range that is emanating from the altar is expanding outside the church "In this way, the stenographic value of the ensemble is accentuated, while simultaneously enhancing the metaphysical significance of the space designated for the celebration of the sacred rite"[42]. The altar space is also flooded with the third source of light, in this case, diffuse light coming from the oculus located directly above it in the ceiling. This oculus is protected by a cover and features perimeter windows, allowing it to capture light.

The fourth type of light is situated directly adjacent to those in prayer, located at the north and south facades, this type of opening is seen in two windows that are a mirror between each other. These openings do not seem to have a particularly theatrical focus, as they take the form of a

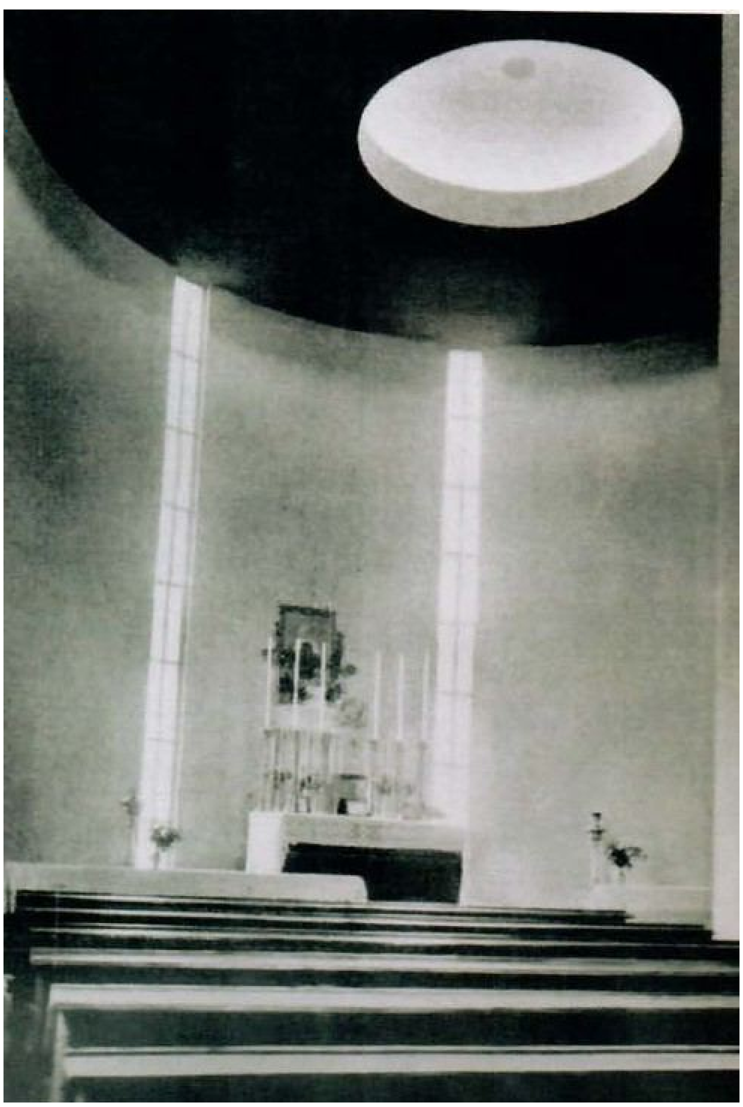


Fig. 42 (left). Interior of the chapel with vertical cut of light (1938)[43].

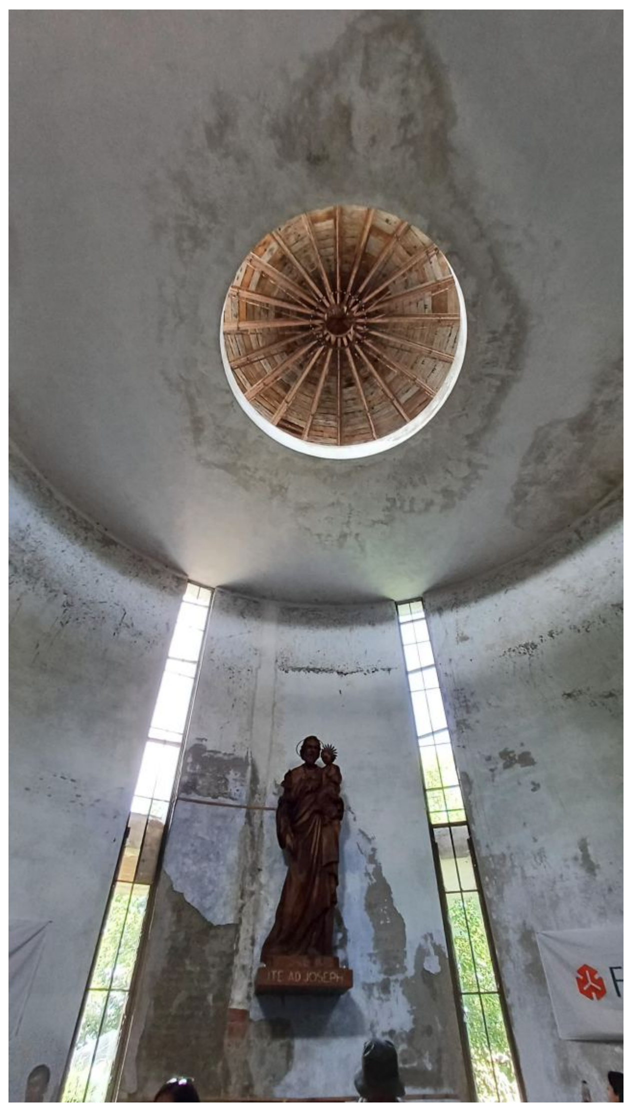


Fig. 43 (right). Interior of the chapel with vertical cut of light. By the authors.

pure shape, a rectangle, and this one is neither interrupting the plane nor being disrupted by any other element. However, its elevated position is notable; its height allows the light to enter while preventing a direct view of the activities taking place in the immediate surroundings, thereby providing a sense of privacy during the Eucharist.

By examining all the previous features, a deeper understanding emerges of how the architectural language of the building reflects a modern reinterpretation of traditional elements of religious architecture. Its design incorporated the principles of rationalism, such as functionality, simplicity, and integration with the natural context, while challenging the ornamental and structural conventions of previous centuries. Through diverse solutions, such as the division of the nave, the strategic use of light, and the symbolic relationship between the interior and exterior, Gardella successfully merges the functional need of a healthcare facility with the spiritual values of a sacred space. This approach demonstrates that even when breaking with tradition, architecture can retain its ability to evoke meaning and emotional connection with its users.

Fig. 44. Gardella's church on a summer day in 2024. Source: By the authors.

Adaptive Reuse of Gardella's church in a modern context: Challenges and significance.

"Among the unfinished projects within the complex, Gardella took on the design of the small church, marking; this building became the first work of one of the future protagonists of the XX century Italian architecture"[43]. However, this church is often overlooked, leading to its near oblivion. Several reasons may explain this, tree of which could stand out: firstly, confusion regarding its authorship may have arisen due to the period when the church was constructed, as it was characterized by being transitional phase where projects were being transferred from Arnaldo Gardella to Ignazio, after the death of the first one in 1928, creating uncertainty that may have led people to mistakenly attribute the work to his father. Secondly, a project designed by an undergraduate student like Gardella at that time can be easily ignored. Lastly, the church may have remained hidden from public recognition due to its location within the healthcare complex, whose primary focus was the treatment of tuberculosis rather than highlighting advancements in religious architecture.

43) *Ibidem.*
44) *Ibidem.*
45) *Ibidem.*
46) *Ibidem.*
47) *Ibidem.*

The church, lacking a recognized and individual identity, found its fate tied to the dynamics of the hospital complex, "which was almost entirely closed by the 80s"[44]; this marked a significant milestone in the sequence of events that contributed to its abandonment. Furthermore, another factor that accelerated the church's deterioration was the flood that occurred in 1994[45]. Desolation and degradation have become a constant presence in Gardella's church; nonetheless, the building has managed to remain standing despite the various types of degradation it has sustained, including the detachment of paint, plaster, and tiles, which have exposed a masonry system – Likewise, it should be noted that this church also uses reinforced concrete system, this one is responsible for supporting the bell tower as discussed in the previous chapter.

The early life of the church was overlooked; its physical presence is crumbling, and its purpose or raison d'être has long ceased to be relevant in the current context. Yet, despite this, the church has managed to endure, even overcoming "an ordinance of its demolition"[46]. The withdrawal of this ordinance demonstrates how the church has started to be recognized by a selected few who value its geometric composition and its significance as a memorial to Gardella's early works.

One of the entities that has taken on the task of preserving this heritage, even managing to gather donations, is the FAI (Fondo Ambiente Italiano), a non-profit organization dedicated to the protection, conservation, and promotion of Italy's cultural and environmental heritage. "The main challenge to address, beyond securing the necessary funds, is undoubtedly identifying a new function that is compatible with the site's unique and essential hospital role while allowing an increasing number of people to enjoy this green oasis scattered with buildings"[47].

Fig. 45, 46, 47, 48 (from left to right). Degradation inside next to the confessional (fig. 45). Degradation of the ambulatory's roof (fig. 46). Degradation of the window at the morgue block (fig. 47). Degradation of a wall in the central nave (fig. 48). Source: By the authors 2024.




The reinterpretation of a building does not mean forgetting its past; rather it involves creating a new functional space that serves as a bridge between different generations – past, present, and future, in other words, "adaptive reuse in architecture is an innovative approach that involves transforming heritage buildings for modern functionality while preserving their historical and cultural significance"[48]. Whether the church gains a new purpose in the short or long term, it is essential to ensure its preservation to facilitate future restoration efforts and its potential reopening to the public. In the case of Gardella´s church, the vision is to repurpose it as a center for research and activities related to "Medical humanities" – an interdisciplinary approach that bridges health sciences and the humanities – within the hospital complex and the park[49].

It's worth highlighting that keeping Gardella´s church alive raises awareness of the significance of both tangible and intangible heritage. The church serves as a testament about how architecture was closely connected to the context of its time not only in terms of design but also in addressing social needs, as previously mentioned the church served the sanatorium for tuberculosis, where men and women were restricted from freely interacting and pharmacological advancements had not yet succeeded in eradicating the disease; however, this dynamic no longer aligns with the context of the 21st century, making the reinterpretation of this space essential to revitalizing the church, which is located within the complex now known as the Teresio Borsalino Multifunctional Rehabilitation Center, serving as an example of how the former sanatorium was adapted to meet contemporary needs.

48) Syafri, Nasrullah. 2024. *Adaptive Reuse in Architecture: Transforming Heritage Buildings for*. The Journal of Academic Science, pp. 395-406.
49) FAI. 2023. *Al via i lavori di messa in sicurezza della chiesa di Ignazio Gardella ad Alessandria*. settembre. Accessed january 2025. fondoambiente.it/news/al-via-i-lavori-di-messa-in-sicurezza-della-chiesa-di-ignazio-gardella-ad-alessandria.
50) Syafri, Nasrullah. 2024. *Op. cit.*
51) *Ibidem.*
52) FAI. 2023. *Op. cit.*
53) Hmood, Kabila Faris. 2019. *Introductory Chapter: Heritage Conservation - Rehabilitation of Architectural and Urban Heritage. Intechopen.*

Fig. 49. The Gardella church as a symbol of new technologies. Source: By the authors 2024.

Fig. 50 (top). Official announcement of safety works at Gardella church. Source: By the authors.

Fig. 51 (down). The Gardella church as a rediscovered architectural icon. Source: Photo taken by DIATI Group (Dipartamento di Ingegneria dell'Ambiente, del Territorio e delle infrastrutture). 2024.

"By repurposing existing structures, adaptive reuse extends the lifespan of buildings, reduces environmental impacts, and conserves resources, aligning with the goals of sustainability"[50]. In this way, while on one hand, it aims to support the environment, this approach does not overlook the fact that society has a history, where people come from a specific place (understanding place like a moment that is happening at a specific time in a specific place), and therefore it respects the past while protecting it for future generations. In other words, "this approach requires a delicate balance between preservation and modernization, often involving creative design solutions that respect the building's historical integrity"[51].

The FAI is firmly committed to protecting, restoring, and valuing all forms of Italian heritage. In partnership with Intesa Sanpaolo Bank, the foundation runs an initiative called Progetto I Luoghi del Cuore. This initiative is a national campaign that encourages citizens to identify and vote for places they consider most valuable or significant in historical, artistic, cultural, or natural terms. Gardella's church, in the special category called luoghi storici della salute won first place with 30,391 votes. As a recognized "place of the heart", it was awarded a grant of 20.000 euros, complemented by co-financing of 5,500 euros provided by the hospital company.

The intervention started in September of 2023 and included renewing the waterproofing of the roofs and terraces to address water infiltration, as well as temporality sealing the windows that currently lack glass. The objective was to counteract the degradation processes affecting the church as a preparatory measure for the full restoration intervention, which remains in its initial planning phase[52].

The story of Gardella's church highlights the delicate interplay between heritage, architecture, and social needs. Despite decades of neglect, degradation, and facing constant changes around its context, its significance as an early work of one of Italy's most influential architects has demonstrated how heritage can persist and now it has begun to be recognized. The efforts led by organizations like FAI to restore and repurpose this space emphasize the importance of adaptive reuse, not only as a tool for preserving the past but also for addressing contemporary needs and ensuring sustainability. FAI is a non-profit organization, and while it has been a key contributor to the maintenance of the church, "without the understanding and support of the public at large, without the respect and daily care of the local communities, which are the true custodian of world heritage, no amount of fund or army experts will suffice in protecting the sites"[53].

The municipality itself also plays a significant role in this matter, as it can operate on multiple fronts and engage with diverse audiences. It can develop "mechanism of action, objectives, laws and strategies to keep abreast of progress and modernity in the field of repair, conservation and project management"[54]. By combining regulation, investment, education, and planning, municipalities can ensure that future generations have the opportunity to enjoy and learn from historical legacies like Gardella's church. Another example in Alessandria is the Citadel, which also suffers from neglect and requires actions as the church. Repurposing Gardella's church for modern functionality, such as a center for Medical humanities, has the potential to bridge the gap between its historical context and future relevance, becoming a symbol of resilience, innovation, and cultural appreciation.

53) Hmood, Kabila Faris. 2019. *Introductory Chapter: Heritage Conservation - Rehabilitation of Architectural and Urban Heritage. Intechopen.*
54) Alhasawi, Mai. 2019. *The Policies and Process of Preserving the Historical and Heritage Buildings in Dubai City: Case Study of Historical District*. The Academic Research Community publication. doi: https://doi.org/10.21625/ARCHIVE.V3I4.537.

Fig. 52. The Gardella church as a resilience symbol. Source: By the authors 2024.

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Part III

3D Survey Methods and Techniques

Foundations of 3D Survey Methods in Architectural Conservation

The integration of advanced 3D survey methods has transformed the field of architectural and cultural conservation, offering unprecedented precision and comprehensive documentation for historic and culturally significant structures. Traditional techniques, such as manual measurements and 2D drawings, while foundational, often fail to capture the intricate details and geometries of complex cultural heritage. In contrast, 3D surveying techniques enable us to capture complex geometries, surface details, and spatial representations with exceptional accuracy. These techniques include but not limited to, point cloud generation, structure from motion (SfM), or digital orthophotography, which collectively ensure that every architectural detail, whether ornamental, or structural, is precisely documented[1]. By capturing the complexity and condition of structures in detail, 3D surveying techniques provide dynamic tools for preserving cultural heritage in their most authentic form.

1) Bianchi, G., N. Bruno, E. Dall'Asta, G. Forlani, C. Re, R. Roncella, M. Santise a, C. Vernizzi a, and A. Zerbi. 2016. *Integrated Survey for Architectural Restoration: A Methodological Comparison of Two Case Studies.* The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences XLI (B5): 175-182. doi:10.5194/isprsarchives-XLI-B5-175-2016.

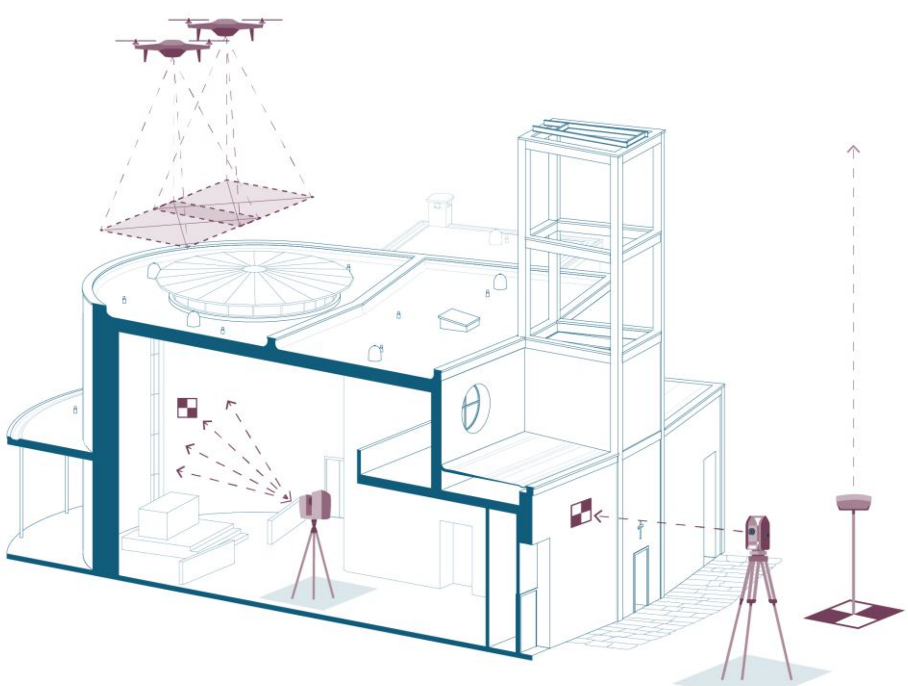

Fig. 1. Tools and methods used in 3D Survey. Source: Elaboration by Authorss.

The application of these techniques is carried out with the help of advanced tools such as Terrestrial Laser Scanning, UAV-based photogrammetry, LiDAR, and the use of Geographical Navigation Satellite Systems for georeferencing. These tools provide high speed data acquisition and improve accuracy, enabling seamless integration of datasets. Terrestrial Laser Scanning TLS, for example, helps to generate dense point clouds to document complex architectural features, while photogrammetry accompanied using high-resolution image capturing drone, help in producing textured 3D models that capture visual realism[2]. This approach not only ensures detailed documentation but also facilitates the long-term management of heritage structures within a dynamic, interactive framework.

The following sections will explore these methods in greater detail, with the emphasis on the techniques utilized in the survey of the Church of Ignazio Gardella in Sanatorium Teresio Borsalino. This analysis of techniques will highlight how advanced 3D survey techniques align with the broader goals of sustainability and preservation in cultural and architectural heritage.

2) Zerbinatti, Marco, Francesca Matrone, and Andrea Lingua. 2021. *Planned Maintenance for Architectural Heritage. Experiences in Progress from 3D survey to intervention programmes through HBIM.* TEMA. - ISSN 2421-4574 7 (1). doi:10.30682/tema0701d.

3) Letellier, Robin, Werner Schmid, and François LeBlanc. 2007. Recording, Documentation, and Information Management for the Conservation of Heritage Places: Guiding Principles. Los Angeles: Getty Conservation Institute.

1.1 Importance of Detailed Surveys in documenting Cultural Heritage

Detailed Surveys play an important role in documenting cultural heritage by providing the critical data necessary for informed decision making in restoration, preservation, and adaptive reuse projects. Unlike generalized assessments, detailed surveys capture the nuanced physical, structural, and material characteristics of a building, enabling a comprehensive understanding of its current state. In addition, they ensure that the elements are thoroughly documented for the future generations to come. By safeguarding the physical essence of historical structures, surveys help preserve the cultural and symbolic significance of the heritage sites. As discussed by[3] it also aids in understanding the evolving relationship between people and their built environment while allowing conservationists to gain insight into the materials, construction techniques, and historical alternations that may have occurred over time, thus supporting evidence-based decision-making in projects.

Moreover, detailed surveys contribute significantly to the long-term management and monitoring of cultural heritage. By providing baseline data, these surveys allow architects and conservationists to track changes in a building's condition over time. This approach helps in identifying early signs of deterioration and the need for restoration. Unlike manual methods that rely on labor-intensive processes and may overlook finer details, modern technologies such as laser scanning, LiDAR, Photogrammetry enable high-resolution, and three-dimensional recording of architectural features. These technologies, offering remarkable accuracy and efficiency, allow us to collect comprehensive data in a fraction of time required by traditional approaches . These methods are also non-invasive, which makes them suitable for fragile or inaccessible structures.

The integration if these techniques in conservation, restoration or adaptive reuse project ensures that cultural identity is preserved while adopting modern methods. For example, in our project, these methods can precisely map surface details and degradation, ensuring future interventions are both accurate and minimally invasive. Additionally, the resulting datasets can be integrated into Building Information Modelling (BIM) platforms, supporting long-term monitoring and planning[4]. These digital records are invaluable for creating virtual reconstructions and simulations, broadening access to cultural heritage while supporting educational research initiatives. In this way, detailed survey bridges the gap between historical authenticity and contemporary conservation goals, ensuring the longevity and relevance of cultural landmarks.

1.2 Image-Based and Range-Based Survey Techniques Image-Based Methods

Image-based methods rely on overlapping images captured using drone or ground-based cameras to generate detailed 3D models of architectural or archaeological heritage. High-resolution cameras and strong image processing software are crucial for this type of survey technique to produce accurate and realistic outputs. For instance, photogrammetry employs Structure from Motion algorithms to process these images and reconstruct three-dimensional geometries of buildings. This type of technique is the base of photogrammetry, which is particularly effective for documenting textured surfaces, capturing both spatial data and material details[5]. This method, when combined with Unmanned Aerial Vehicles UAVs, allows for rapid data acquisition while maintaining the level of detail required for accurate reconstruction or preparation of a BIM model. Furthermore, advanced software tools automate data processing with least amount of human involvement, by automatically identifying the points with matching features[6]. This process is very efficient and least time consuming in the survey methods.

4) Bianchi, *et al., op. cit.*, 2016.
5) Stylianidis, Efstratios, and Andreas Georgopoulos. 2017. *Digital Surveying in Cultural Heritage: The Image-Based Recording and Documentation Approaches*. In *Handbook of Research on Emerging Technologies for Digital Preservation and Information Modeling, edited* by Alfonso Ippolito and Michela Cigola, 119-149. New York: IGI Global.
6) Adamia, Andrea, Francesco Fassi, Luigi Fregonese, and Mario Piana. 2018. *Image-based Techniques for the Survey of Mosaics in the St. Mark's Basilica in Venice.* Virtual Archaeology Review 9 (19): 1-20. doi:https://doi.org/10.4995/var.2018.9087.

7) Tsiachta, Alexandra, Panagiotis Argyrou ORCID, Ioannis Tsougas, Maria Kladou, Panagiotis Ravanidis, Dimitris Kaimaris, Charalampos Georgiadis, Olga Georgoula, and Petros Patias. 2024. *Multi-Sensor Image and Range-Based Techniques for the Geometric Documentation and the Photorealistic 3D Modeling of Complex Architectural Monuments*. Multi-Sensor Data Fusion 24 (9): 2671. doi:https://doi.org/10.3390/s24092671.

8) Hastings, Jordan T., and Linda L. Hill. 2016. *Georeferencing*. In *Encyclopedia of Database Systems*, edited by Ling Liu and M. Tamer Özsu. New York: Springer. doi:https://doi.org/10.1007/978-1-4899-7993-3_181-2.

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Range-Based Methods

Range-Based survey techniques rely on active remote sensing technologies to acquire precise spatial data by measuring distance between a sensor and the target surface. These technologies use LiDAR (Light Detection and Ranging), terrestrial laser scanners, or total station, which work by emitting laser pulses and calculating the time-of-flight or phase difference of the returned signals. The resulting measurements generate dense 3D point clouds, providing highly accurate geometric data that captures intricate architectural details and complex geometries. These methods offer a high degree of accuracy and are indispensable for documenting irregular surfaces and structural conditions[7].

For example, Terrestrial Laser Scanning systems are stationary tools ideal for detailed documentation, while mobile LiDAR devices mounted on UAVs are better suited for rapid data acquisition in larger or inaccessible environments. These technologies play a crucial role in the process of documenting a heritage site, enabling professionals to have precise results for restoration and structural analysis.

For the documentation and survey of the Church of Ignazio Gardella, an integrated approach of both image-based and range-based data acquisition is utilized for ensuring spatial accuracy and precision.

1.3 Role of Georeferencing in Survey

Explanation of Georeferencing

The process of geospatially referencing objects, data, text documents, photographs, imagery, etc. to their proper location on Earth is called Georeferencing; it can be done in two ways: the formal way is to assign geospatial coordinates directly to the information objects and data; the informal way is to indirectly relate non-georeferenced objects to one or more pre-existing objects which are already georeferenced[8]. Georeferencing establishes a spatial reference for data points, aligning them either to a global or a local coordinate system. Global Systems, such as the most used World Geodic System 1984 (WGS1984) or the European Terrestrial Reference System 1989 (ETRS89), use a datum to define the Earth's shape and provide a universal reference for geographic locations. These systems are essential for large-scale projects that require interoperability across regions. Conversely, local coordinate systems, customized for specific areas, reduce distortions and are often employed for site specific precision[9] This distinction is especially important in architectural surveying, where global systems establish overarching control networks, while local systems refine data for detailed structural documentation. This dual approach ensures spatial accuracy and contextual relevance in diverse conservation projects.

Methods of Georeferencing

Georeferencing can be achieved using Ground Control Points (GCPs) and Global Navigation Satellite Systems (GNSS). GCPs are physical markers on the ground with precisely known coordinates, often established using GNSS or Total Station. These serve as anchors for aligning spatial data within a coordinate system. GNSS directly provides real-time positioning by leveraging satellite signals, while Total Station adds precision by measuring angles and distances between control points and the instrument[10]. The combination of these methods ensures that datasets collected from different surveying tools – such as photogrammetry or LiDAR – can be integrated seamlessly.

10) Juad, Marion, Pauline Letortu, Emmanel Augereu, Nicholas Le Dantec, Mickael Beauverger, Veronique Cuq, Christophe Prunier, Rejanne Le Bivic, and Christophe Delacourt. 2017. *Adequacy of pseudo-direct georeferencing of terrestrial laser scanning data for coastal landscape surveying against indirect georeferencing*. European Journal of Remote Sensing 50 (1): 155-165. doi: https://doi.org/10.1080/22797254.2017.1300047.

Importance in Integrating Datasets

Georeferencing is critical for merging datasets from various technologies, such as LiDAR scans, Total station, Mobile mapping, and photogrammetric models etc. For example, a point cloud generated with LiDAR technology provides structural data, while a photogrammetric model captures surface colors and textures. Georeferencing aligns these datasets in one place within the same spatial framework, by ensuring that the combined outputs are accurate and comprehensive.

By facilitating the integration of multiple datasets, georeferencing enhances the accuracy, utility, and interpretability of spatial information, making it a cornerstone of modern architectural surveying practices.

2. Data Acquisition and Processing: Surveying Technologies Utilized

This section explores the advanced technologies and methodologies used in data acquisition and processing for architectural surveys, emphasizing their role in producing accurate and comprehensive datasets. Modern surveying techniques, including topographic surveys with Ground Control Points (GCPs), GNSS, Total station, etc., form the foundation of spatial accuracy. These methods are essential for establishing reliable georeferenced frameworks that enable seamless integration of data from varying sources.

Building upon this foundation, the first section explores the Topographic survey, using Ground Control Points (GCPs), their georeferencing using GNSS, and then taking the measurements along with data accumulation using technologies like Total Station and LiDAR. The second section examines photogrammetric methods such as UAV-based, which capture high-resolution images for the reconstruction of textured 3D mod-

2.1.1 Ground Control Points (GCPs)

GCPs are specific locations within an area of interest that have accurately known geographic coordinates. These points are established at specific ground locations, whose coordinates were traditionally measured using topographic maps or digitizing tablets but today more advanced tools like Global Navigation Satellite Systems (GNSS) are used[14]. Being the crucial part of topographic surveys, GCPs also play a significant role in Aerial surveys, by providing reference points to improve the spatial accuracy of datasets. Particularly, the ground control points help with the indirect georeferencing, by serving as fixed points within the survey, providing spatial anchors that tie the arbitrary reference system of the initial 3D model to a predefined coordinate reference system. Their integration ensures that the surveyed data aligns accurately with the global geospatial standards, improving the reliability of measurements and spatial analysis[15].

The authorss[16], while discussing the role of GCPs in photogrammetry state that; their role in Indirect Georeferencing methods is crucial because they can be identified in the photographs captured on ground or by air borne devices, and since their coordinates are precisely known, they can be added as an input into the photogrammetry software, which uses these coordinates to scale, orient, and position the datasets into the desired coordinate system. This ensures more accurate results in comparison to Direct Georeferencing. Direct Georeferencing is not considered a very advisable method since it relies on recording the camera's position and orientation at the exact moment each photo is taken, using GNSS data. This can pose challenges, since the UAV device motion is affected by many external reasons like weather and wind, leading to synchronization issues. These unresolved GNSS ambiguities can reduce achievable positional accuracy to decimeter or meter scale even with advanced equipment.

Establishing GCPs involves careful planning and implementation. First, GCP locations are selected based on accessibility and visibility, ensuring an even distribution across the survey area to maximize accuracy. Next, physical (legible) markers (inform of fabric, colorful spray or object) are places at these locations, which are then measured using high-precision GNSS or Total Station (depending on the location) to determine their coordinates. Finally, the calibration process aligns these measurements with the chosen coordinate system, correcting any distortions or offsets. The number of GCPs depends on the project size and area as the study by[17], states that for a minimum of three GCPs are required to bring the results into a desired coordinate system, however, a site of 1 hector, require up to 20 GCPs to acquire highest precision.

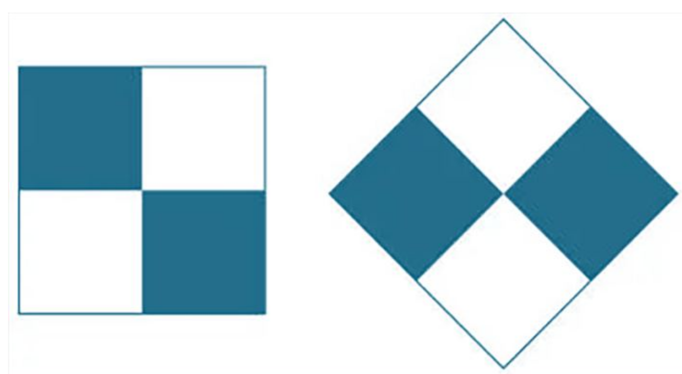
14) Smhh, David P., and Samuel F. Atkinson. 2001. *Accuracy of Rectification Using Topographic Map versus GPS Ground Control Points.* Photogrammetric Engineering & Remote Sensing 67 (5): 565-570.

15) Sanz-Ablanedo, Enoc, Jim H. Chandler, José Ramón Rodríguez-Pérez, and Celestino Ordóñez. 2018. *Accuracy of Unmanned Aerial Vehicle (UAV) and SfM Photogrammetry Survey as a Function of the Number and Location of Ground Control Points Used.* Structure from Motion (SfM) Photogrammetry for Geomatics and Geoscience Applications 10 (10): 1606. doi:https://doi.org/10.3390/rs10101606.

16) *Ivi.*

17) Oniga, Valeria-Ersilia, Ana-Ioana Breaban, Norbert Pfeifer 3ORCID, and Constantin Chirila. 2020. *Determining the Suitable Number of Ground Control Points for UAS Images Georeferencing by Varying Number and Spatial Distribution.* Structure from Motion (SfM) Photogrammetry for Geomatics and Geoscience Applications 15 (5): 876. doi:https://doi.org/10.3390/rs12050876.

Fig. 2. Typical Ground Control Point Patterns.



els. This section outlines workflows from image acquisition to processing, focusing on methods like Structure from Motion (SfM) and Dense Image Matching. The third section details the integration of datasets, such as point cloud registration and geospatial alignment, ensuring that data from all these technologies are unified within a single georeferenced model. Together these methodologies enable precise, non-invasive documentation critical to architectonic surveys.

2.1 Topographic Survey

A Topographic Survey is a detailed and specialized process of surveying land to capture and represent its physical characteristics, encompassing both natural and artificial features. These features include the terrain's relief, such as hills, valleys, plains, depressions, and summits, as well as man-made structures like roads, buildings, bridges, dams, and fences. The primary goal of a topographic survey is to accurately determine the horizontal (X, Y coordinates) and vertical (Z or elevation) positions of these features to represent the landscape's three-dimensional nature[11-12].

The data collected through a topographic survey is used to create a topographic map, which provides a graphical representation of the surveyed area. The map illustrates the natural contours of the land along with human-made modifications, offering critical information about elevations, slopes, boundaries, and other essential elements of the terrain. Such surveys often go beyond simple boundary mapping (in cadastral surveys) to uncover intricate details of the landscape[13].

These types of surveys may be carried out using tools and techniques such as Theodolites, Total Station, GNSS, and/or Aerial photography. These tools enable surveyors to collect data with high precision and efficiency, making it possible to survey even large areas quickly and accurately. Moreover, the integration of traditional methods like Total Station with advanced technologies like LiDAR and GNSS, the resultant acquired data ensures reliability and precision.

This survey is extremely critical in the documentation of heritage buildings, but it also serves in a variety of fields, including military planning, geological studies, urban development, and civil engineering. Some of the techniques utilized in our project are discussed ahead in the sequence of process.

11) Khalaf, Abbas Zedan, and Sally Salwan. 2015. *Topographic Survey with Analytical Close Range Photogrammetry*. Engineering and Technology Journal 34 (8): 1605-1614. doi:10.30684/etj.34.8A.11.
12) Okwuenu, Chike Michael, Esomchukwu Igbokwe, and P. C Anyadiegwu. 2024. *Topographic Survey of Comprehensive Secondary School Nawfia, Anambra State*. International Journal of Research Publication and Reviews 5 (6): 2036-2042.
13) *Ivi*.

18) Bhatta, B. (Basudeb). 2021. *Global navigation satellite systems : new technologies and applications*. 2nd. Florida: CRC Press - Taylor & Francis.
19) *Ivi.*
20) Santra, Atanu, Somnath Mahato, S.Mandal, Sukabya Dan, Pratibha Verma, P.Banerjee, and Anindya Bose. 2019. *Augmentation of GNSS utility by IRNSS/NavIC constellation over the Indian region*. Advances in Space Research 63 (9): 2995-3008. doi:https://doi.org/10.1016/j.asr.2018.04.020.
21) Bhatta, B. (Basudeb). 2021. *Op. cit.*

2.1.2 Global Navigation Satellite Systems GNSS

Global Navigation Satellite Systems GNSS are satellite-based systems that provide geospatial positioning and navigation services. The are very accurately defined by[18] as.

"GNSS is a system consisting of a network of navigation satellites monitored and controlled by ground stations on the earth, which continuously transmit radio signals that are captured by the receivers to process, thus making it possible to precisely geolocate the receiver by measuring distances from the satellites and to provide precise time information anywhere in the world at any time".

Around the world, numerous GNSS are operational, out of which the most known is the Global Positioning System (GPS) which is American led. The other core GNSS include the Russian GLONAAS, European GALILEO, the Chinese BeiDou and. Regional satellite augmentation systems also include EGNOS (European Union), Japanese MSAS, or Indian GAGAN[19] and Indian IRNSS[20].

Thus far, there are only four constellations which cover the whole earth, that are, the GPS Global Positioning Systems, GLONASS Global Orbiting Navigation Satellite System, Galileo, and BeiDou. Each GNSS consists of three segments, the Space Segment, the Control Segment and the User Segment.

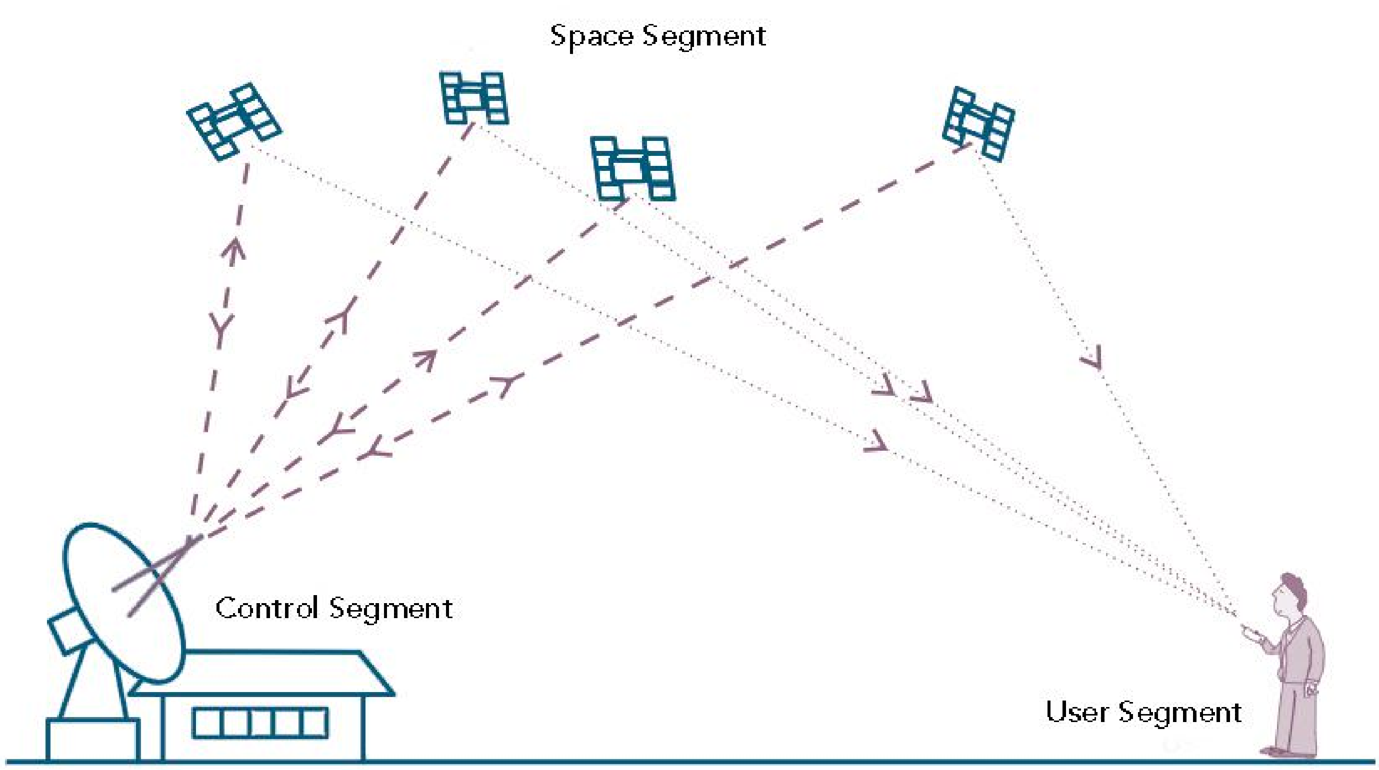


Fig. 3. Functional Segments of GNSS[21].

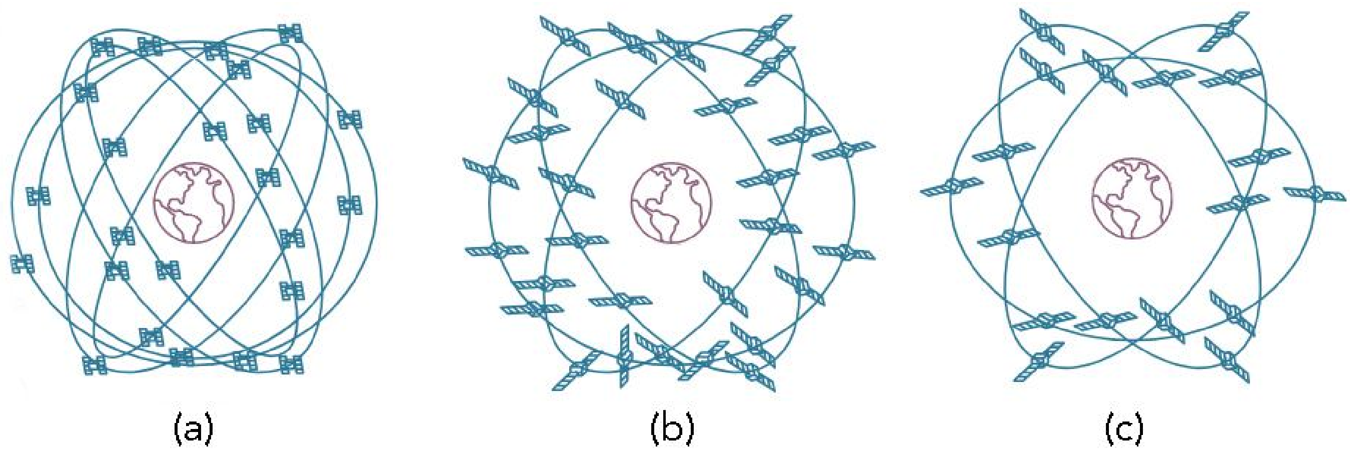


Fig. 4. Constellations of satellites for (a) GPS, (b) Galileo, and © GLONASS[24].

Control Segment

It is also referred to as Ground Segment, which is responsible for managing and maintaining the satellite constellations. It complies with monitoring stations, upload stations, and one or more master control stations. Monitoring stations track satellites, providing data to the master control station, which computes clock and orbital corrections. These updates are sent to satellites via upload stations, ensuring accurate broadcast information for GNSS users[22].

User Segment

This segment consists of GNSS receiver devices that process signals from satellites to determine the user's position, time and speed. These receivers typically include an antenna, a processor, and a stable clock. Modern receivers have multiple channels that allow them to receive the signals simultaneously from numbers of satellites, across multiple constellations like GLONASS, GPS, or BeiDou. The main task of the receiver includes selecting visible satellites, acquiring their signals, measuring propagation time and Doppler shifts, and calculating position, speed and time. GNSS receivers are available in many forms, such as smartphones, cars or watches and specialized equipment for surveying, navigation or military use[23].

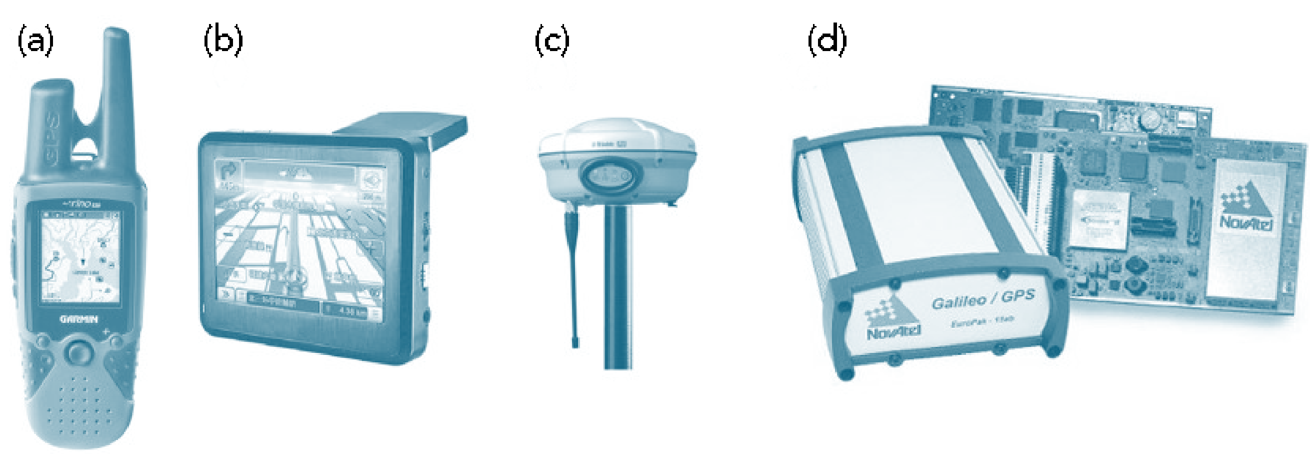


Fig. 5. (a) Handheld GPS receiver from Garmin; (b) Automobile GPS navigation receiver; (c) GPS/GLONASS survey receiver from Trimble; (d) GPS/Galileo receiver from NovAtel[25].

22) *Ivi.*
23) *Ivi.*
24) *Ivi.*
25) *Ivi.*

26) *Ivi.*
27) Clamadieu, Victor, Julie Antic, Pedro Roldan, and Sébastien Trilles. 2024. *PPP Corrections: A Need for Greater Accuracy*. Inside GNSS. April 3. Accessed December 20, 2024. https://insidegnss.com/ppp-corrections-a-need-for-greater-accuracy/.
28) Hartnett, Richard, Keith Gross, Ben Bovee, and Sam Nassar. 2003. *DGPS Accuracy Observations and Potential Data Channel Improvements*. Proceedings of the 59th Annual Meeting of The Institute of Navigation and CIGTF 22nd Guidance Test Symposium. Albuquerque, NM. 518 - 527.

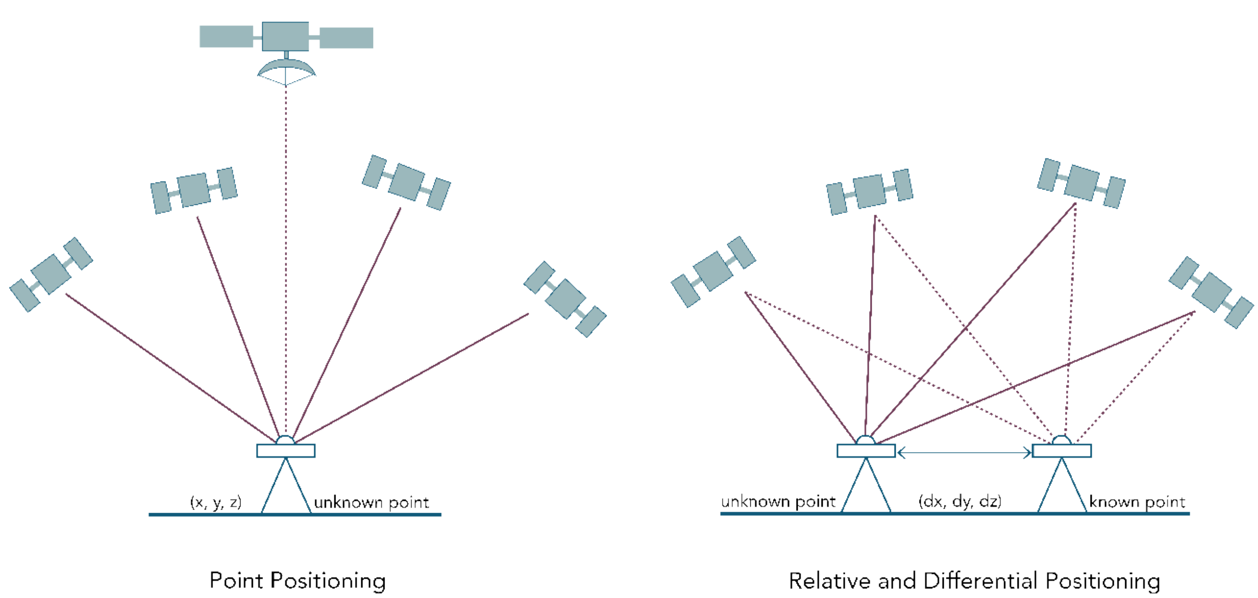
Surveying Methods Using GNSS

The methods applied during the survey depend on the positioning models of the GNSS. These methods are important for the horizontal and vertical accuracy of the data acquired for the Ground control points in a survey. In his book[26], explains that they are broadly classified into pseudorange measurements (coarser positioning) such as: static point positioning, and carrier phase measurements (more precise positioning) such as relative and differential positioning which are also called (dynamic or kinematic GNSS). Below is the brief explanation of these measurement methods provided by the reference book referred to earlier:

Static Point Positioning

This type of positioning involves GNSS receivers that remain stationary throughout the observation period. It relied on extended measurements, typically using carrier-phase observation, to achieve high precision. Observations collected over a longer duration allow for redundancy and higher precision. The stationary nature of this method allows for error correction, making it a preferred technique for geodetic surveys which require millimeter to centimeter accuracy.

Fig. 6. Point and Relative / Differential positioning techniques[27].



Relative Positioning

Relative positioning involves at least two receivers; a reference receiver placed at a point with known coordinates and one or more roving receivers at unknown positions. This technique uses the difference in signal measurements between the two locations to eliminate common errors like satellite clock and atmospheric delays. Relative positioning can be applied in both static and dynamic setups, making it flexible for various applications. It offers accuracy within millimeters to centimeters, which are essential for engineering projects, and construction surveys.

Differential Positioning

Differential positioning is a refined version of relative positioning, as it provides real-time or post processed corrections. A base station at a known location transmits correction data to roving receivers to refine their positions. This methos is widely used in Real-Time Kinematic (RTK) surveys, agricultural guidance systems, and marine navigation where high accuracy is essential.

For the Case Study, the coordinates of the on-ground GCPs were taken with the help of Geomax Zenith 35. Geomax Zenith 35 Pro is a high-precision GNSS receiver widely used in architectural surveys for establishing coordinates of the Ground Control Points GCPs. It uses Real-Time Kinematic (RTK) positing to establish precise GCPs, which are critical for georeferencing. RTK positioning utilizes differential corrections transmitted in real-time from a reference base station or Continuously Operating Reference Station (CORS) network. These corrections resolve errors in GNSS signals, enabling centimetre-level potential accuracy. According to the manual of this device, they can achieve horizontal accuracies as fine as ±8mm and vertical accuracies around ±15mm, depending on environmental conditions and signal obstructions.

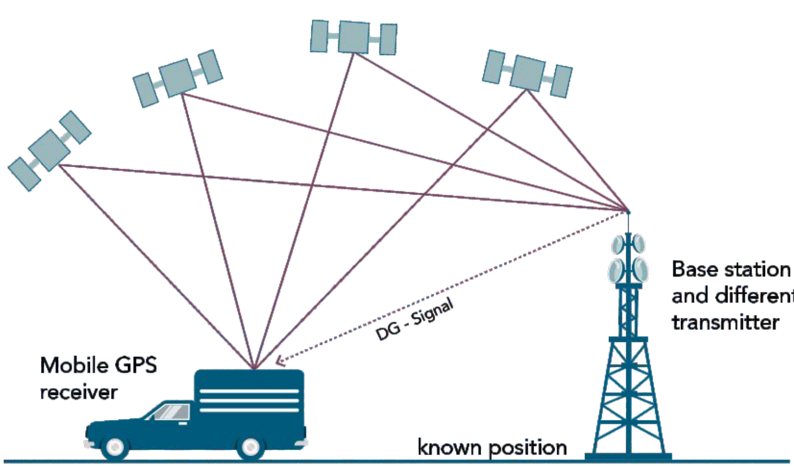


Fig. 7. Real Time Differential Positioning[28].

Fig. 8. GNSS RTK GeoMax Zenith 35 Pro[31].

The Zenith35 Pro integrated additional functionalities like Tilt&Go, which corrects for the inclination of the survey pole. This feature is vital for field conditions where perfect vertical alignment cannot be maintained, ensuring accurate data collection even on uneven terrain. The high precision data obtained with the help of this technology is indispensable for aligning survey output with global coordinate systems and integrating them into BIM or CAD workflow.

2.1.3 Total Station

At the beginning of every project, wherever constructed or unconstructed, one of the primary tasks in the design and construction process is to gain a comprehensive understanding of the area or building in a physical manner. This involves recognizing the pre-existence conditions, understanding the topographical characteristics of the terrain and obtaining accurate measurements. One of the tools that normally used in the construction, engineering, and land surveying projects to acquire this data is the Total Station (ST).

The total station is a precise geodetic instrument used for point-based surveying. The basic function of the TS is measurement of vertical and horizontal angles as well as distances. These measurements are distinguished by their precision, achieving accuracy in single angular seconds for the angle's measurement and a few millimeters in the measurement of distance. In addition to its precise accuracy, another innovative aspect of this equipment is its ability to simplify work by reducing the number of tools required for a task, as a result, errors are reduced .

While distances and angles are typically measured using EDM and Transit or Theodolite, the Total Station (TS) integrates all these functions into a single device giving an automatic recording of these data, to then be processed by the operators later. By this acquisition it is possible to know, for instance, the highness of a point, or even the determination of the cartesian coordinates, and by getting all of this and the integration of other software it is possible to generate the modeling of the surveyed project .

To understand how a Total Station works and how can collect data, it is essential to comprehend its components as well as its axes of rotation. It should be noted that there are various models of total stations available in the market, which may include modifications in the machine's components or additions that facilitate its use or improve the precision of the results. However, despite these variations, there are general components that make the TS a sought-after mechanism, which are:

29) Hankus-Kubica, Agnieszka, Bartosz Brzozowski, Karol Cheda, Maciej Kulinski, and Piotr Wieczorek. 2020. *Verification tests of total station usability for UAV position measurements.* 7th International Workshop on Metrology for AeroSpace (MetroAeroSpace). Pisa, Italy: IEEE. 331-335. doi:doi: 10.1109/MetroAeroSpace48742.2020.9160081.
30) El-Ashmawy, Khalid L.A. 2014. *A comparison between analytical aerial photogrammetry, laser scanning, total station and global positioning system surveys for generation of digital terrain model.* Geocarto International 30 (2): 154-162. doi:https://doi.org/10.1080/10106049.2014.883438.
31) Source: geomax-positioning.com.

- **Base Plate**: This is the inferior part of the Total Station, which helps to connect the instrument to a tripod giving more stability to it and therefore helps to reduce error. It consists of a base plate and an upper plate, equipped with lowering screws and a spherical level that helps to level the instrument and an optical plummet that helps in a precise alignment of the instrument over a specific ground point.
- **Alidada**: It's the part connected to the base plate, and at the same time is the movable part of the instrument. It includes graduated circles which helped with the angular readings (azimuth and zenith). The alidade can rotate horizontally around the base of the instrument and the telescope in the alidade can be tilted vertically, facilitating the acquisition of angles. It also has space for the keyboard and a screen that displays the data that is being acquired.
- **Telescope**: Equipped with an objective lens, is used to identify and align a point, and determine the inclined distance through the distance meter (EDM) by emitting radiation. It's able to move perpendicular to the principal axis of the instrument.

Fig. 9. Main component of total station. Source: Imaged created by the authorss based on information sourced from the presentation of William Meschieri.

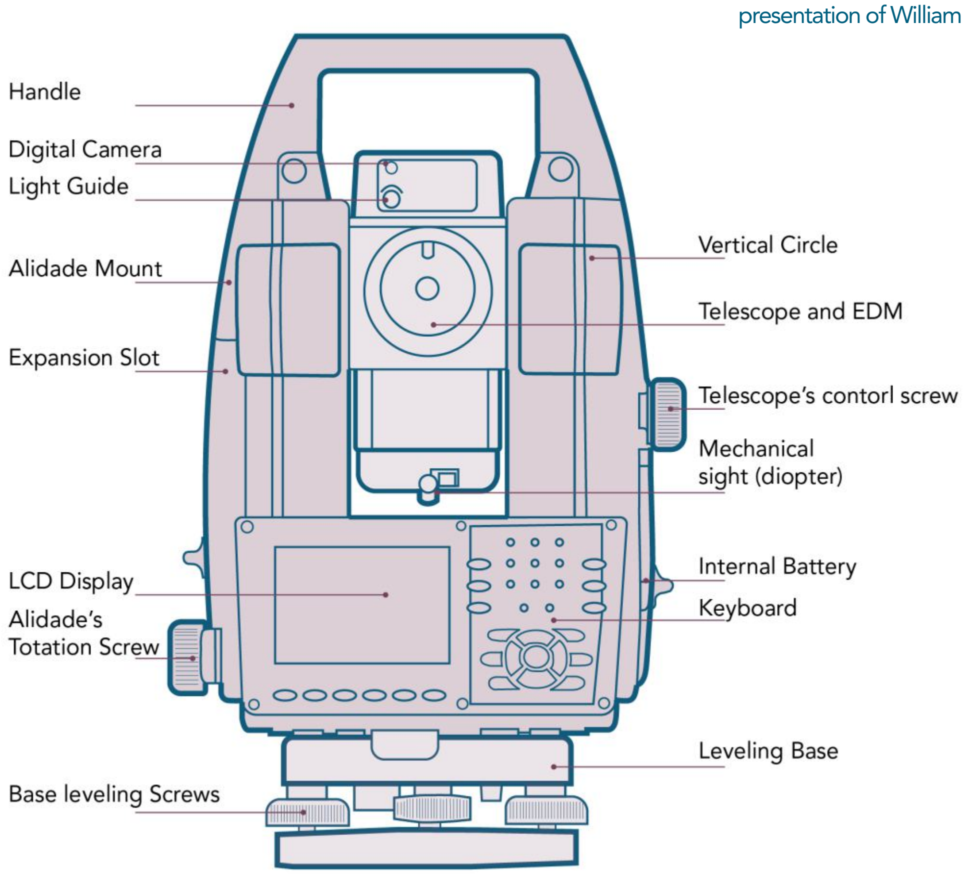
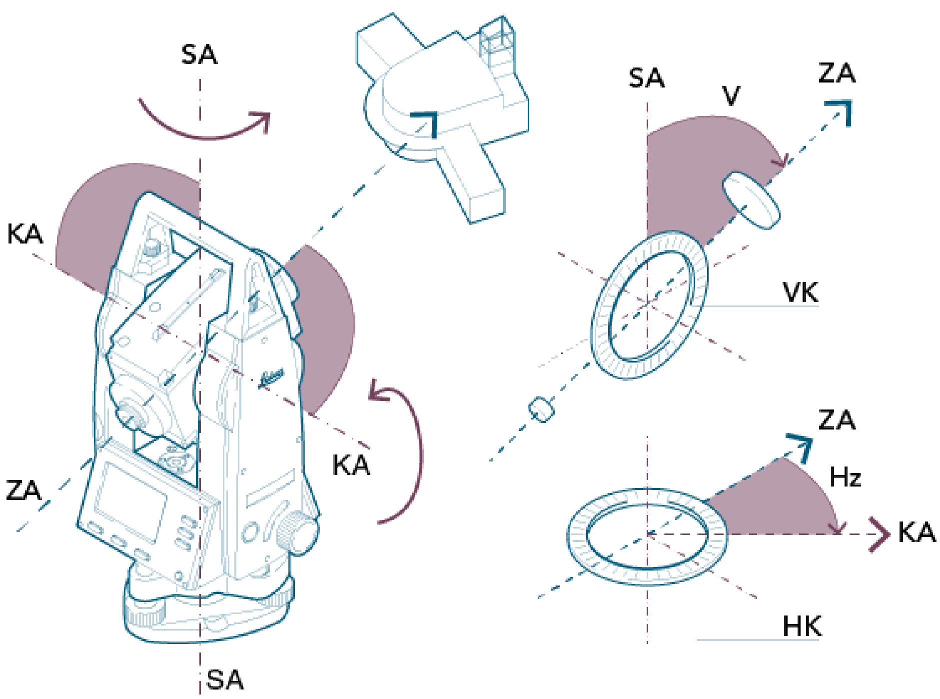


Fig. 10. Technical diagram of a total station, highlighting the axes and angles. Source: Imaged created by authors based on information sourced from Leica Geosystems User Manual TC ® 110 V.1.0

ZA: Line of sight
SA: Standing Axis
KA: Tilting Axis
V: Vertical Angle
Hz: Horizontal Angle
VK: Vertical Circle

Understanding how the coordinates of a point are determined requires recognizing that the TS works using three axes. Utilizing rotation plates, the Total Station can have free movement in both vertical and horizontal planes, which are being manipulated by the standing axis (vertical rotation axis of the Total Station) and tilting axis (horizontal rotation axis of the telescope) respectively (figure 10). In addition, there is a third axis which is the collimation axis, or the line of sight, this is an imaginary line that extends from the reference point of the telescope's eyepiece to the focal point of the target being discovered. The outcome of the relationship between these axes determines the angles. The interaction between the standing axis and the collimation axis yields the vertical or also called zenith angles, while the interaction between the tilting and collimation axis provides the horizontal or azimuth angle as is shown in figure 10. These three axes intersect at a point called the "analytical center".



Modern TS utilizes two distance measurement methods. The first method employs infrared technology, where an electromagnetic pulse is directed towards a prism, which reflects the same beam back to the station. The second method, known as reflectorless, involves directing a pulse towards any point on an object and having it reflected to the station by the material component. The collimation axis is directed towards a target, this one must be easily recognizable, it can be a mark that represents a cross or a chessboard, to be identified since it will be collimated during the photogrammetric or LiDAR process.

For a point-based survey in the Case Study, and for being able to acquire the data from GCPs located in the facade and interior of the building, the Total Station used was Leica Viva TS16. It is a robotic total station equipped with Auto Height technology, allowing automatic measurement of the instrument's height at setup. This innovation reduces human error and ensures consistent accuracy during surveys. The instrument uses high-precision angle measurement systems and electronic device measurement (EDM) to deliver sub-millimeter accuracies. As per the manufacturer's website, this model can achieve accuracy levels suitable for architectural surveys, with the range of 1.5m to 3500m achieving accuracy of 1mm and 1.5 ppm with proper calibration and prism use. This instrument can also be paired with GNSS receivers to georeferenced data in global coordinate systems, a critical requirement for architectural surveys and restoration projects.

2.2 LiDAR Technology

Light Detection and Ranging (LiDAR), is a detailed metric surveying technology that combines methods and tools to measure distances and create 3D models of the real world. The scope of this methodology goes beyond architecture, reaching fields with no direct relation. The first LIDAR system was introduced in 1961 by Malcolm Stitch. At that time, LiDAR's intended use was for aircraft tracking, and it was initially called Coherent Light Detecting and Ranging, the term LiDAR, as it is known nowadays, was coined in 1963[32].

Over time, LiDAR expanded into other fields, from military application to topographic mapping. This technology made its way into the construction sector due to the need for sensors in aerial photogrammetry. The expansion towards various disciplines demanded new research and developments in this field. The implementation of LiDAR in construction improved after the arrival of commercial GPS in the '80s and inertial measurement units, enabling LiDAR to provide accurate geospatial measurements. Since then, more research has been done to make this system accessible to everyone and applicable in various scenarios; even today, some iPhones can employ this technology.

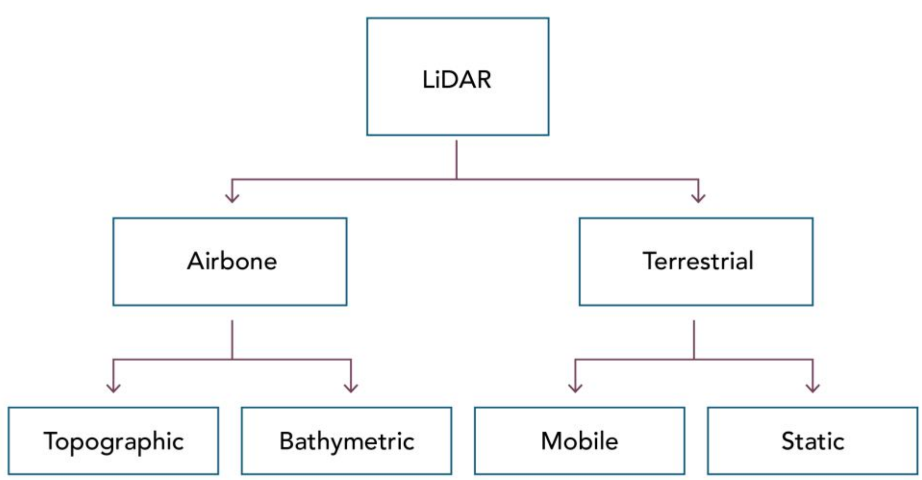
LiDAR technology works by emitting laser light onto a target and measuring the reflected light to determine the distance. The system calculates the time it takes for the light to return to its source, known as the time of Flight (ToF). By measuring variation in wavelength and arrival time of the reflected light, LiDAR accurately determines the position and distance of objects. Depending on the LiDAR sensor, scanners can emit millions of laser pulses per second, each pulse calculates the distance between the object and the sensor using the velocity of light. The acquired data integrated with the information provided by GPS technology determines the three-dimensional position of a point and its spatial distribution. Consequently, the relationship between one point and all the other millions of processed points generates a dense 3D visualization known as point cloud data; Denser the cloud, means a more detailed model, meaning that in the survey more data was acquired.

Fig. 11. Leica Viva TS16 Total Station – used for the Survey.

Fig. 12. LiDAR Classification. Source: Imaged created by authorss based on information sourced from Neoge, Srushti, and Ninad Mehendale. 2020. Review on LiDAR technology. Mumbai, India: KJSCE, Vidyavihar, Mumbai, India. Accessed 2024. https://ssrn.com/abstract=3604309.

32) Neoge, Srushti, and Ninad Mehendale. 2020. *Review on Lidar Technology.* SSRN doi:http://dx.doi.org/10.2139/ssrn.3604309.

33) FARO Technologies. 2024. FARO Focus Premium Max and Core AECO Brochure. November. Accessed Jan. 2025. https://tinyurl.com/33z2hzcp



Based on their operational platforms, LiDAR can be divided into two main categories as is shown in figure 12:

- **ALS – Airborne Laser Scanning**: They are mounted usually on aircraft drones or helicopters. The scan is pointed downwards, emitting laser pulses towards the same direction, and typically scans 180 degrees of solid angle. These characteristics permit the scan to be applied in large-scale mapping and surveying, giving high-resolution data that can be processed and create a digital surface and terrain model (DSM and DTM). There are two types of ALS:
  - **Topographic**: Used for examining the surface. Example: Describe forest structures. In the architecture field, it can assist with large-scale projects like urban planification giving data on the terrain and constructed areas.
  - **Bathymetric**: Used for water penetration applications. It can examine the elevation and water depth simultaneously. Example: Coastal monitoring.
- **TLS – Territorial laser scanning**: They are mounted on ground-based platforms such as tripods or vehicles. The sensor captures data by emitting laser pulses horizontally or vertically, typically it covers 360 degrees in 1-D or 2-D, and the distance from the scan to the object can vary between centimeters up to one kilometer. Usually, TLSs are used to survey highways and create 3D models for spaces. Depending on the type of platform the scan is mounted, it can be classified as:
  - **Mobile**: The system is mounted on a moving platform, such as a vehicle train, or boat. In the construction sector, it can be used to analyze road infrastructure.
  - **Static**: The sensor is usually mounted on a tripod mount. This type of LiDAR is a good asset for architectural surveys, as it can generate point clouds from the exterior and interior parts of a building.

As previously mentioned, LiDAR operates by projecting laser light towards a target and analyzing the reflected light to measure the distance. It is essential to clarify that these laser pulses can be reflected by an object or the ground surface. The way the system detects these changes in elevations depends on the number of times the pulse returns to the scan. A single emitted laser pulse can return to the sensor as one or multiple returns; each return pulse indicates that the light has encountered a reflective surface as seen in figure 13. The first laser pulse return is the most significant and typically corresponds to the highest entity in the landscape, such as a tree canopy or the roof of a building. In some cases, the first return represents the ground, and in this scenario, the LiDAR system will detect only one return.

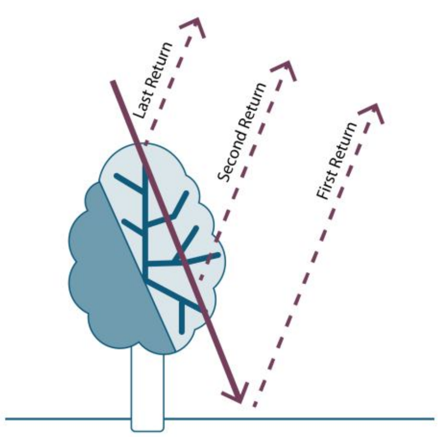
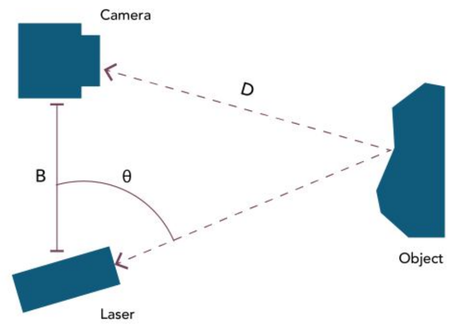


Fig. 13. LiDAR explanation. Source: Imaged created by authors based on information sourced from Tarrat Martin, Diego. 2020. Aplicación del sensor LiDAR en la medición de las variables zoométricas de los caballos. Sevilla, Spain: Universidad de Sevilla. Accessed 2024. https://biblus.us.es/bibing/proyectos/abreproy/71797/fichero/TFM-1797+TARRAT+MART%C3%8DN%2C+DIEGO.pdf.

Lasers can also be categorized based on the techniques they use to calculate the distance from the emission and reception of laser radiation. Among the most well-known techniques, it can be found the distance scanner.



- Distance scanner: They work with the same principles as a total station, meaning that for each point, coordinates are determined by measuring the azimuth angle, the zenith angle, and an inclined distance between the center of the instrument and the target. It can be classified according to the measurement process into:
  -Time of flight (TOF): This is based on calculating the time elapsed between the emission of a light pulse towards an object and the reflection of that pulse back to the receiver. By knowing the refractive index of the medium and using the speed of light, it is possible to deduce the distance traveled by the light. This method is used for long-range calculations.
  -Compensation of phase: The emitted signal is a continuous laser beam with a sinusoidal pattern and a known frequency. The distance is calculated indirectly by knowing the wavelength and measuring the phase difference between the initial and final wave using a phase compensation device. This method is used in medium-range systems.

Fig. 14. Acquisition of data using distance scanner technique. Source: Imaged created by authors based on information sourced from Pellegrino, Eleonora. 2021. "Geomatica e HBIM per il patrimonio - il Campanile della Chiesa di Santa Marta di Bernardo Vittone. Thesis Supervisor: Filiberto Chiabrando, Lorenzo Teppati Lose'." Thesis for Master's Degree Program in Architecture, Construction, and City, 178. Accessed 2024.

Fig. 15. FARO focus. Source: FARO Technologies 2024

In the case study of the church of Gardella, a laser scanner survey was made for the inside and outside areas of the church. The aim of using a laser scanner is to carry out a non-invasive and efficient survey to document and accurately analyze its architecture. For this purpose, a Faro Focus x 330 terrestrial laser scanner was used, employing time-of-flight technology to generate a 3D model of space. These scans stand out for their ability to scan distances of up to 330 meters while capturing millions of points in three-dimensional space, achieving a precision level of up to±1 mm, depending on the model and selected configuration. The scanner allows users to adjust parameters such as scan range, point density, and capture speed, making it highly versatile for various applications. The captured data is exported in standard formats like .e57, or. Las or point clouds compatible with 3D modeling and CAD software, enabling seamless integration into workflows for analysis, design, and documentation.

34) Russo, Michele, Fabio Remondino, and Gabriele Guidi. 2011. *Principali tecniche e strumenti per il rilievo tridimensionale in ambito archeologico*. Archeologia e Calcolatori 22: 169-198. https://www.archcalc.cnr.it/journal/articles/592.
35) Almagro, Antonio. n.d. *Photogrammetry for Everybody*. International CIPA Symposium. Olinda, Brasil.

2.3 Photogrammetry Survey

Just as our eyes capture two different images and the brain can recreate them as a single composition through homologous points and calculate the depth of the objects inside the viewed frame, photogrammetry performs the same process. Imaged-based reconstruction or photogrammetry is the science of obtaining reliable information about the properties such as position, shape, and measurements of surfaces and objects without physical contact through photographs acquired with terrestrial, aerial, or satellite sensors[34].

This technique originated in the 19th century and since that date different worldwide advances have helped in the progress of this technique. Its progress during history can be divided into 4 generations:

- **1st**: Marked by the daguerreotype (the first commercially marketed photographic process), focused on pioneering experiments for terrestrial and aerial (ballons) surveys.
- **2nd**: Known as analog photogrammetry, it began with Pulfrich's invention of stereophotogrammetry in 1901 and the creation of cartography through aerial methods during World War I.
- **3rd**: Analytical photogrammetry, computers enabled advances in precision through mathematical adjustments and new instruments like the analytical plotter. The analytical plotter is an instrument that helps to transform the coordinates of points on a photograph into map coordinates.
- **4th**: Digital photogrammetry, leverages digital images in microprocessors, revolutionizing the field with faster and more efficient data access.

This technique, like many others, is in constant change due to technological advances. This progress generates interest from other disciplines in adopting this method, as this is an extremely useful assistant that helps in the acquisition of metric information of representative buildings, facilitating the creation of a 3D model. This type of documentation has become of prime importance in the fields of historic preservation, tourism, education, and real state (Bertocci, Arrighetti & Bigongiari [2019] quoted in Rahaman 2021) because it made it easier to solve precisely the most difficult problems the direct measuring system presented[35].

Bearing in the last statement, it is noteworthy the importance of photogrammetry in the cultural heritage field. Numerous buildings are classified as heritage sites on a local, national, or international scale, and due to their cultural significance and heritage value, these buildings deserve to be studied, documented, protected, and preserved. Photogrammetry facilitates this by providing a set of outputs that allow for detailed documentation and analysis, enabling a clearer understanding of the building's current condition and the necessary actions required for its maintenance or restoration. The products this technique can give can be divided into 3 categories:

- "Computational results: It delivers the 3D position of points, measured in photographs, in a ground control coordinate system. It helps to create profiles and cross-sections.
- Image products: Derivatives of a single photograph or composites of overlapping photographs. In this way, orthophotos, photomosaics, and orthophoto maps can be acquired.
- Maps: Planimetric maps which contain the horizontal position of ground features; topographic maps that include elevation data."

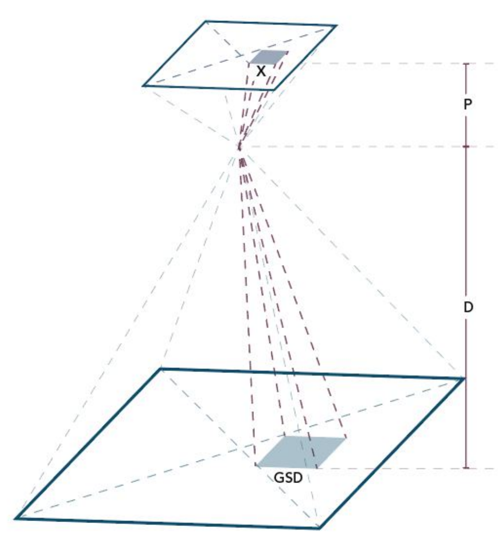
The products are acquired through the data collection process, in this way photogrammetry can also be classified based on the method used to capture photographs, distinguishing between aerial and terrestrial photogrammetry. Although this distinction exists, the photogrammetric process for both is the same and can be summarized in three steps: acquisition of data, orientation, and restitution:

- **Acquisition of data**: This is the process of taking photos (aerial or terrestrial). The known information at this point is the studied object (x, y, z) and the camera (position and type). When a photograph is used for metric purposes, it is referred to as a photogram. The photogram illustrates a transformation where the dimensions of the images are called relative to those of the real world; the scale of the photogram is calculated based on the internal geometry of the camera and the shooting distance. In digital photography, the average scale of the frame can be determined by focusing on the pixel size, as each pixel represents a specific area of the terrain; therefore, to define the actual ground distance represented by a pixel in the image, the concept of Ground sample distance (GSD) is used as it is shown in Figure 16 through the next formula.

Fig. 16. Representation of data acquisition, considering the transformation of real-world data into a photogram through GSD Sourced: Imaged created by the authors based on information sourced from Spanò, Antonia Teresa. 2019. Metodi 3D Imaging and Ranging per la documentazione del patrimonio. Torino: Politecnico di Torino.

$$GSD = (D * X)/P$$

Where:
G: Shooting Distance
X: Size of the pixel
P: Focal distance (Lense's property)



- Orientation: Transforming the images into 3D data through three main phases. Internal orientation, which reconstructs the camera's geometry by correcting optical distortions. Relative orientation, which aligns two frames to create a 3D model with an arbitrary system using homologous points, "this process is carried out by image correlation methods such as ABM (Area Based Matching), which relies on comparing different grey levels in small areas between images;

FBM (Feature Based Matching), focusing on identifying points, lines or areas between images; RM (Relation Matching), uses different entities (topological, radiometric, and spatial) to define their counterparts in other images" . Absolute orientation adjusts the model to the real-world coordinate system using GCPs. In simple terms, this step provides all the parameters necessary to establish the analytical relationship between the image points and the object points, in this way it ensures a spatial accuracy between the 3d model and the reality.

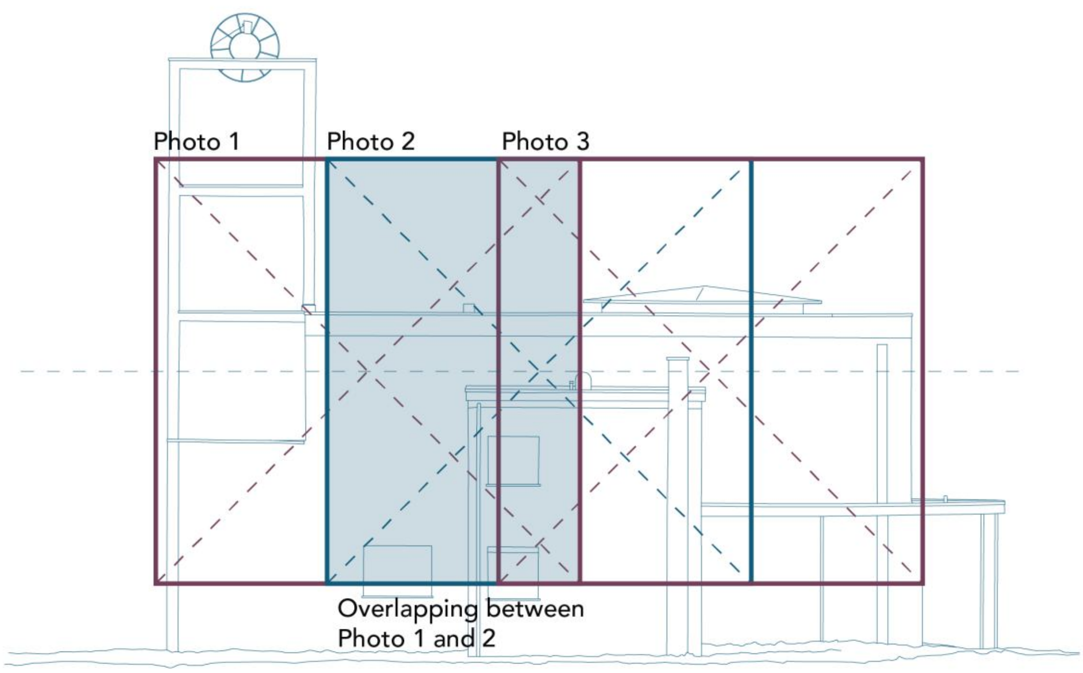


Fig. 17. Relative Orientation for Image Overlap. Source: By authors.

- **Restitution**: This is the process through which, once the photograms have been oriented and the two, dimensional coordinates in the image are known, the object is measured and reconstructed into a 3D model. This step is crucial as it enables the creation of final products such as plans, maps, or 3d models of the surveyed object. The most advanced technique employs modern restitution tools, which allow direct work with digital images using computer software performing automatic calculations to align and measure images.

Photogrammetry techniques have evolved significantly over time, transitioning from analog photogrammetry, characterized by its manual processes, to analytical and finally to today's digital photogrammetry. Modern digital methods, distinguished by the use of advanced algorithms like Structure from Motion (SfM), enable the processing and analysis of images to generate highly detailed three-dimensional models. This evolution by leveraging computational results, image products, and maps, has contributed to fields such as cultural heritage preservation.

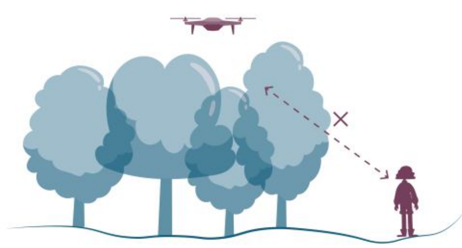
2.3.1 Aerial Photogrammetry – UAV

UAVs, unmanned aerial vehicles, are characterized by their ability to operate remotely without requiring an onboard pilot. An example would be drones; however, it is important to note that UAV is not limited to these devices, reaching more complex systems such as UAV helicopters or autonomous aerostats. The function of these devices is based on the aerodynamics principles, a branch of science that studies the movement of air and other gases and their interaction with moving bodies through them.

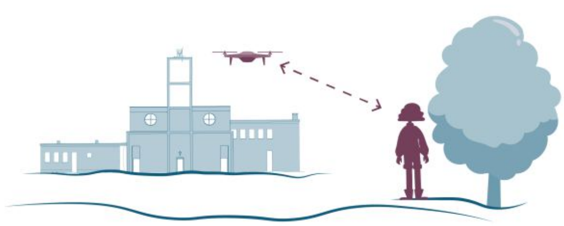
Drones are tools that contribute to large-scale, real-time data collection, which can support photogrammetric studies by providing visual data, as they can be integrated with other technologies such as RGB cameras or even LiDAR technology, thereby expanding their scope within the field of photogrammetry.

The flexibility of the flight plans makes drones useful in the field of photogrammetry, as they can adapt to a wide variety of applications and specific needs. Among the flight plans and their relationship with the operator, the following can be identified:

- **Beyond Visual line of sight**: Refers to situations where the drones operate beyond the visual range of the operator.



- **Visual Line of sight**: Indicates that the drones always remain within the operator's visual field during their flight.



In addition to this classification, drones can also be categorized based on their flight trajectory and camera orientation, as outlined below:

36) Santamaría Peña, Jacinto, y Teofilo Sanz Méndez. 2011. *Fundamentos de Fotogrametría*. Universidad de la Rioja, Servicio de Publicaciones.
37) *Ivi*.
38) Cortés, Carlos Martín , Mauricio Acuña, Guillermo Palacios Rodríguez, Borja García Pascual, Adrián Regos Sanz, Miguel Ángel Lara Gómez , and Rafael Navarro Cerrillo. 2024. *Principios generales de los UAS*. In *Geociencias aplicadas a la gestión forestal*, 477-494. UCOPress - Editorial Universidad de Córdoba.

- Nadiral Flight: The axis of the lift (the extension of the focal point) is completely vertical. "However, achieving this is nearly impossible"[36] due to practical limitations and environmental factors.
- Vertical flight: This occurs when the angle of separation between the vertical axis and the axis of the lift is less than 3°. Vertical flight can be generally considered nadiral without introducing significant errors[37] in the precision and the quality of the data acquired.
- Inclined flight: This takes place when the angle exceeds 3°.

Apart from the camera orientation, drones can also be classified based on how they are controlled. For example, in an automated flight, UAVs follow a preprogrammed route or make autonomous decisions using algorithms and sensors, which is ideal for missions that require prior planning and a specific flight itinerary, such as those designed for photogrammetry. Another example is an assisted flight, which employs technologies like automatic stabilization and GPS to aid the operator in controlling the drone, making this type of flight particularly useful in scenarios where enhanced precision and stability are required, thereby further contributing to the field of photogrammetry[38].

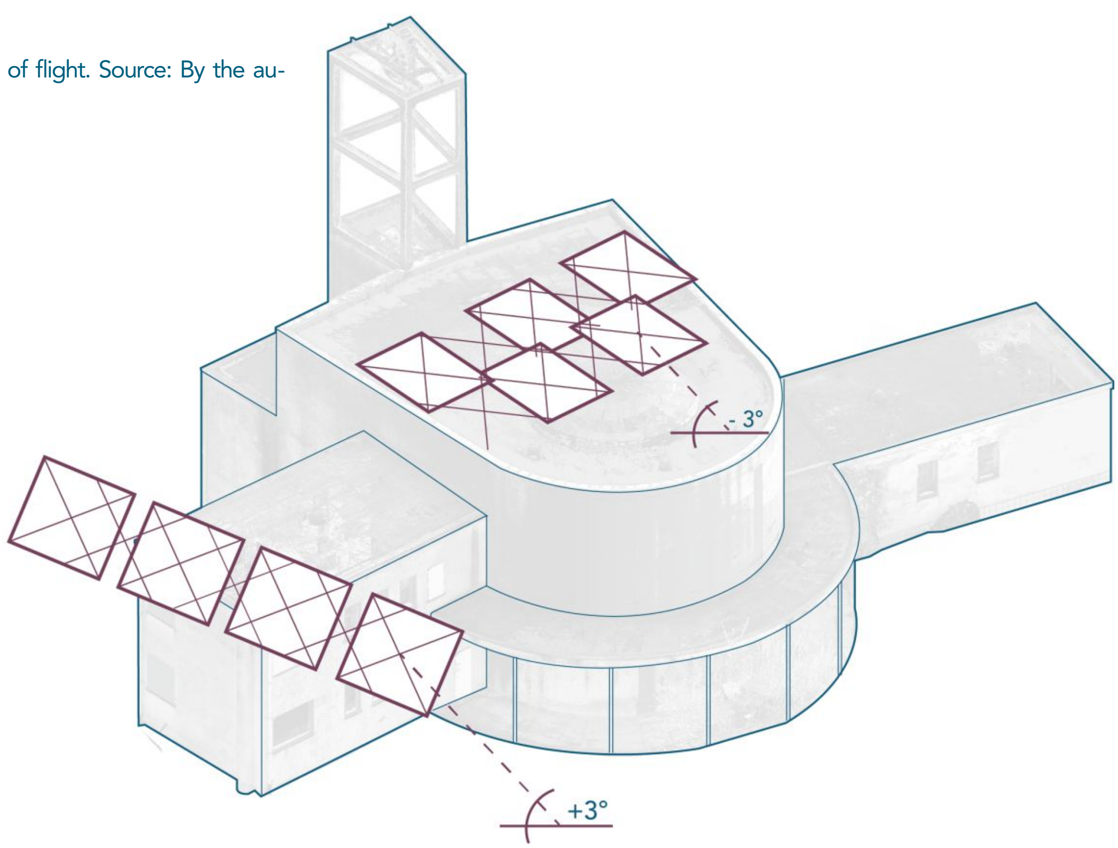


Fig. 18. Type of flight. Source: By the authors.

As mentioned, navigating systems can integrate precise location data to enhance UAV operations. The most common positioning systems include GPS, GLONASS, BeiDoud, and Galileo. These systems assist UAVs in various ways: they enable them to maintain a stable altitude and position, they facilitate georeferencing of acquired data to streamline the creation of maps and 3D models, they support the programming of predefined routes and help maintain flight trajectories by correcting deviations when necessary.

By understanding the capabilities of drones (as mentioned in the previous paragraph) their potential in data collection can be maximized. For instance, flight altitude, defined as the vertical distance between the drone and the Earth's surface, plays a crucial role in the quality and applicability of the data obtained by UAVs. For instance, flying at a higher altitude allows the area of interest to be covered in less time but may compromise the resolution and accuracy of the captured data. Conversely, a lower altitude improves data quality but increases the flight time required to cover the same area; therefore, understating the capabilities of the drone being used is crucial, for instance, knowing the battery life of the device will help in the creation of an optimal flight plan strategy.

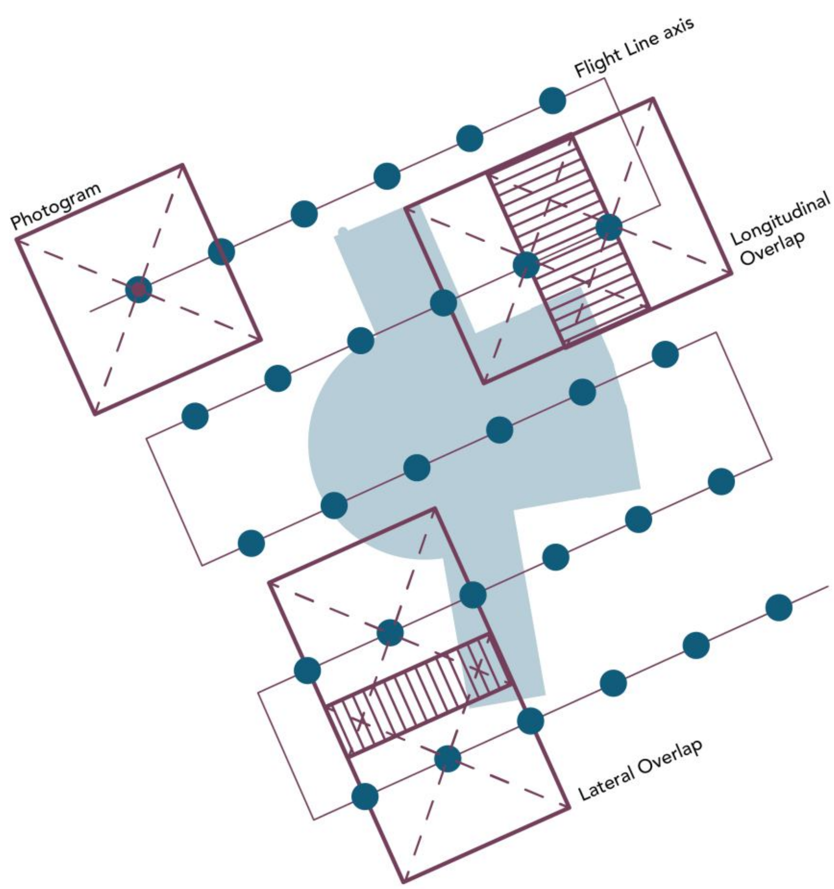


Fig. 19. Scheme of a flight plan and types of overlap in data capture. Source: By the authors.

Understanding the capabilities of drones, such as those mentioned in the previous paragraph, allows for better optimization in data collection. One key factor is flight altitude, which refers to the vertical distance between the drone and the surveyed object. The ability to control the altitude has a direct and significant impact on the quality and applicability of the data collected by the UAS (Unmanned Aerial System). For instance, flying at a higher altitude enables the coverage of larger areas in less time, but it may compromise the resolution and accuracy of the captured data. Conversely, a lower altitude enhances data quality but increases the flight time required to cover the same area. For this reason, it is crucial to understand the specific capabilities of the drone being used. By taking into account the instrument's features, such as battery life, an optimal flight plan can be effectively designed.

In aerial photogrammetry, a flight plan involves more than just the drone or aircraft's route or the previously mentioned altitude. There are additional parameters that contribute to effective data coverage, such as camera orientation and the method used to capture images, these being important aspects that contribute to ensuring the image overlap. There are two main types of overlap in photogrammetric operation: longitudinal, which occurs in the flight direction, meaning that is moving in the same axis as the flight line, where all the principal points of the frame are connected; lateral overlap is the one that takes place between adjacent flight lines. Both types of overlap are essential for obtaining accurate and consistent data during photogrammetric surveys.

Generating adequate overlap between images facilitates their correct alignment and assembly during the data analysis process. According to the Metashape Agisoft Manuel (photogrammetry manual) "In the case of aerial photography, the overlap requirement can be summarized as follows: 60% side overlap + 80% forward overlap". To achieve proper overlap, the camera's shots must be synchronized with the aircraft's speed. As mentioned earlier, the drone's flight is influenced by aerodynamic principles meaning that it's affected by environmental conditions such as air density, humidity, and wind. Considering the wind's direction, orientation and speed is essential for establishing a correct flight axis. Wind triangulation plays a crucial role in determining the drone's trajectory and orientation, especially during tasks requiring precise aerial photography. The concept is as follows:

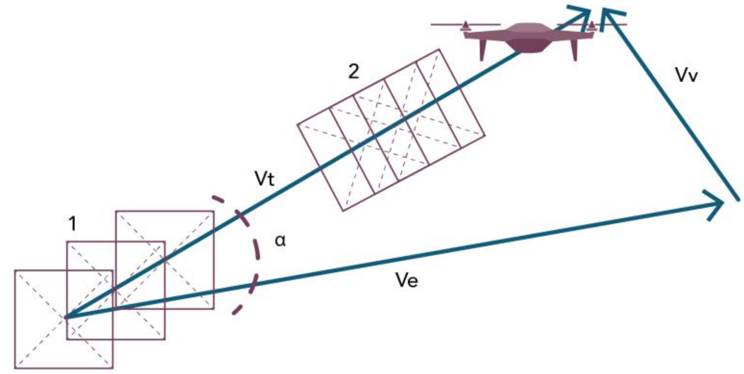


Fig. 20. Source: By the authors source from Santamaría Peña, Jacinto, and Teofilo Sanz Méndez. 2011. *Fundamentos de Fotogrametría*. Universidad de la Rioja, Servicio de Publicaciones.

- When the drone flies in the presence of wind, its actual trajectory **(Vt)** becomes a vector, understood as the product between its own speed **(Ve)** – it is clarified that this movement neglects the air around it – and the wind speed **(Vv)**. If this effect is not compensated for the captured images will be misaligned as shown in form 1 in Figure 20.
- To correctly capture the images, the drone's camera must rotate by an angle equal to **α**, referred to as the drift angle. This is the angle the drone must adjust to counteract the deviation caused by the wind and maintain the desired trajectory. This adjustment ensures that the photos remain straight and aligned with the terrain as shown in form 2 in Figure 20.

Due to modern technologies, today's drones can make use of sensors and navigation systems to automatically calculate and adjust the drift angle during the flight. In this case, the study was done with the Mavic 3M drone. This is a compact and portable drone which is distinguished by its advanced system, which combines a 20 MP RGB camera featuring a 4/3 CMOS sensor and mechanical shutter, along with four multispectral cameras of 5MP each. This configuration allows the drone to capture highly detailed and accurate images under various conditions. Additionally, it is equipped with an integrated sunlight sensor that enhances data precision by compensating for solar irradiance in the captured images. Its RTK module provides centimeters level positioning, ensuring precise georeferencing of the acquired imagery. The drone also offers flight autonomy of up to 43 minutes and a transmission range up to 15 km.

Fig. 21. Mavic 3M drone. Source: DJI Mavic 3M. n.d. DJI Agriculture. Accessed January 10, 2025. https://ag.dji.com/it/mavic-3-m.

Aerial photogrammetry using UAVs, such as drones, has revolutionized the field by enabling efficient, precise, and adaptable data collection. These devices, equipped with advanced technologies like RGB cameras, LiDAR, and navigation systems, have enhanced the ability to create 3D models, maps, and other outputs. The flexibility of UAVs, including customizable flight plans, camera orientations, and automated or assisted navigation, plus modern advancements, such as algorithms, have improved the quality of aerial surveys, ensuring the alignment and precision of the captured images, even in challenging conditions.

2.3.2 Structure from Motion (SfM)

Structure from Motion (SfM) is a modern technique within the broader field of digital photogrammetry. It integrates automation to minimize errors and optimize time, with the primary goal of generating three-dimensional (3D) models from two-dimensional (2D) overlapping images captured from different perspectives using standard compact cameras, often combined with georeferencing data[39].

Since Structure from Motion (SfM) is part of photogrammetry, its foundations are fundamentally the same. Returning to a concept introduced in the previous section, this can be explained through an analogy drawn from a familiar daily process: how humans perceive the world.

39) Eltner, Anette, and Giulia Sofia. 2020. *Developments in Earth Surface Processes.* Vol. 23, in Chapter 1, *Structure from motion photogrammetric technique*, edited by Simon M. Mudd Paolo Tarolli, 1-24. Elsevier. doi:https://doi.org/10.1016/B978-0-444-64177-9.00001-1.

40) Green, Susie, Andrew Bevan, and Michael Shapland. 2014. *A comparative assessment of structure from motion methods for archaeological research*. Journal of Archaeological Science 46: 173-181. doi:doi.org/10.1016/j.jas.2014.02.030.
41) Westoby, M.J., J. Brasington, N.F. Glasser, M.J. Hambrey, and J.M. Reynolds. 2012. *Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications*. Geomorphology 300-314. doi:doi.org/10.1016/j.geomorph.2012.08.021.

The human brain has the ability to create a single cohesive image from two distinct viewpoints – the eyes. This phenomenon, known as binocular vision, enables the perception of the world in three dimensions. Depth perception is achieved by interpreting the differences between the images perceived by each eye, a mechanism referred to as binocular disparity. When this biological concept is translated into a technological and scientific approach, it is referred to as stereophotogrammetry. In the context of SfM, the depth perception of a space is achieved through stereophotogrammetry by using two or more images captured from different viewpoints, analogous to observing a space while a person is in motion.

Unlike traditional photogrammetry, which requires images to be captured under controlled conditions (specific angles and predetermined geometries), the SfM approach allows for photos to be taken from any position or angle, much like the variability in human visual input. As Szeliski (2010) aptly describes "It is the computer vision equivalent of a human's ability to understand the 3d structure of a scene as they move through it"[40].

Another advantage of SfM compared to traditional photogrammetry is that SfM calculates results based on the overlap of images, without requiring prior information about the camera's location and orientation or the topographical reference points in the scene[41]. Although this information can be added and utilized, SfM employs advanced computer algorithms, such as bundle adjustment, to calculate camera position and generate a point cloud model without relying on pre-existing data.

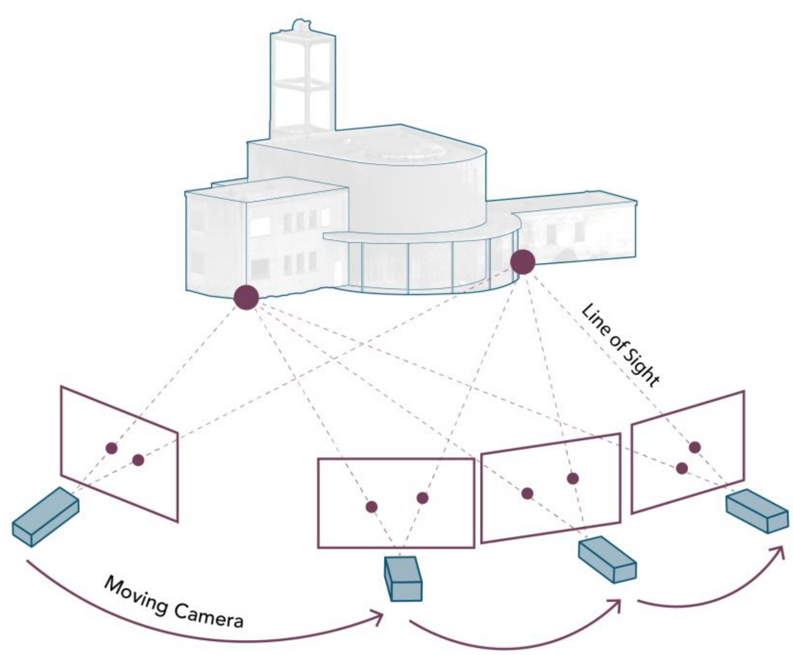


Fig. 22. Structure from Motion techniques requires multiple overlapping photographs. Source: Interpretation by the authors.

Rather than being a single technique, SfM is best described as "a workflow that employs multiple algorithms developed from computer vision, traditional photogrammetry, and more conventional survey techniques" (Carrivick [2016] quoted in Eltner and Sofia 2020). This approach allows for the creation of a 3D point cloud, which can then be further processed to create various outputs, such as mesh clouds, textured clouds, DEMs, rectified images, scaled plans, elevations, and cross-sections.

The process previously mentioned will be briefly explained here and further developed in the next section, in conjunction with the case study of Gardella's church. The process is as follows:

- **Preliminary preparation**: Selection of the appropriate instruments. For instance, a camera with a specific resolution, and a specific model of total station. Place the GCPs if georeferencing the model is required. Plan de captured area
- **Acquisition of Images**: Capture a significant number of frames during the survey phase. The greater the number of photos, the easier it will be for the software to find common points.
- **Image alignment**: Estimation of the cameras' intrinsic and extrinsic parameters, generating a sparse point cloud.
- **Dense Matching**: Scale adjustment and georeferencing using GCPS, GPS, or additional data. Generation of a dense cloud using dense image-matching algorithms.
- **Outcomes**: From the dense cloud, mesh clouds, DEMs, orthophotos, and textured meshes can be created for analysis and visualization.

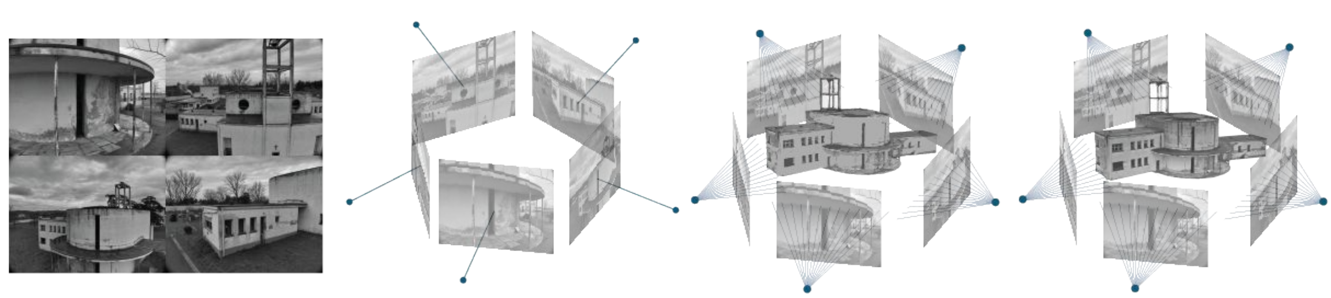


Fig. 23. Structure from Motion process from left to right. Image acquisition, image orientation, dense matching (3D reconstruction), and outcome (texture mapping). Source: interpretation by authors.

Workflow from data collection to data processing

3.1 Data acquisition

The survey was conducted by the DIRECT group from the Polytechnic University of Turin. This team, also known as the disaster recovery team, is a multidisciplinary group composed of students and faculty members from the field of architecture and engineering. Their objective is to promote and sustain continuous training in advanced technologies related to 3D Metric Surveying and Remote Sensing using innovative techniques. Among its main areas of focus, the DIRECT team emphasized the enhancement of cultural heritage, both tangible and intangible. Within this framework falls the case study of Ignazio Gardella's church in Alessandria.

The survey phase was carried out on 02/23/2025 by the team. The instruments utilized include the GNSS RTK GeoMax Zenith 35 Pro, Leica Viva TS16 Total Station, the Navic 3M Drone, and for LiDAR, the scanner FARO focus x330 has been used. GNSS was used to define a topographic network, subsequently the Total station was used to obtain the coordinates of the GCPs on the terrain, inside and outside the building, the LiDAR system was employed to get different scans of the outside but principally was used for the inside, while the drone was used for surveying just the exterior in a closed and long-range - meaning not only the church was surveyed, but also its immediate context – through a photogrammetry study.

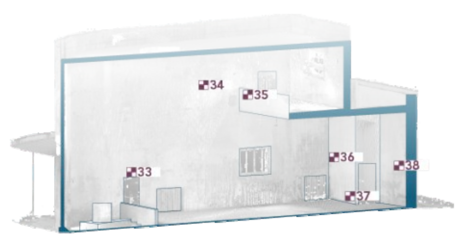
After the survey, a second step was carried out, involving the processing of the acquired data. The information obtained from the FARO scanner was processed by the DIRECT team, giving a point cloud as a result. Meanwhile, the data acquired through the UAV photogrammetry survey was processed by the authors.

Control network & detailed survey

Vertices A, B, and C were registered to define the control network, which serves as a structured framework. This network establishes the initial coordinates that provide a basis for subsequent measurements, enabling the Total Station to orient itself to a reference point. From this point, all angular measurements are linked to a specific coordinate system.

The GCPs were positioned in three different areas: around the building, on the building's façade, and inside of the central nave (the inside of the other two blocks of the building were not surveyed due to restricted access). During the detailed survey, the Total station provided a coordinate list for each marker as it outputs. The ground markers were labeled 100-111, the external façade markers were labeled from P01 to P22, and the interior markers were labeled from 30 to 47. Each GCP has its own coordinates and can be identified in the different eidotypes about the building to localize all the marks efficiently.

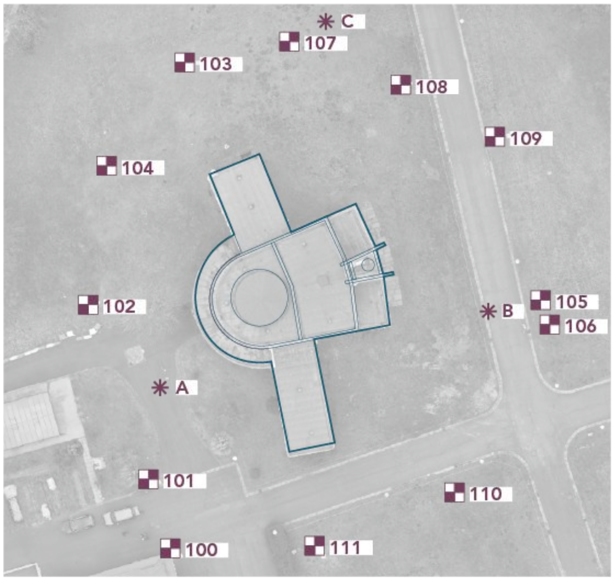
Inside view 1



Inside view 2

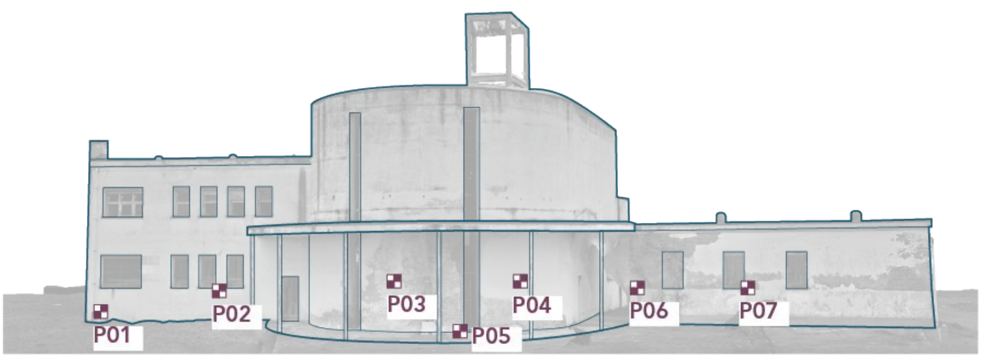
Fig. 24. Interior Ediotypes with GCP Co-ordinates

Marker	Longitude	Latitude	Height
30	469726.335	4976286.902	93.838
31	469724.58	4976290.989	93.898
32	469726.035	4976294.725	93.684
33	469728.931	4976296.508	93.809
34	469734.900	4976299.089	98.728
35	469735.49	4976298.495	97.846
36	469740.612	4976300.934	93.688
37	469741.158	4976299.655	92.124
38	469743.516	4976297.972	93.754
39	469733.579	4976292.044	93.756
40	469745.185	4976292.391	93.703
41	469744.062	4976290.238	91.99
42	469744.373	4976288.342	93.772
43	469734.321	4976286.026	93.727
44	469738.187	4976291.079	97.769
45	469738.649	4976288.324	97.531
46	469738.695	4976286.778	98.866
47	469738.897	4976286.821	92.513



Top view

Fig. 25. Exterior Ediotypes with GCP Coordinates (Top View & South Façade).

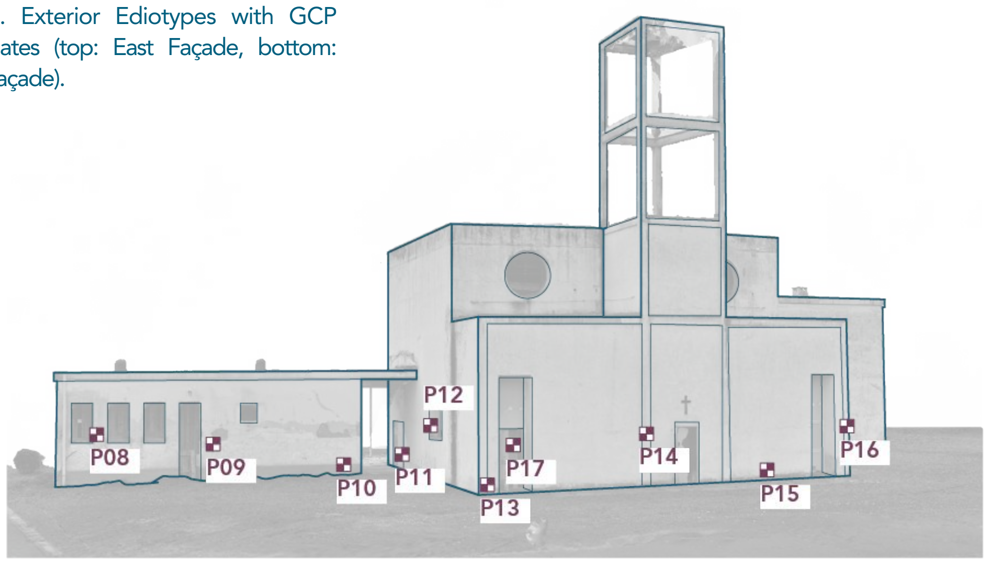


View from vertex A

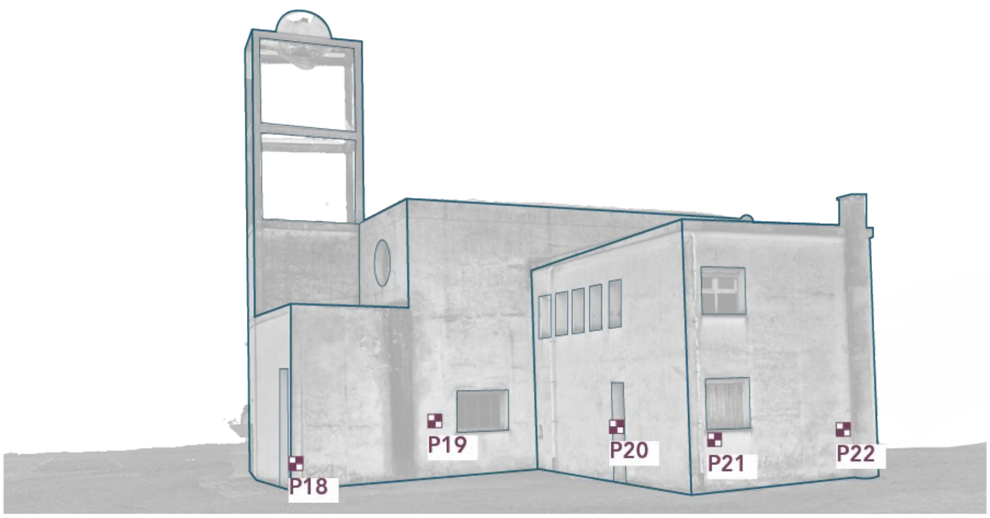
Marker	Longitude	Latitude	Height
100	469719.692	4976257.951	91.286
101	469716.914	4976267.433	91.197
102	469709.057	4976290.505	91.458
103	469721.938	4976321.285	91.241
104	469711.253	4976308.078	91.571
105	469769.359	4976288.138	90.987
106	469769.344	4976288.131	90.981
107	469734.672	4976324.045	91.370
108	469749.119	4976318.604	91.219
109	469761.712	4976311.895	90.934
110	469755.615	4976266.155	91.203
111	469738.028	4976257.908	91.248

Marker	Longitude	Latitude	Height
P01	469723.532	4976306.215	92.092
P02	469725.851	4976300.88	93.069
P03	469724.095	4976289.801	93.705
P04	469727.067	4976285.619	93.741
P05	469725.106	4976287.388	91.813
P06	469731.597	4976282.404	93.064
P07	469732.413	4976277.744	93.076

Fig. 26. Exterior Ediotypes with GCP Coordinates (top: East Façade, bottom: North Façade).



View from vertex B



View from vertex C

Marker	Longitude	Latitude	Height
P08	469739.023	4976273.266	93.468
P09	469738.259	4976277.612	93.092
P10	469737.307	4976283.2	92.028
P11	469731.779	4976285.056	91.957
P12	469738.975	4976286.334	93.696
P13	469746.616	4976287.662	91.856
P14	469745.587	4976293.805	93.621
P15	469743.78	4976298.774	91.965
P16	469742.112	4976302.727	93.647
P17	469744.415	4976288.955	93.071

Marker	Longitude	Latitude	Height
P18	469741.899	4976302.808	92.515
P19	469737.696	4976300.935	93.526
P20	469731.444	4976304.908	93.498
P21	469728.986	4976309.155	93.132
P22	469724.579	4976307.266	93.137

LiDAR Survey

The LiDAR survey was carried out by the DIRECT Team using the FARO Focus x330, a terrestrial laser scanner that employs time-of-flight technology to generate a highly detailed 3D model of the church. This scanner was used for the interior and exterior of the building to ensure a comprehensive representation of its geometry. With a maximum acquisition range of 330 meters, the FARO focus x 330 can measure any point within that distance from its position, however, due to the complexity of the building's geometry 25 scans were performed from different positions. These individual scans were later merged into a unified point cloud.

The scanner was configured to operate at a quality level of 4x, meaning that each measured "point" is recorded four times. Here, it is important to note that the term "point" does not refer to a single isolated location, but rather to all the million points recorded during the scanning process. Each of these points represents a small section of a surface, and measuring each of them multiple times ensures greater precision by reducing noise and averaging out errors caused by environmental factors or equipment limitations.

Additionally, a resolution of 1/5 was selected, which determines the density of points in the resulting point cloud. Specifically, at 10 meters, points are separated by approximately 7.7 mm on the measured surface. This value does not come from directly diving 10 by 5; rather, it is based on the scanner's angular resolution, as the laser beams are projected at small angular intervals. As the distance from the scanner increases, the separation between points also grows. The resolution of 1/5 provides a high level of detail, capturing intricate architectural features such as textures.

Each scan took approximately 8 minutes to complete, primarily due to the selected high-quality settings (x4) and fine resolution (1/5), which require the scanner to record a large number of points. During each scan, the device captured the data in two simultaneous directions: a vertical acquisition range of 90° to -60°, covering areas from the ceiling to the floor (except the section obstructed by the tripod), and a horizontal acquisition range of 0° to 360°, encompassing the full horizontal plane around the scanner. This simultaneous acquisition is made possible by the scanner's internal rotating mirror system, which allows for both vertical and horizontal measurements during the scanning process.

UAV – Photogrammetry.

The photogrammetric survey carried out by the DIRECT team was conducted using the Mavic 3M drone, integrated with an M3M camera model, which was pre-calibrated while doing the survey, and it has a focal length of 129.29 mm. This setup allows the capture of images in .JPG format with a maximum resolution of 5280 x 3956 pixels.

Two flight plans were executed the same during the same day, 02/23/2025 in the same gap of time between 11:30 am and 13:00 to ensure consistent lighting and environmental conditions. The first was characterized as an inclined flight, consistently tilting toward the target (Gardella´s church), with a flight altitude of 6.98 meters. This flight was named aerial close-range, as it allowed the capture of detailed features of the façade, including its state of degradation, through the acquisition of 709 images with a pixel size of 3.36 x 3.36 μm.

The second flight was conducted from a greater distance, where the church was not always visible in the captured images. The purpose of this flight was to understand the church´s surroundings and to facilitate a more comprehensive analysis of its roof. This flight was called aerial range, where 322 images were captured with an altitude of 59.8m and a pixel size of 3.36 x 3.36 μm.

Based on these parameters, it is possible to calculate the initial Ground Sampling Distance of these images per flight. It is worth remembering that the GSD is an indicator describing the level of detail an image can capture, representing the actual ground size covered by each pixel.

For each flight, the calculation is as follows:

$$GSD = (D * X)/P$$

Where:

G: Shooting Distance
X: Size of the pixel
P: Focal distance (Lense's property)

Aerial Close range
GSD = 6.98 m * 3.36 * 10-6 m / 0.01229 m
GSD = 1.91 mm. This means that every pixel in the image represents 1.91mm of terrain.

Aerial Range
GSD = 59.8 m * 3.36 * 10-6 m / 0.01229 m
GSD = 16.35 mm pixel. This means that every pixel in the image represents 16.35 mm of terrain.

It should be clarified that GSD will be later influenced by the process applied during data processing in Metashape software. At this stage, several parameters related to the position orientation, and distortion of the camera used in the model will be adjusted.

3.2 Processing the data

The following section explains how the images captured by the UAV and the coordinates of the GCPs contribute to the creation of a textured 3D model in Metashape software.

After the model is created, it will be merged with the cloud obtained from LiDAR in cloud compare.

The process goes as follows:

3.2.1 STEP 1 – Loading source data.

- **Images:**

As previously discussed, the study on Gardella's church was conducted using two flight plans: aerial close range and aerial range; because they were conducted at different distances, hence the image processing will be carried out using two chunks. This methodology is recommended as the sets of photographs from each flight path exhibit variations in terms of scale and perspective due to the differing distances at which the drone captured the images.

By handling these photographs in two separates chunks, each set can be individually aligned and processed. A chunk is a segment of a photogrammetry project that includes a set of images and their related data. The chunks facilitate the division of a large project with a huge amount of data into smaller and manageable sections, permitting each bank of images to be processed in an independent way.

To load a set of images they need to have a format accepted by Metashape. For **aerial close range a total of 709 images** were uploaded, while for the **aerial range a total of 322 images** were uploaded. Before uploading the photos, they were not rotated, resized or geometrically transformed, by doing any kind of these actions, it will lead to an error in the alignment of photos.

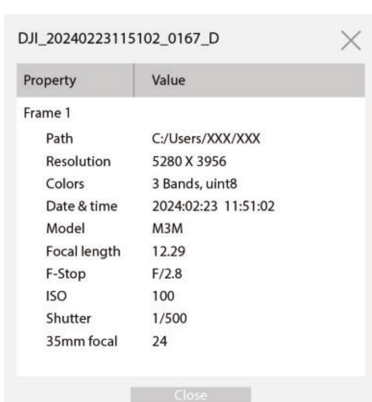


Fig. 27. EXIF Metadata per image.

When importing the photos, each chunk will have its corresponding folder. These pictures will contain: EXIF Metadata, such as light, color data, the dimension of the photo, as well as the date and time it was taken (figure 27). Additional information provided by the images the coordinates as seen in figure 28. This information assists Metashape to have a better understanding about the conditions under which the photos were taken, allowing necessary correction and preparing images for the alignment process.

Cameras	Longitude	Latitude	Altitude (m)	Accuracy (m)	Error (m)	Yaw (°)	Pitch (°)	Roll (°)	Accuracy (°)
DJI...	8.616606	44.939324	137.862000	10.000000		289.700	84.300	0.000	10.000
DJI...	8.616609	44.939330	137.857000	10.000000		299.700	84.300	0.000	10.000
DJI...	8.616625	44.939324	137.892000	10.000000		300.100	84.300	0.000	10.000
DJI...	8.616656	44.939313	137.826000	10.000000		300.100	84.300	0.000	10.000
DJI...	8.616655	44.939313	137.332000	10.000000		300.100	84.300	0.000	10.000
DJI...	8.616657	44.939313	137.527000	10.000000		300.100	84.300	0.000	10.000
DJI...	8.616657	44.939312	137.727000	10.000000		300.100	84.300	0.000	10.000
DJI...	8.616658	44.939313	137.611000	10.000000		300.100	84.300	0.000	10.000
DJI...	8.616690	44.939356	137.604000	10.000000		296.200	84.300	0.000	10.000

Fig. 28. Uploaded Images with coordinates data.

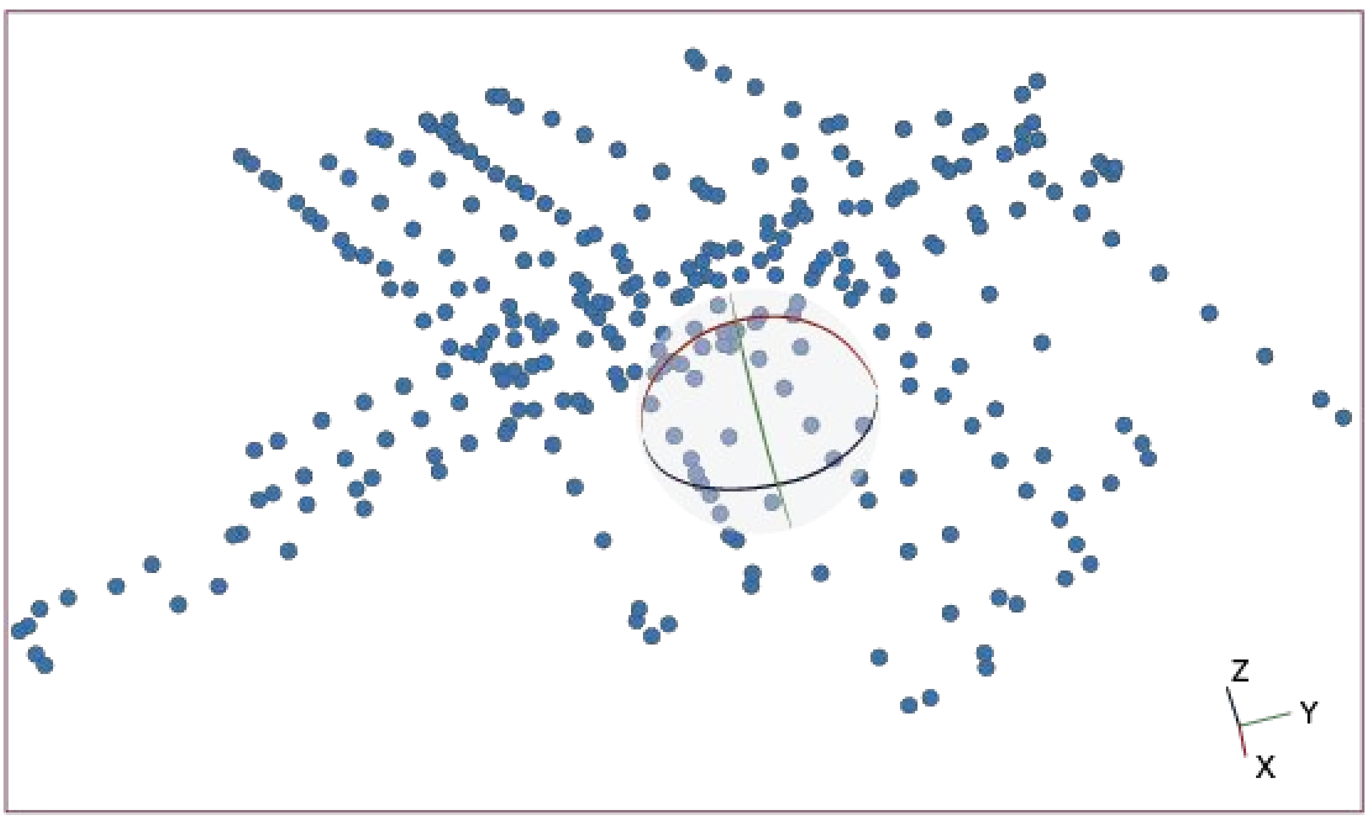


Fig. 29. Imported images without alignment in aerial range chunk / 0 Points.

3.2.2 STEP 2 – Alignment of photos

The initial phase of image processing involves their alignment; importing the photos even though they have information on it, it is insufficient to construct an internal reference system or identify common points between images, in other words, there is a lack of information necessary to create an accurate and georeferenced 3d model. In metaphase, the alignment parameters are first calculated in a local spherical coordinate system. Subsequently, when a specific coordinate system is defined, the software converts these parameters into a geographic coordinate system

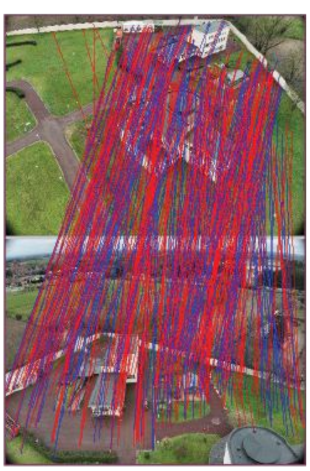
The way the software processes the alignment is by searching "notable feature points "(i.e. geometrical similarities such as object edges or other specific details) using an approach similar to the SIFT algorithm (a modification of the Lowe algorithm, since SIFT is protected by the copyright) and, subsequently, it monitors the movement of those points throughout the sequence of multiple images. Each point has its own local descriptor, based on its local neighbor-hood, which is subsequently used to detect point correspondences across the complete image set[42].

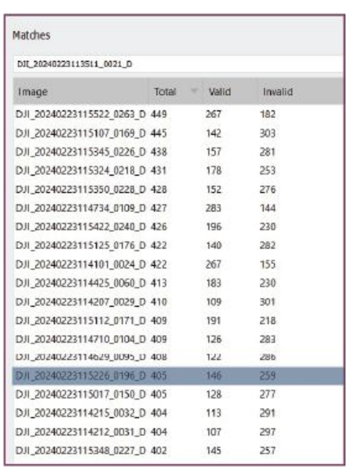
In simple terms, these unique features are referred to as "key points". Each image contains diverse key points, and the software is responsible for matching them across all other pictures. The program attempts to combine the key points and then project them onto a 3D plane. By identifying coincidences and matching them with their counterparts, these key points become 'tie points" as seen in Figure 30, these points are identified by color, gray and blue respectively.

Metashape analyzed these tie points, where some can be deemed valid (blue color) and others invalid (red color). The valid points refer to those with low reprojection error and contribute effectively to the geometric accuracy of the model, demonstrating how the images are aligned with each other. For example, in Figure 31, a comparison between two photos in the aerial range chunk shows a match of 146 valid points and 259 invalid points.

42) Verhoeven, G., Taelman, D., Vermeulen, F., 2012. Computer vision based orthophoto mapping of complex archaeological sites: the ancient quarry of Pitaranha (Portugal-Spain), Archaeometry. 54.6, pp. 1114-1129.

Fig. 30. Key points and tie points.
Fig. 31. Valid and invalid tie points.

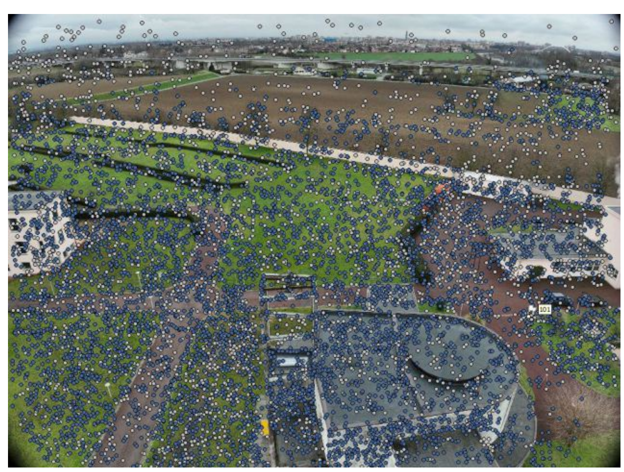




Matches

DJI_20240223113511_0021_D

Image	Total	Valid	Invalid
DJI_20240223115522_0263_D	449	267	182
DJI_20240223115107_0169_D	445	142	303
DJI_20240223115345_0226_D	438	157	281
DJI_20240223115324_0218_D	431	178	253
DJI_20240223115350_0228_D	428	152	276
DJI_20240223114734_0109_D	427	283	144
DJI_20240223115422_0240_D	426	196	230
DJI_20240223115125_0176_D	422	140	282
DJI_20240223114101_0024_D	422	267	155
DJI_20240223114425_0060_D	413	183	230
DJI_20240223114207_0029_D	410	109	301
DJI_20240223115112_0171_D	409	191	218
DJI_20240223114710_0104_D	409	126	283
DJI_20240223114629_0095_D	408	122	286
DJI_20240223115226_0196_D	405	146	259
DJI_20240223115017_0150_D	405	128	277
DJI_20240223114215_0032_D	404	113	291
DJI_20240223114212_0031_D	404	107	297
DJI_20240223115348_0227_D	402	145	257



Additionally, this step produced a sparse point cloud also known as tie point, upon which the depth maps will subsequently be built. The primary objective of the sparse point cloud is to establish the basic structure and orientation of the photographed scene, and it has fewer points than a dense point cloud. As seen in Figure 32 the basic structure of the church is identified by a limited number of points after the alignment process was made.

The alignment of photos in both chunks was made through high accuracy, making the software work with the images at their original size, and with the generic preselection selected.

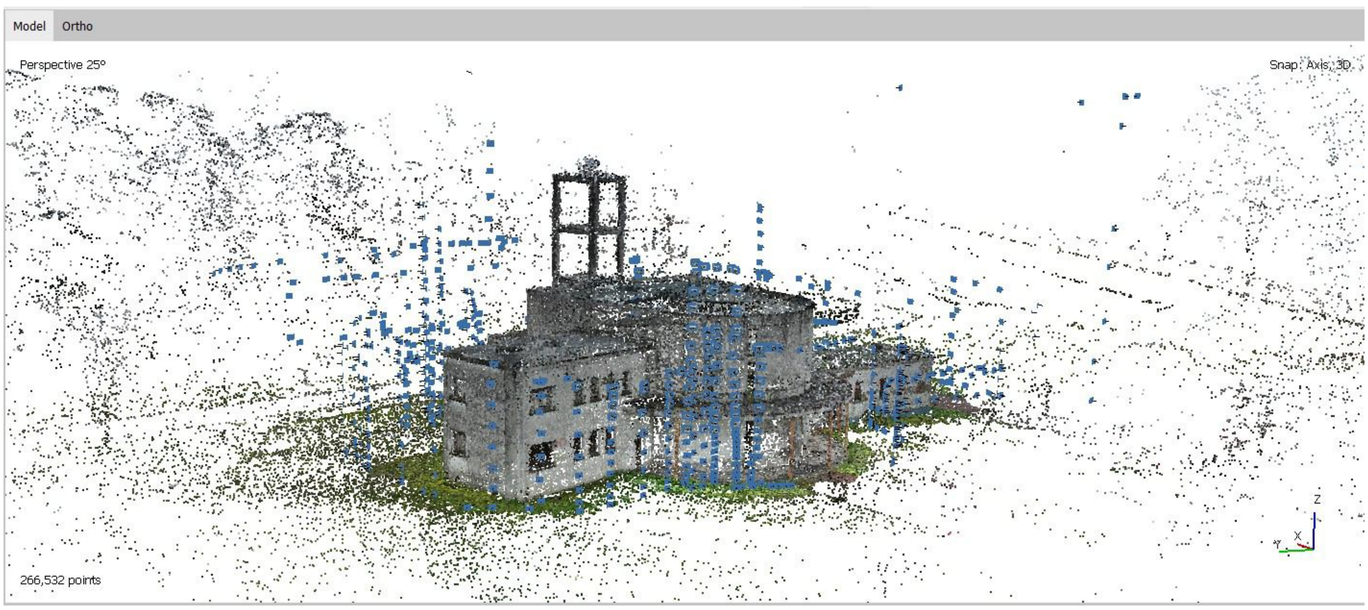


Fig. 32A. Sparse point cloud Aerial Close Range / 266,532 points.

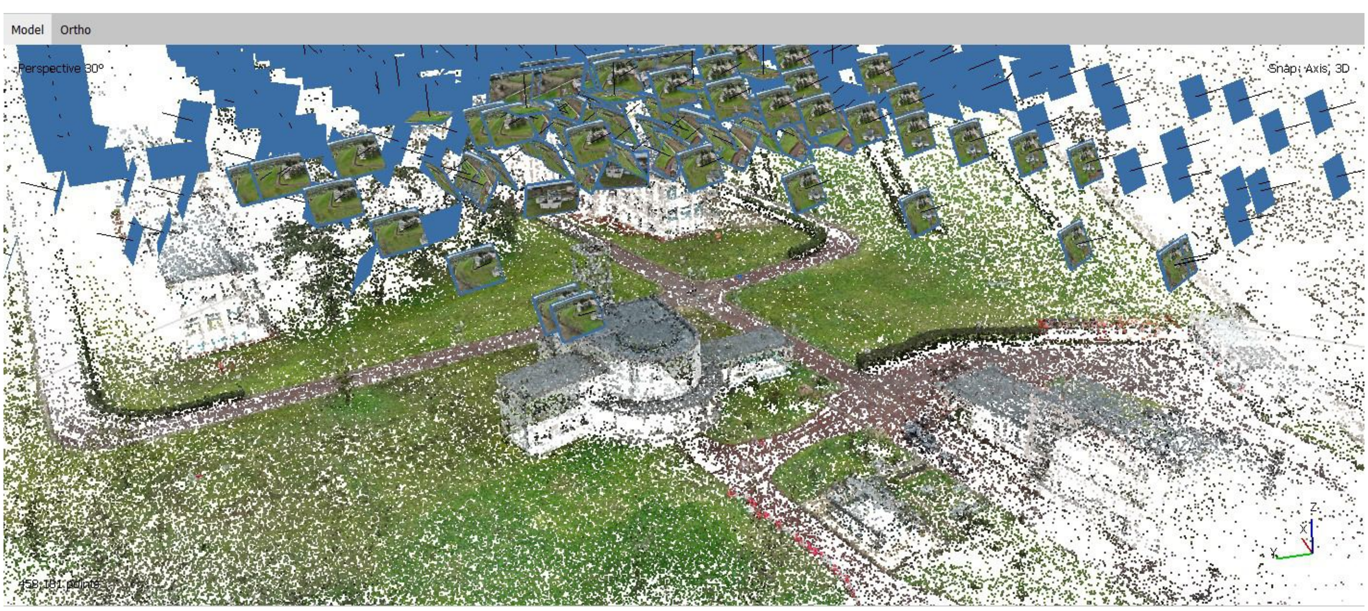


Fig. 32B. Sparse point cloud Aerial Range / 458,181 points.

-Generic Preselection: This option was checked to speed up the process. Identifying similar points between images is a time-intensive task, particularly when dealing with high-quality images in large sets. This process is streamlined by using this command, which assists the program in comparing these images by initially overlapping and matching them using a lower accuracy setting to speed up the process.

The information provided by the report showed the surveyed data seen in table 1 and table 2:

Number of Images	709
Flying altitude	6.98 m
Ground Resolution	2.63 mm/pix
Coverage Area	8.29e + 03m2
Camera stations	709
Tie points	266,532
Projections	2,068,254
Reprojection error	0.978 pix

Aerial Close Range

Tab. 1. Aerial Closed Range Surveyed Data.

Number of Images	322
Flying altitude	59.8 m
Ground Resolution	1.99 cm/pix
Coverage Area	0.113 km2
Camera stations	322
Tie points	458,181
Projections	2,151,474
Reprojection error	0.757 pix

Aerial Range

Tab. 2. Aerial Range Surveyed Data.

Ground control points are marks in the terrain with known coordinates "X, Y, Z" and precise measurements. To obtain the coordinates of these markers, the data must be imported into the software. This will be done by using a TEXT file, which contains the data obtained through the Total station (Leica Viva TS16). The reason for importing this information is to improve the quality of the sparse cloud after the alignment process. After importing the GCP into a local coordinate system, the information provided per mark is the coordinates X, Y, and Z (Figure 33).

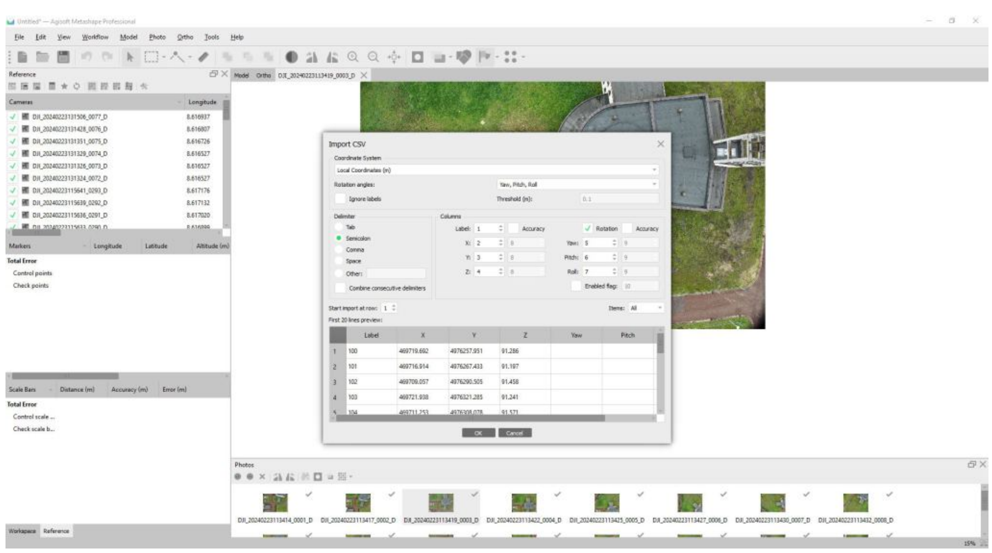


Fig. 33. GCP DATA parameters.

Metashape will try to match each row of the external marks file with an existing marker in the chunk. However, the chunks don't have any marks yet since they are being created in this step. Taking this into account, after importing the information, a pop-up window will appear on screen saying: "Can't find a match for ### entry. Create a new marker?" For this dialog tab, click "yes to all" and continue.

For obtaining results of the highest quality, in terms of geometrical precision and georeferencing accuracy, in aerial photography, it is essential to use evenly spread a set of at least 10 GCPs across the area[43].

In Gardella's church survey, a total of 11 markers were placed to be identified during the aerial range flight (Section 3.1). However, upon analyzing the data, it was evident that marks 105 and 106 shared almost identical coordinates, indicating that the same mark had been surveyed twice. Consequently, mark 105 was removed as a reference point. Ultimately, the aerial range chunk includes 10 GCPs positioned above the terrain.

On the other hand, the aerial close-range survey focused primarily on the building's geometry rather than the surrounding landscape. This approach required the implementation of additional markers to produce a more detailed 3D model of Gardella's church.

After importing the GCP coordinates, they will appear in the markers tab inside the reference menu as seen in Figure 34. In this section, seven columns are displayed:

Fig. 34. Markers' information after importing GCP in the Aerial Range chunk.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
100	469719.692	4976257.951	91.286	0.005000	0	0.000	
101	469716.914	4976267.433	91.197	0.005000	0	0.000	
102	469709.057	4976290.505	91.458	0.005000	0	0.000	
103	469721.938	4976321.285	91.241	0.005000	0	0.000	
104	469711.253	4976308.078	91.571	0.005000	0	0.000	
105	469769.359	4976288.138	90.987	0.005000	0	0.000	
106	469769.344	4976288.131	90.981	0.005000	0	0.000	
107	469734.672	4976324.045	91.370	0.005000	0	0.000	
108	469749.119	4976318.604	91.219	0.005000	0	0.000	
109	469761.712	4976311.895	90.934	0.005000	0	0.000	
110	469755.615	4976266.155	91.203	0.005000	0	0.000	
111	469738.028	4976257.908	91.248	0.005000	0	0.000	

Total Error

Control Points
Check Points

43) Agisoft. 2024. *Agisoft Metashape User Manual: Professional Edition, Version 2.1.* https://www.agisoft.com/pdf/metashape-pro_2_1_en.pdf.
44) *Ibidem*, p. 100.
45) *Ivi*.

- Label: Identification name of the markers taken on-site. Since the locations and the model are referenced in the same coordinate system, the markers will be tagged with a blue flag.
- Coordinates: One column per coordinate in X, Y, and Z axis in meters.
- Accuracy (m): Indicates how accurate the position of the marker is in relation to the real-world location.
- Projections: This column shows the number of images in which the marker has been detected or manually placed.
- Error (pix): mean square root for the reprojection error for the marker, calculated over all images where the marker has been placed. Works as an indicator of the discrepancy a marker can have.

This photogrammetry survey aims to achieve a total error (pix) of less than 1 cm. The lower the error the better, it indicates that the marker projections are well-aligned in all the images. Reducing the error pix is vital to obtain an accurate 3D model.

3.2.4 STEP 4 – Georeferencing - placing markers

Placing diverse markers on the images is essential to enhance the accuracy and reliability of the 3D model. These markers play a crucial role in the alignment process by helping to detect errors related to alignment quality and model precision, such as discrepancies between the projected position of a marker in the images and its actual position in the model. "The position of the markers is determined by their coordinates in the images. To determine the special coordinates of the markers, it is necessary to measure the planar coordinates of the markers on at least 2 images"[44].

Fig. 35. Automatically placed markers as gray & manually placed markers as green flags.

Metashape software can support two ways of placing markers, in this work both approaches were done in the following order:

1. **Guided approach**: The software automatically projects the corresponding ray onto the model's surface and determines the markers' projections in all the other photos where they are visible. This helps to save time in the workflow process by displaying all marks on each image, indicated by a gray flag icon.
   The gray flag indicates that these markers were automatically placed but required verification or manual adjustment by the user. Until confirmed, they are not used in any calculation, they merely represent an estimate coordinate.
2. **Manual approach**: The markers' projections must be indicated manually on each image where the marker is visible. For doing it, "Place a marker" must be used, since "add a marker" is for creating a new marker that doesn't exist in the project. After the place of it, the marker will be highlighted with a green flag icon (Figure 35).

The same strategy was used for positioning markers in both chunks (Aerial Close Range and Aerial Range Chunk). The approach involved a gradual method; this means that not all markers were placed at once. Instead, a limited number of markers were initially placed in a small number of images, and subsequently, the number of projected markers increased.

The reason behind this gradual approach is to provide the program with a precise base for alignment. Reducing the workload minimizes the

Fig. 36. Placing three markers in three different images in the Aerial close range chunk.

margin of error (as the placement of these maskers is done manually) and saves time, allowing corrections on early alignment errors if they exist. The program uses these initial markers as a base to automatically project the position of the remaining markers.

The gradual process of placing the markers in the images was the same for both chunks as follows:

1. Per chunk, three markers were selected. Since the selected markers need to have at least two projections placed on the aligned images[45] each marker was projected three times (Figure 36).
2. After placing the markers on the images, the coordinate system will not be updated automatically. To recalculate the coordinates, it must be used the Update transform tool. Once this action is performed, the new data in the markers panel is displayed as illustrated in Figure 37.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
P01	...	...	...	0.005000		0	0.000
P02	...	...	...	0.005000		0	0.000
P03	...	...	...	0.005000	0.000610	3	0.253
P04	...	...	...	0.005000		0	0.000
P05	...	...	...	0.005000		0	0.000
P06	...	...	...	0.005000		0	0.000
P07	...	...	...	0.005000		0	0.000
P08	...	...	...	0.005000	0.000619	3	0.411
P09	...	...	...	0.005000		0	0.000
P10	...	...	...	0.005000		0	0.000
P11	...	...	...	0.005000		0	0.000
P12	...	...	...	0.005000		0	0.000
P13	...	...	...	0.005000		0	0.000
P14	...	...	...	0.005000	0.000631	3	0.263
P15	...	...	...	0.005000		0	0.000
P16	...	...	...	0.005000		0	0.000
P17	...	...	...	0.005000		0	0.000
P18	...	...	...	0.005000		0	0.000
P19	...	...	...	0.005000		0	0.000
P20	...	...	...	0.005000		0	0.000
P21	...	...	...	0.005000		0	0.000
P22	...	...	...	0.005000		0	0.000
Total Error							
Control Points					0.000620		0.317
Check Points							

Fig. 37A. Total error after placing three markers in three different images in the Aerial close-range chunk.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
100	...	...	...	0.005000	0.001933	3	0.654
101	...	...	...	0.005000		0	0.000
102	...	...	...	0.005000		0	0.00
103	...	...	...	0.005000	0.001942	3	0.646
104	...	...	...	0.005000		0	0.000
105	...	...	...	0.005000		0	0.000
106	...	...	...	0.005000	0.002118	3	0.793
107	...	...	...	0.005000		0	0.000
108	...	...	...	0.005000		0	0.000
109	...	...	...	0.005000		0	0.000
110	...	...	...	0.005000		0	0.000
111	...	...	...	0.005000		0	0.000
Total Error							
Control Points					0.001999		0.701
Check Points							

Fig. 37B. Total error after placing three markers in three different images in the Aerial range chunk.

As is shown in Figure 37, after positioning the markers, the marker's tab includes a section for Total error, where the control and checkpoints are located. They indicate:

Control points: Points that are used to reference the model

Checkpoint: Unselected control points. They are not used to optimize camera alignment but can be used to check the optimization results.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
P01	...	...	...	0.005000	0.004613	5	0.670
P02	...	...	...	0.005000	0.007414	5	0.684
P03	...	...	...	0.005000	0.009255	5	1.524
P04	...	...	...	0.005000	0.007411	5	0.546
P05	...	...	...	0.005000	0.007304	5	0.475
P06	...	...	...	0.005000	0.010496	5	0.592
P07	...	...	...	0.005000	0.010150	5	0.731
P08	...	...	...	0.005000	0.019292	5	0.546
P09	...	...	...	0.005000	0.013527	5	0.468
P10	...	...	...	0.005000	0.008285	5	0.411
P11	...	...	...	0.005000	0.013128	5	0.658
P12	...	...	...	0.005000	0.006851	5	0.271
P13	...	...	...	0.005000	0.011368	5	0.469
P14	...	...	...	0.005000	0.008326	5	0.351
P15	...	...	...	0.005000	0.006125	5	0.618
P16	...	...	...	0.005000	0.007698	5	0.475
P17	...	...	...	0.005000	0.002028	2	0.165
P18	...	...	...	0.005000	0.007041	5	1.031
P19	...	...	...	0.005000	0.006034	5	0.499
P20	...	...	...	0.005000	0.009843	5	0.622
P21	...	...	...	0.005000	0.009687	5	0.409
P22	...	...	...	0.005000	0.012505	5	0.380
Total Error							
Control Points					0.009674		0.637
Check Points							

Fig. 38A. Total error after placing 5 projections of each marker in the Aerial Close Range chunk.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
100	...	...	...	0.005000	0.017149	5	0.704
101	...	...	...	0.005000	0.008605	5	0.635
102	...	...	...	0.005000	0.007726	5	0.401
103	...	...	...	0.005000	0.015505	5	0.727
104	...	...	...	0.005000	0.006294	5	0.486
106	...	...	...	0.005000	0.013646	5	0.980
107	...	...	...	0.005000	0.010781	5	0.782
108	...	...	...	0.005000	0.008839	5	0.831
109	...	...	...	0.005000	0.008852	5	0.592
110	...	...	...	0.005000	0.007963	5	0.574
111	...	...	...	0.005000	0.005883	5	0.582
Total Error							
Control Points					0.010723		0.681
Check Points							

Fig. 38B. Total error after placing 5 projections of each marker in the Aerial Range chunk.

3. Since the error is below 1 cm (Figure 37), this serves as an early indication that the markers and the model are well aligned. Consequently, more markers will be projected as seen in Figure 38.

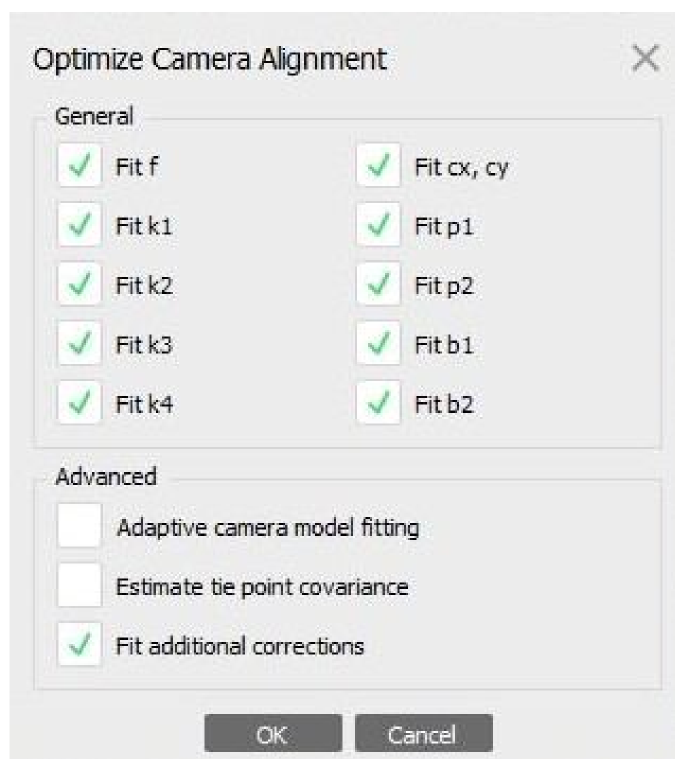
46) *Ibidem*, p. 106.

Per chunk each marker was projected 5 times after it, the Update transform tool was used again so the model alignment reflects these changes. In the Aerial Close range, the marker P17 was projected twice. When placing a marker, the visibility of it cannot be blurry or obscured by an object; in the case of P17, its position and the angle at which the photographs were taken resulted in shots where it was either not captured or appeared blurred, in those cases it is better not to place the marker.

The placement of the markers is conducted to align the images and ensure they fit correctly in the 3D model. The model can be georeferenced because the survey was conducted with known coordinates. Additionally, the markers help to correct image distortion caused by the camera lens. This is why this third step of increasing projections was taken.

4. To improve the error for each chunk, and by "improve" it is meant to reduce it, the Optimize Camera Alignment tool located in the reference toolbar should be used as seen in Figure 39. All the camera parameters located in the general section must be optimize, plus the "additional correction" command will be used, as it addresses certain distortions or deviations not covered by the basic camera parameters, thereby improving the accuracy of the model.

Fig. 39. Optimize Camera Alignment chosen parameters



"This command performs a full bundle adjustment procedure on the aligned photogrammetric block, simultaneously refining exterior and interior camera orientation parameters and triangulated tie point coordinates. The adjustment is performed based on all available measurements and corresponding accuracies, i.e. coordinates of projections of tie points and markers on images in the image coordinate system; GPS coordinates of camera positions; GCP coordinates; scale bar distances"[46], in brief, using this tool allows the software to adjust the camera based on this additional data (The projections of GCPs), enhancing the georeferencing.

After optimizing the camera alignment, as is seen in Figure 40, the error has decreased.

Fig. 40A. Total error after placing 5 projections of each marker and using the Optimize camera alignment tool in the Aerial Close Range chunk.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
P01	...	...	...	0.005000	0.007130	5	0.362
P02	...	...	...	0.005000	0.009383	5	0.371
P03	...	...	...	0.005000	0.006792	5	0.398
P04	...	...	...	0.005000	0.004133	5	0.756
P05	...	...	...	0.005000	0.002732	5	0.355
P06	...	...	...	0.005000	0.008382	5	0.241
P07	...	...	...	0.005000	0.010262	5	0.546
P08	...	...	...	0.005000	0.011952	5	0.360
P09	...	...	...	0.005000	0.011349	5	0.348
P10	...	...	...	0.005000	0.007777	5	0.276
P11	...	...	...	0.005000	0.009592	5	0.512
P12	...	...	...	0.005000	0.007444	5	0.422
P13	...	...	...	0.005000	0.010855	5	0.331
P14	...	...	...	0.005000	0.008627	5	0.317
P15	...	...	...	0.005000	0.006425	5	0.193
P16	...	...	...	0.005000	0.006032	5	0.375
P17	...	...	...	0.005000	0.001717	2	0.131
P18	...	...	...	0.005000	0.005390	5	0.340
P19	...	...	...	0.005000	0.005576	5	0.318
P20	...	...	...	0.005000	0.009245	5	0.658
P21	...	...	...	0.005000	0.008560	5	0.336
P22	...	...	...	0.005000	0.010741	5	0.471
Total Error							
Control Points					0.008179		0.412
Check Points							

Fig. 40B. Total error after placing 5 projections of each marker and using Optimize camera alignment tool in the Aerial Range chunk.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
100	...	...	...	0.005000	0.017358	5	0.611
101	...	...	...	0.005000	0.010937	5	0.580
102	...	...	...	0.005000	0.005874	5	0.240
103	...	...	...	0.005000	0.013363	5	0.399
104	...	...	...	0.005000	0.008324	5	0.357
106	...	...	...	0.005000	0.010900	5	0.729
107	...	...	...	0.005000	0.008636	5	0.480
108	...	...	...	0.005000	0.005967	5	0.435
109	...	...	...	0.005000	0.010299	5	0.462
110	...	...	...	0.005000	0.008816	5	0.487
111	...	...	...	0.005000	0.006766	5	0.391
Total Error							
Control Points					0.010277		0.487
Check Points							

5. As mentioned earlier, the model must include control points and checkpoints (Figure 41). Control points are essential for anchoring the model to a real coordinate system as they are incorporated not the calculations to correct positional and orientation errors. Checkpoints, on the other hand, are used to verify the model's accuracy without influencing the calculations.

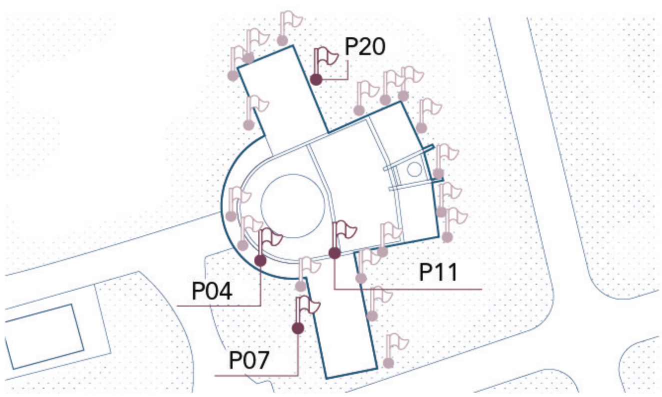


Fig. 41A. Choosing Check Points in Aerial Close Range Chunk.

Fig. 41B. Choosing Check Points in Aerial Range Chunk.

The checkpoints were selected in a manner that ensured their distribution across the project area. Additionally, points with minimal error were avoided as checkpoints, as these play a crucial role in the model's creation. The reduction in error was as follows:

Fig. 42A. Total error after choosing check marks and adding more projections in Aerial Close Range Chunk.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
☑ P01	...	...	...	0.005000	0.006509	5	0.363
☑ P02	...	...	...	0.005000	0.008977	5	0.346
☑ P03	...	...	...	0.005000	0.008200	5	0.436
☐ P04	...	...	...	0.005000	0.006570	5	0.809
☑ P05	...	...	...	0.005000	0.005038	5	0.284
☑ P06	...	...	...	0.005000	0.009791	5	0.265
☐ P07	...	...	...	0.005000	0.011226	14	0.518
☑ P08	...	...	...	0.005000	0.014334	5	0.385
☑ P09	...	...	...	0.005000	0.011390	7	0.486
☑ P10	...	...	...	0.005000	0.008832	5	0.310
☐ P11	...	...	...	0.005000	0.090878	5	0.296
☑ P12	...	...	...	0.005000	0.007127	5	0.439
☑ P13	...	...	...	0.005000	0.012948	7	0.246
☑ P14	...	...	...	0.005000	0.009469	5	0.337
☑ P15	...	...	...	0.005000	0.006661	5	0.204
☑ P16	...	...	...	0.005000	0.006358	5	0.407
☑ P17	...	...	...	0.005000	0.001225	2	0.180
☑ P18	...	...	...	0.005000	0.003912	5	0.343
☑ P19	...	...	...	0.005000	0.004808	5	0.317
☐ P20	...	...	...	0.005000	0.011452	5	0.706
☑ P21	...	...	...	0.005000	0.010834	5	0.377
☑ P22	...	...	...	0.005000	0.016948	5	0.262
Total Error							
Control Points					0.009316		0.348
Check Points					0.046258		0.586

Fig. 42B. Total error after choosing check marks and adding more projections in Aerial Range Chunk.

Marker	X(m)	Y(m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
☑ 100	...	...	...	0.005000	0.019058	5	0.597
☐ 101	...	...	...	0.005000	0.026860	5	0.387
☑ 102	...	...	...	0.005000	0.003528	5	0.206
☑ 103	...	...	...	0.005000	0.012161	6	0.323
☑ 104	...	...	...	0.005000	0.005754	5	0.307
☐ 106	...	...	...	0.005000	0.041847	5	0.428
☐ 107	...	...	...	0.005000	0.014341	5	0.394
☑ 108	...	...	...	0.005000	0.004503	5	0.399
☑ 109	...	...	...	0.005000	0.010133	10	0.367
☑ 110	...	...	...	0.005000	0.007031	5	0.424
☑ 111	...	...	...	0.005000	0.008250	5	0.498
Total Error							
Control Points					0.009982		0.400
Check Points					0.029879		0.403

The following tables provide evidence of how in "Step 4: Georeferencing and placing marker" the process made, permitted to achieve an error lower than 1 cm.

1. Place three markers in three different images
2. Update transform tool
3. Project all markers in more than 2 images. In this survey, 5 projections were the aim.
4. Optimize camera tool
5. Convert some control points as checkpoints and increase some projections.

2	Control Point (11)	Check Points (0)
Error (m)	0.000620	--
Error (pix)	0.317	--

3	Control Point (11)	Check Points (0)
Error (m)	0.009674	--
Error (pix)	0.637	--

4	Control Point (11)	Check Points (0)
Error (m)	0.008179	--
Error (pix)	0.412	--

5	Control Point (18)	Check Points (4)
Error (m)	0.009316	0.046258
Error (pix)	0.348	0.586
X Error (cm)	0.796157	4.42463
Y Error (cm)	0.419863	1.24039
Z Error (cm)	0.240099	0.53084
XY Error (cm)	0.900084	4.5952
Total (cm)	0.931557	4.62576

Fig. 43A. Error in relationship with each step of the process in Aerial Close range.

2	Control Point (11)	Check Points (0)
Error (m)	0.001999	--
Error (pix)	0.701	--

3	Control Point (11)	Check Points (0)
Error (m)	0.010723	--
Error (pix)	0.681	--

4	Control Point (11)	Check Points (0)
Error (m)	0.010277	--
Error (pix)	0.487	--

5	Control Point (8)	Check Points (3)
Error (m)	0.009982	0.029879
Error (pix)	0.400	0.403
X Error (cm)	0.525082	1.47329
Y Error (cm)	0.684949	0.942346
Z Error (cm)	0.501501	2.42261
XY Error (cm)	0.863057	1.74889
Total (cm)	0.998183	2.98791

Fig. 43B. Error in relationship with each step of the process in the Aerial range.

3.2.5 STEP 5 – Camera calibration check

Camera calibration determines the intrinsic parameters such as; focal length, principal point, distortion coefficient, etc., and extrinsic parameters such as; rotation matrix and translation vector of a camera, which are necessary for; correcting lens distortions (radial, tangential), establishing accurate geometric relationships between the 3D scene and its 2D image projection, and ensuring precision in applications such as 3D modeling, surveying, and photogrammetric reconstruction.

To understand the results of Camera Calibration, we need to understand a bit about the parameters of the camera, which are discussed below.

Camera Calibration Parameters

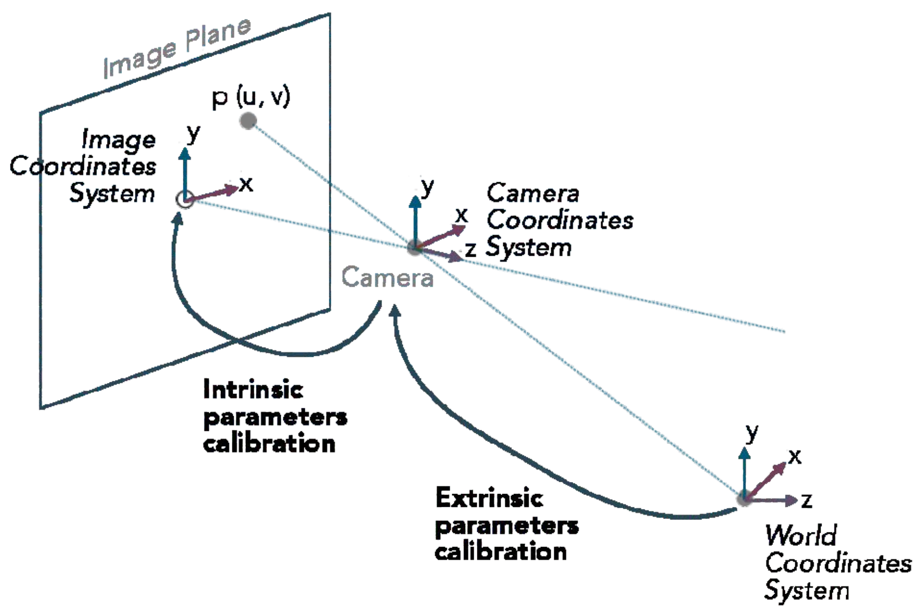


Fig. 44. Camera's Intrinsic and Extrinsic parameters. Source: Clarkson, Matt, Steve Thompson, Ester Bonmati, Ann Blandford, Tom Dowrick, e Yipeng Hu. 2019. «5.5. Intrinsic camera parameters calibration». Computer Assisted Surgery and Therapy from MPHY0026 at University College London (UCL)

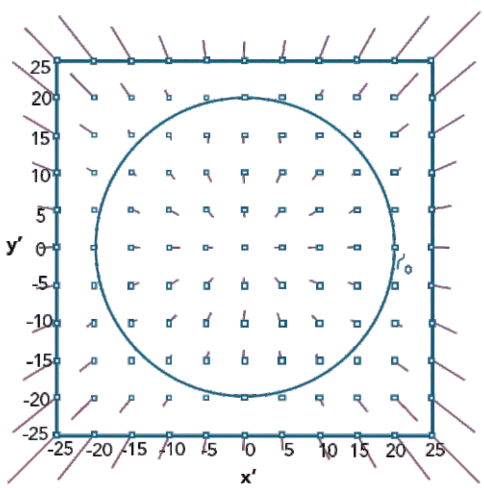
Intrinsic Parameters

These parameters define the internal optical characteristics of the camera, influencing how 3D points in the real world project onto the 2D image plan. These include:

Focal point (fx, fy): is the camera's zoom level or magnification. It is expressed in pixels.

Principal Point (cx, cy): is the optical center of the camera sensor, typically close to the geometric center of the image. Their variations indicate lens alignment issues.

Radial Distortion Coefficients (k1, k2, k3, …): displays how the lens introduces distortion that increases with distance from the principal point (center of the image). It is caused by variations in light refraction through lens components[47]. The common patterns are Barrel Distortion which are Lines curve outward from the image center (negative k1 value), and Pincushion Distortion where Lines curve inward toward the image center (positive k1 value).



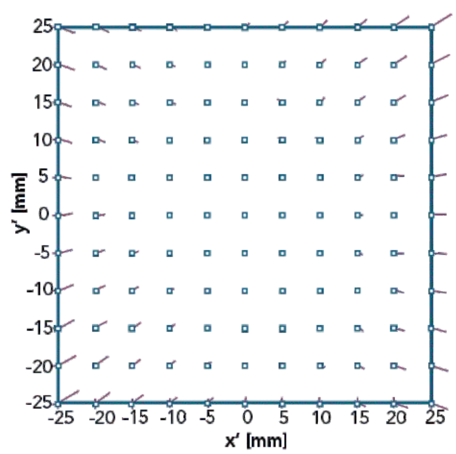


Fig. 45. Left. Example of Radial distortion. Source: Luhmann, Thomas, Stuart Robson, Stephen Kyle, and Ian Harley. 2006. Close Range Photogrammetry: Principles, Techniques, and Applications.

Fig. 46. Right. Example of Tangential distortion. Source: Luhmann, Thomas, Stuart Robson, Stephen Kyle, and Ian Harley. 2006. Close Range Photogrammetry: Principles, Techniques, and Applications.

Affinity and Skew (b1, b2): they refer to geometric distortions in imaging systems that affect the orthogonality and uniform scaling of the image coordinate system axes. These distortions can arise from; affinity (deviation in uniform scaling, where one axis is scaled differently than the other), and skew (misalignment of the coordinate axes, causing them to deviate from being perpendicular)[48]. These errors are rare to occur using modern cameras.

47) Luhmann, Thomas, Stuart Robson, Stephen Kyle, and Ian Harley. 2006. *Close Range Photogrammetry: Principles, Techniques and Applications*. Scotland, UK: Whittles Publishing Ltd.
48) *Ivi.*

Extrinsic Parameter:

The parameters are the set of values that define the camera's position (translation) and orientation (rotation) in the world. These parameters allow for the accurate transformation of 3D points in the world coordinate system into the camera's coordinate system. They are essential for multi-camera setups, enabling alignment and consistent mapping between different viewpoints.

In the process of Photogrammetry for the case study, since the images already had EXIF Metadata, Metashape automatically divided them into calibration groups according to the image resolution, camera type, and focal length. And since the images were imported in two chunks with different ranges, the image alignment and optimization were run separately for both chunks. After the step of alignment, the calibration data is adjusted and is displayed on the Adjusted tab of the Camera Calibration dialogue box. The results of calibration are shown in the figures below.

Fig. 47. Left: Camera Calibration Initial Values; Right: Camera Calibration Adjusted values (after alignment process) / Chuck Aerial Close Range.

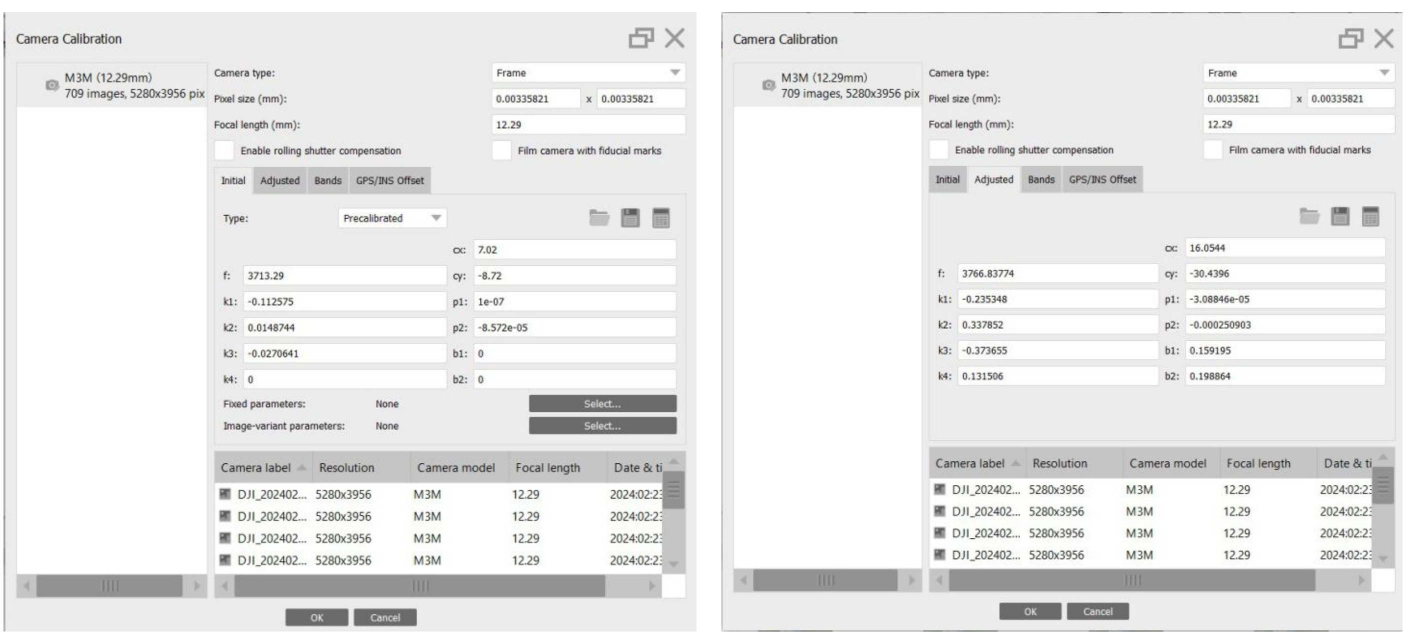
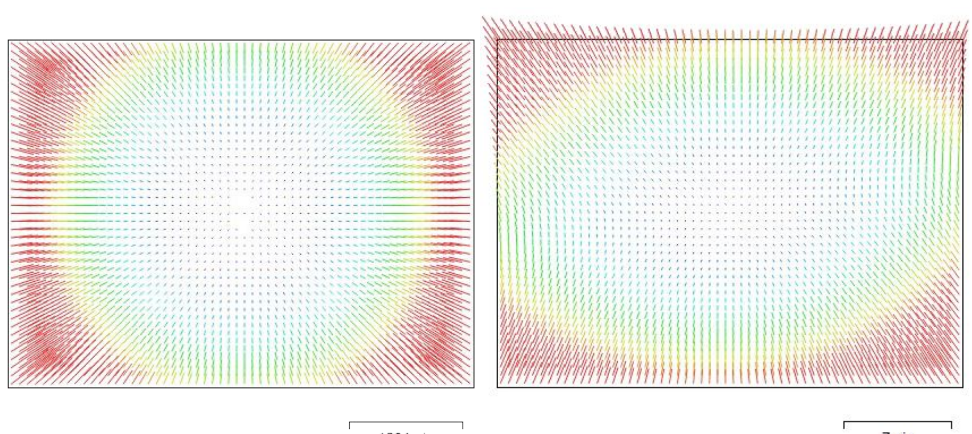


Fig. 48. Left: Radial Distortion Plot; Right: Tangential or Decentring Distortion Plot



3.2.6 STEP 6 – Building 3D Products

- **Building Dense Cloud**

A dense cloud is a three-dimensional representation comprising millions of densely distributed points, each with precise spatial coordinates and color information. As part of the workflow for generating the dense cloud, the software produces a depth map, which represents the relative distance of each pixel in the images from the camera to the surface of the object under study.

The dense cloud consists of discrete points, not a continuous surface which is required for orthorectification. Considering the previous statement, the dense cloud cannot be used directly to create an orthophoto; instead, it serves as the foundation for generating a mesh cloud or a Digital Elevation mode (DEM), both are surfaces that Metashape can use to project photographs.

To reduce noise in the dense cloud while preserving as much detail as possible – crucial for this survey's goal of degradation analysis – "mild" depth filtering was used during the cloud generation process. The results were as follows:

Fig. 48A. Aerial Close Range Dense Cloud - 48,228,357 Pts.

Fig. 48B. Aerial Range Dense Cloud - 17,262,277pts

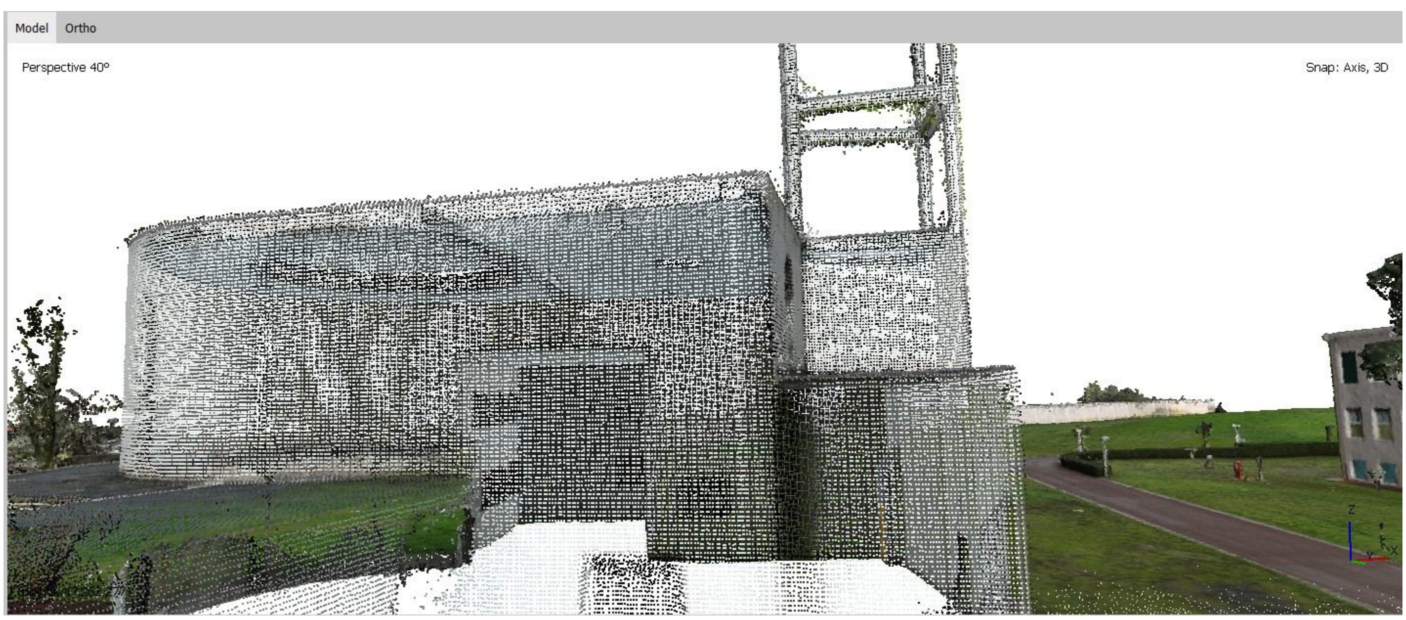


Fig. 49. Aerial Range Chunk, Zoom in.

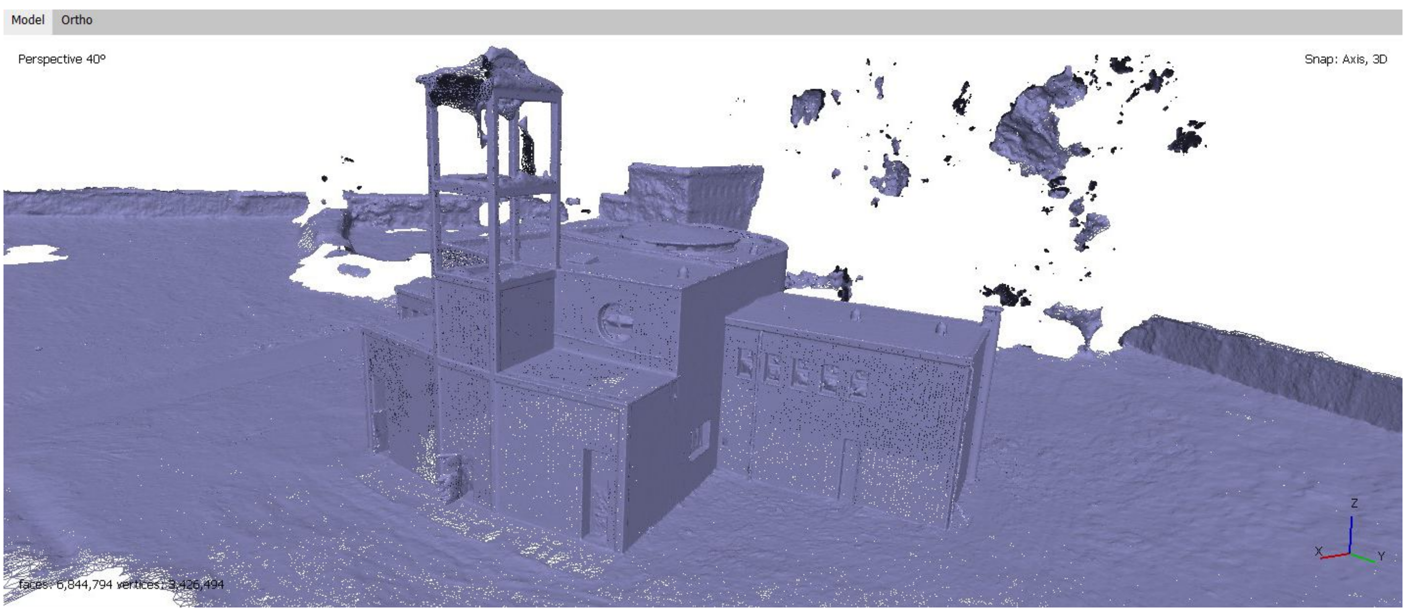
Note: Due to the distance at which the photo was captured, the dense cloud may appear to resemble a smooth surface. However, upon zooming in, it becomes evident that the image is, a cloud composed of points, as shown in Figure 18.

- **Building Mesh Cloud**

The mesh is a three-dimensional representation composed of a network of polygons, typically triangles, that form a continuous surface. It is a geometric reconstruction that describes the shape and volume of the object surveyed – Gardella's church.

When creating a mesh, the sourced data can be selected from depth maps, dense or tie points, with each option offering specific advantages and limitations. Between tie points and the dense cloud, the second one contains more information due to the greater number of points it includes. Similarly, depth maps, as an initial and simplified representation of depth and by being an intermediate step in the creation of the dense cloud, also contain less information. For this study, the mess is generated based on the dense cloud, and Arbitrary 3D as a source type, since the subject of the study is a three-dimensional object.

Fig. 50A. Mesh cloud of Aerial Close Range - 6,844,794 faces and 3,426,494 vertices.



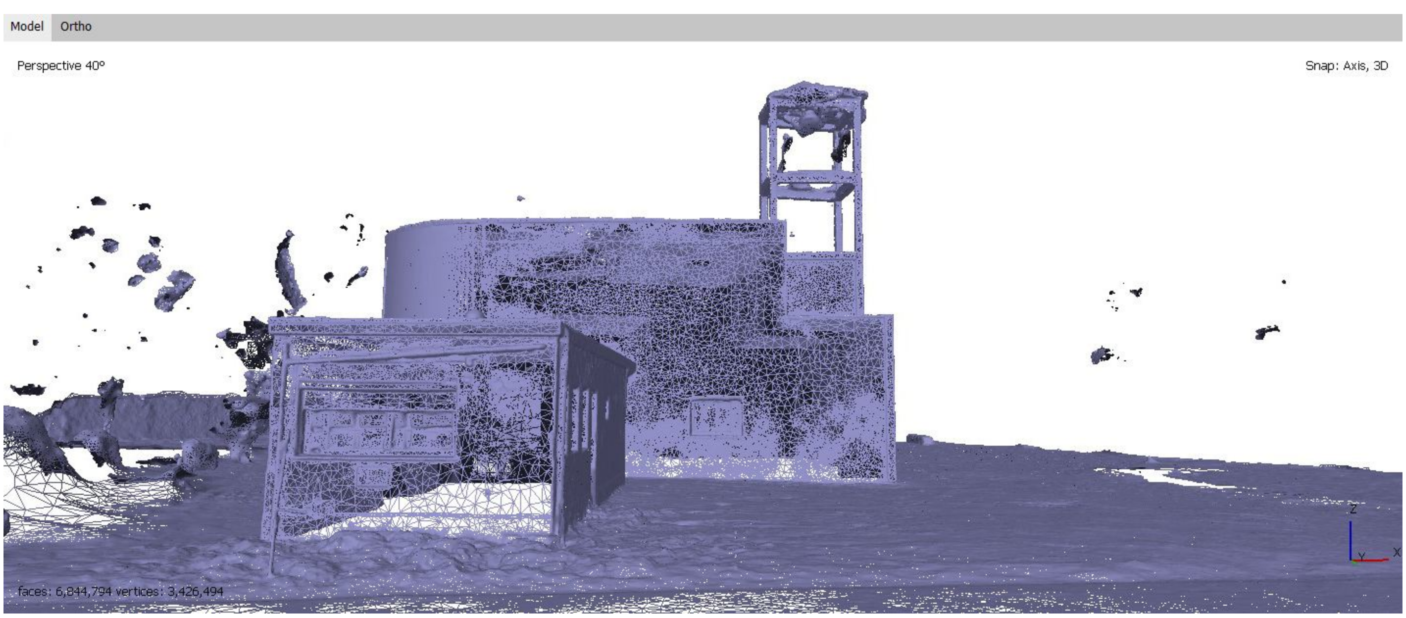
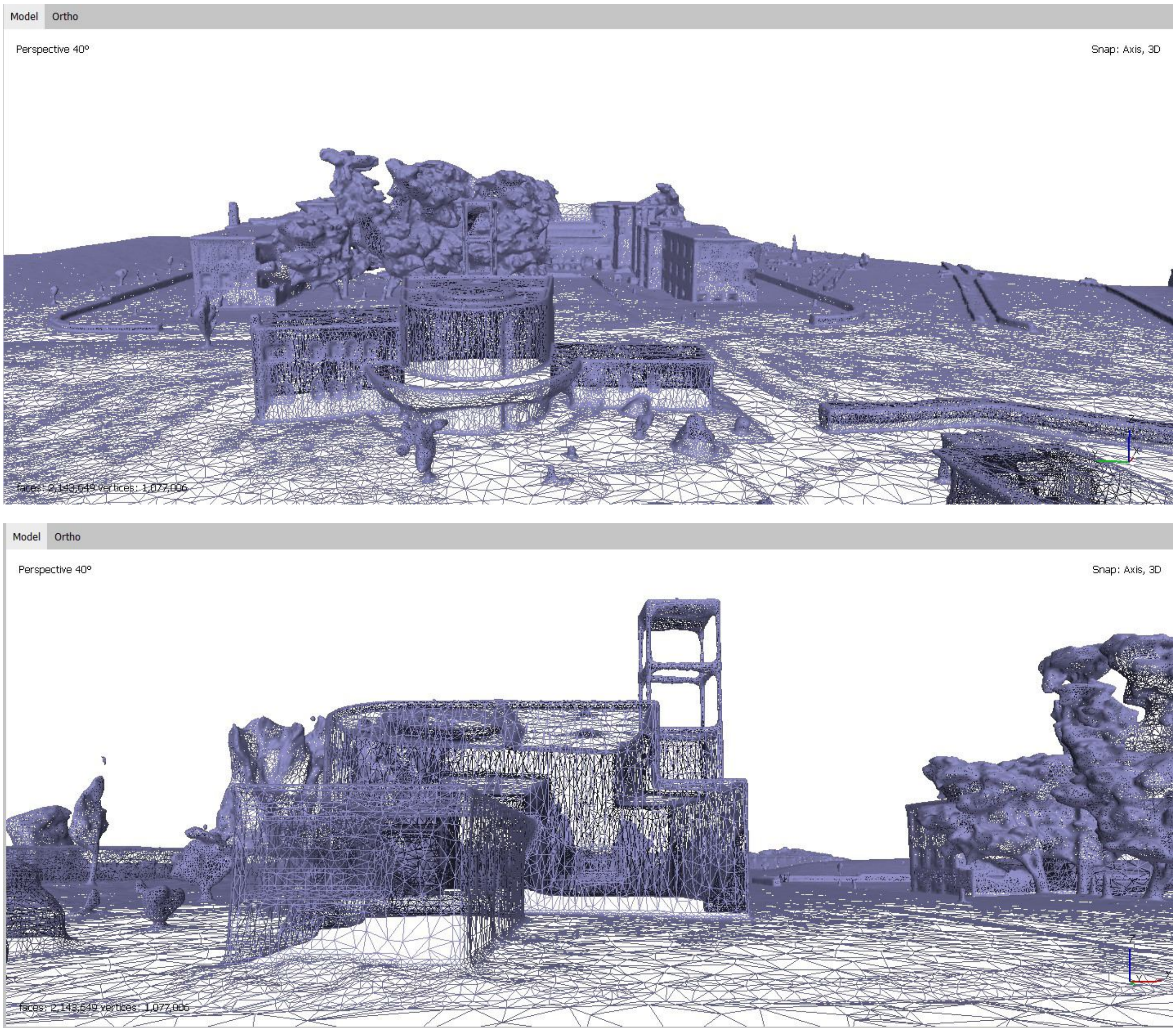


Fig. 50B. Mesh Cloud of Aerial Range -
2,143,649 faces and 1,077,006 vertices.



The software connects the points from the dense cloud by using triangles to create a continuous surface. Due to the geometric structure of the mesh being continuous, the program can project the original images onto it, thereby creating a textured model.

The results were as in the images in this and in the previous page.

- **Building Textured Model**

Visual detail serves as a complementary element to the geometry of the model, adding the possibility of having a rapid identification of the current state of degradation presented in a building. That said, the textured model provides a three-dimensional representation of the studied object - in this case, Gardella's church - where the original images are projected and mapped onto the geometry, or in other words, onto the polygonal mesh.

This study aims to preserve and document the visual aspect of the church, capturing its original color, stains, and signs of deterioration, for this reason, the texturing process was conducted using "diffuse map" as the texture type. This feature is generated by projecting the original images onto the 3D model's mesh, accurately reflecting the colors captured by the input images and producing a photorealistic result.

The way these images are projected onto the surface depends on the mapping mode chosen. In this study, "generic mapping" was selected due to its flexibility in adapting to any geometry. As noted in the manual, "no assumptions are made about the type of scene to be processed; the program attempts to create a texture as uniform as possible"[50].

Given the use of multiple images as the source for creating the texture, it is necessary to determine how the pixel color values from different cameras will be combined in the final texture. The blending mode chosen was "mosaic". As explained in the manual, this approach "involver a two-step process: it blends the low-frequency components of overlapping images to avoid the issue of seam lines, while the high-frequency components, responsible for image details, are taken form a single image with a good resolution for the area of interest"[51].

Using these parameters, the goal was to produce a textured model with high visual fidelity. The results were as follows:

50) Agisoft, 2024, *Op. Cit.*
51) *Ibidem*, p. 54.

Fig. 51A. Texturized cloud of Aerial Close Range - 6,844,794 faces and 3,426,494 vertices.

Fig. 51B. Texturized cloud of Aerial Range - 2,143,649 faces and 1,077,006 vertices.

3.2.7 STEP 7 – Building 2.5D products

- **DEM**

"A Digital Elevation Model (DEM) is a 2.5 D representation of a surface, structured as a regular grid where each cell stores height value" . Dems can be classified into the following categories:

- DSM (Digital Surface Model): Represents the surface including all objects on it, such as buildings, trees, and other structures.
- DTM (Digital Terrain Model): Represents only the bare terrain surface, excluding objects like vegetation and structures.

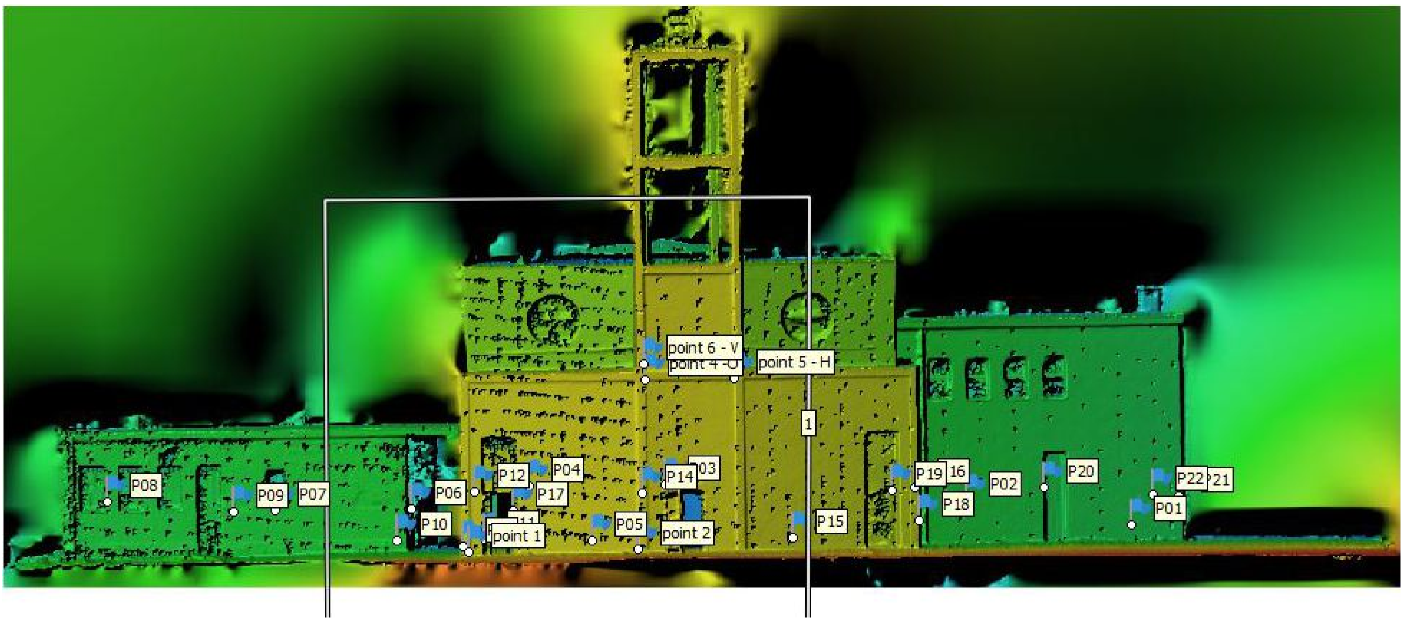
Fig. 52. DSM (Dashed purple line) – DTM (Continuous purple line).

When creating a DEM, it serves as the base for generating an orthophoto. The original images are projected onto this model, ensuring that variations in relief are accounted for, resulting in accurate orthophotos. An orthophoto of a façade corresponds to a DSM since it captures all visible elements on the surface, from architectural elements to surface and finishing details[52].

The source data for creating the DEM in this survey was the dense point cloud, as this one will give the most accurate DEM results[53]. The default interpolation option fills areas with no data by estimating values, providing a smoother and more uniform surface (as shown in Figure 53). However, for this study, such interpolation is irrelevant. Therefore, the chosen interpolation option was "disabled", leaving areas with missing height information blank as seen in Figure 55.

52) Over, Jin-Sin R., Andrew C. Ritchie, Christine J. Kranenburg, Jenna A. Brown, Daniel Buscombe, Tom Noble, Christopher R. Sherwood, Jonathan A. Warrick, and Phillipe A. Wernette. 2021. *Processing Coastal Imagery With Agisoft Metashape Professional Edition, Version 1.6—Structure From Motion Workflow Documentation.* Open-File Report 2021-2039, June: U.S. Geological Survey, science for a changing world. doi:https://doi.org/10.3133/ofr2021103.
53) *Ivi.*

Fig. 53. Interpolation parameter when Enabled (default) option was chosen.



Since the project is not oriented precisely to the north and features a complex geometry with curves and bends, creating the DEM required the application of a custom plane to ensure the model was aligned with the desired angle. To set this plane, new markers were located to define the reference system for the DEM. The markers must represent the origin, the horizontal and vertical axis; since these markers are newly defined and manually positioned, it is crucial to understand their relationship and how they interact with one another. This is clearly illustrated in Table 5.

Tab. 5. Relationship between coordinates.

	X	**Y**	**Z**
Origin	Point O	Point O	Point O
Rx	Point X	Point X	Point O
Ry	Point O	Point O	Point O + #

For the generation of DEMs for the facades, considering the need to select a reference plane as seen in Figure 54, the following points were chosen:

East	**X**	**Y**	**Z**
Origin	469746.562771	4976287.833024	91.620098
Rx	469742.159912	4976302.565781	91.620098
Ry	469746.562771	4976287.833024	97.620098

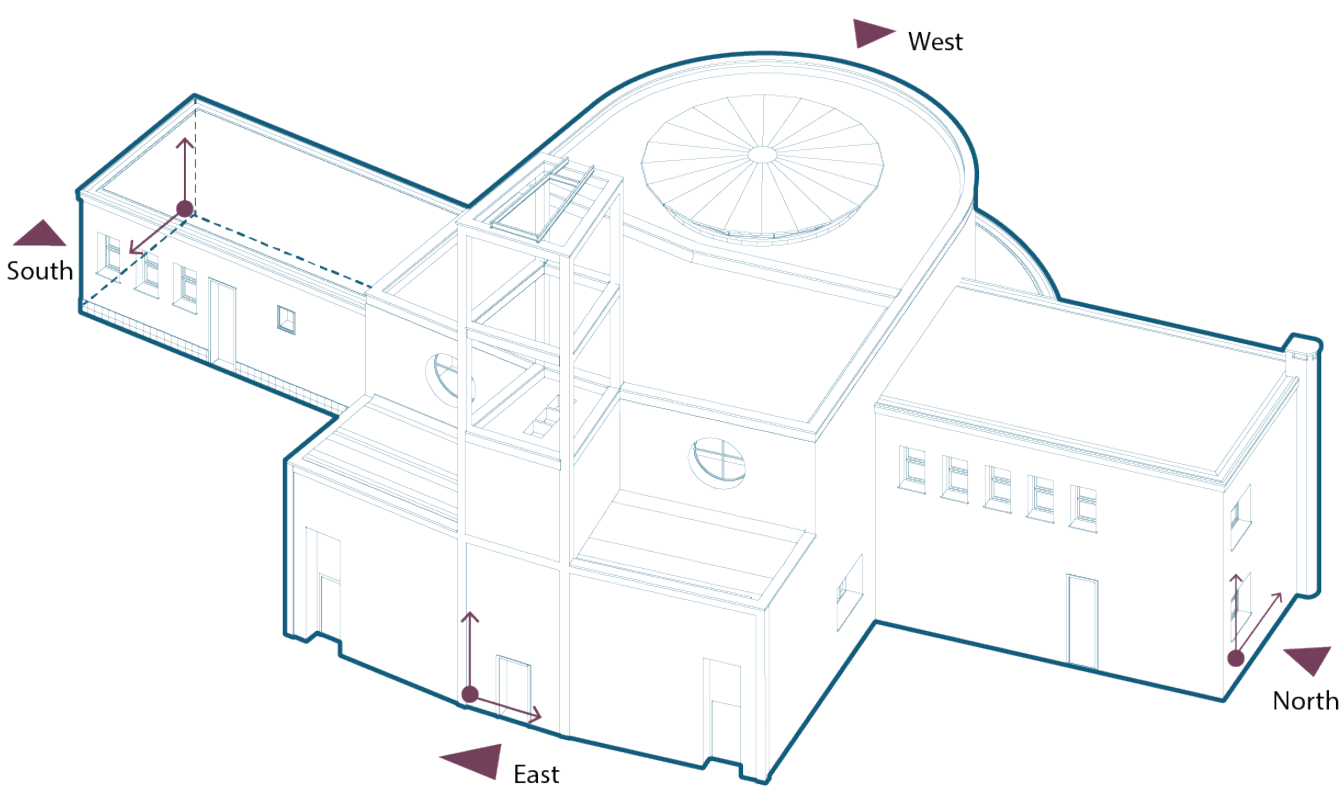
Tab. 8. Chosen coordinates for creating DEM for each façade.

South	X	Y	Z
Origin	469733.627854	4976270.786456	92.105991
Rx	469739.283992	4976271.757570	92.105991
Ry	469733.627854	4976270.786456	95.578271

West	X	Y	Z
Origin	469723.976577	4976291.397408	100.652165
Rx	469725.227025	4976287.193241	100.652165
Ry	469723.976577	4976291.397408	101.652165

North	X	Y	Z
Origin	469729.626783	4976287.833024	99.129493
Rx	469724.214106	4976302.565781	99.129493
Ry	469729.626783	4976287.833024	99.362998

Fig. 54. Planes chosen for North, South, and East façade.



This project aims to produce the floor plans and elevations of Ignazio Gardella's church, along with a degradation analysis. As part of this, elevations of the north, south, east, and west facades, as well as the roof will be exported.

Up to this point, the project has been managed using two chunks: aerial close range and aerial range. To obtain the desired outputs, the aerial close-range chunk (ACR Chunk) will be used for the facades, as it provides greater detail in these areas, while the aerial range chunk (AC Chunk) will be utilized for the roof, and this DEM was made with XY projection plane.

Fig. 55A. DEM North Façade using ARC Chunk.

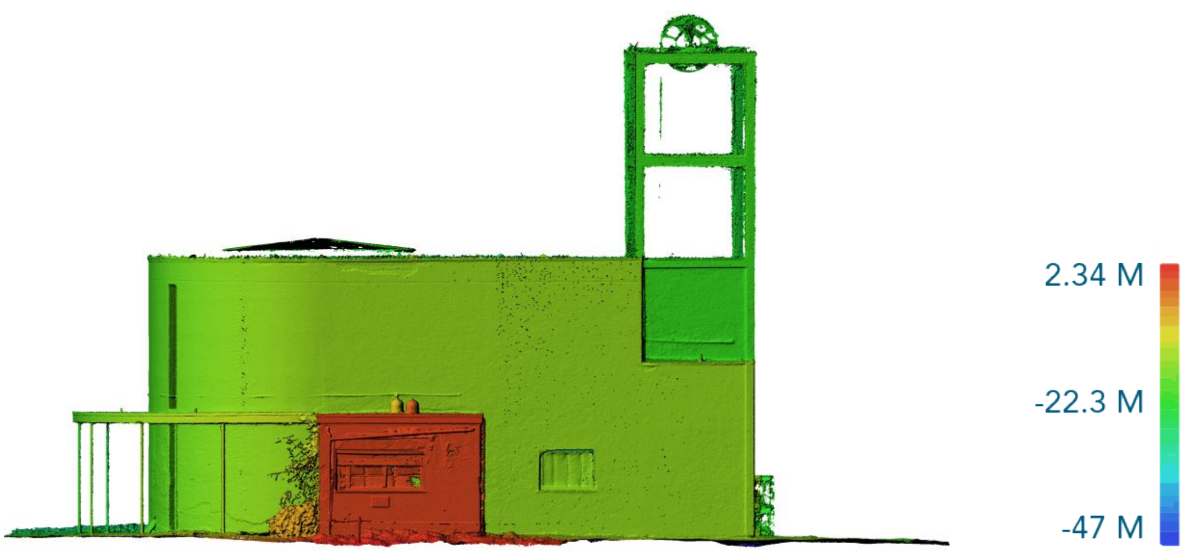


Fig. 55B. DEM South Façade using ARC Chunk.

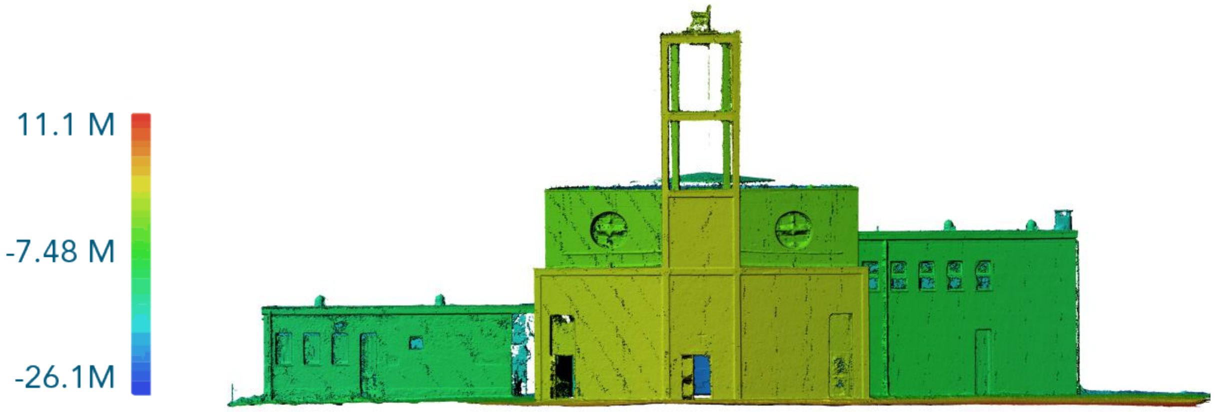


Fig. 55C. DEM East Façade using ARC Chunk.

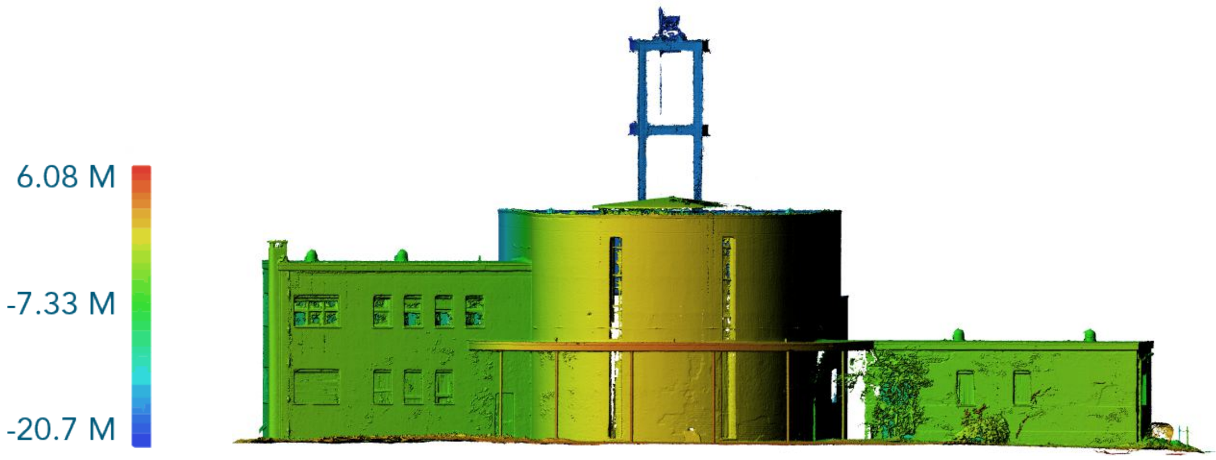


Fig. 55D. DEM West Façade using ARC Chunk.

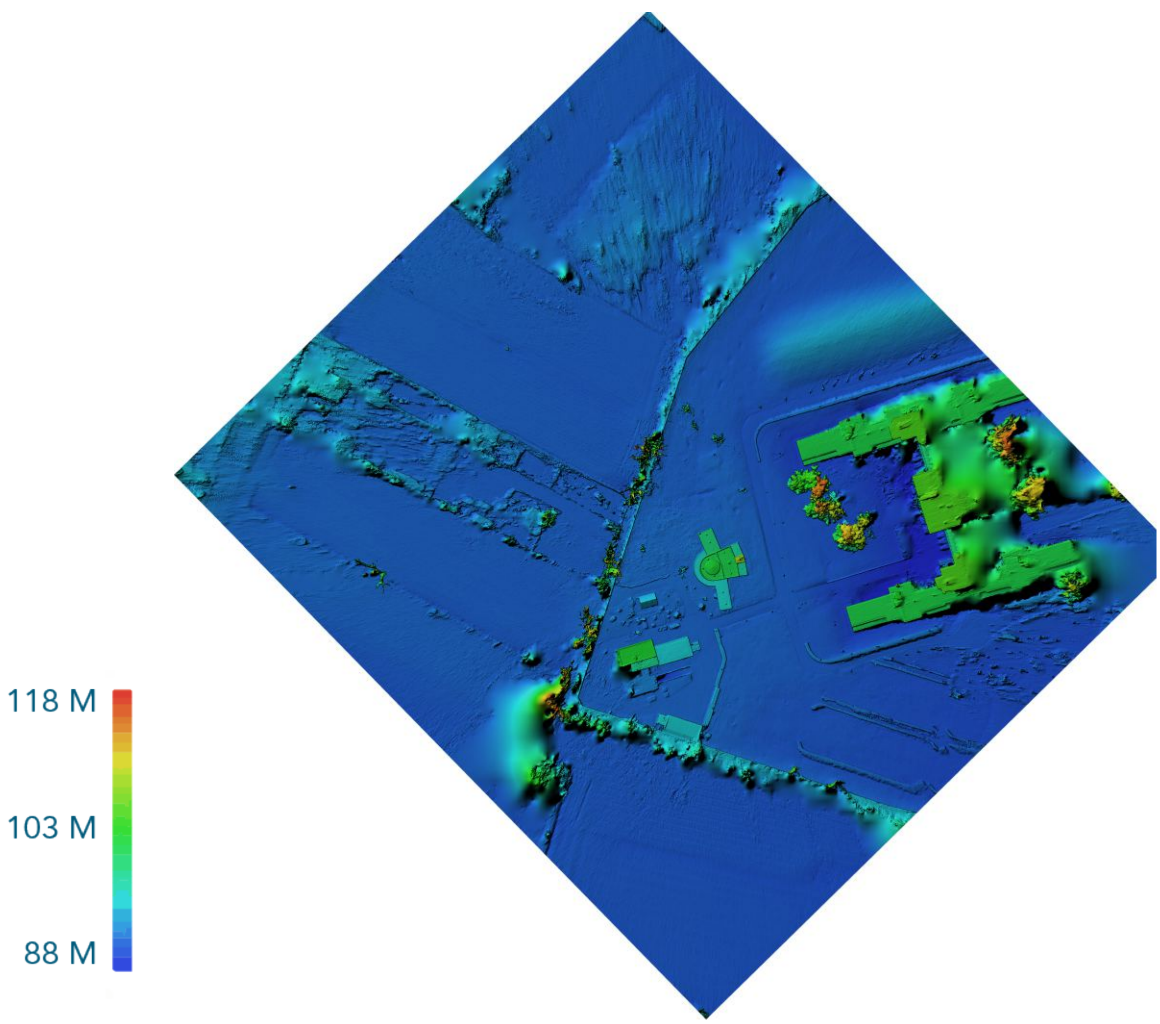


Fig. 55E. DEM Roof view using AR Chunk.

3.3 Step 8 – Building Ortho mosaics

The orthophoto is a combined image created by the projection of the original images seamlessly merged on top of the object surface and transformed into the selected projection. A polygonal model (mesh) or a digital elevation model can be selected as a surface where the images will be projected[54]. In this survey, the DEM was used, since this one is especially efficient for aerial survey data processing scenarios, in addition, it helps to save time, rather than the mesh option, which requires a high amount of memory RAM and processing power. To avoid the salt-pepper effect, the "enable hole filling" option was activated, and the image blending method was left with the default parameter, namely mosaic.

An orthophoto is an invaluable tool for documenting Cultural Heritage, as it combines radiometric data with precise measurement, enabling comprehensive and accurate representation of the analyzed object from all perspectives, whether terrestrial or aerial. Furthermore, for professionals involved in restoration or requalification projects, it serves as a critical resource for mapping materials, assessing decoration, and identifying other significant factors affecting the preservation of the heritage site under study[55].

When creating the orthomosaic, the software requires specifying the desired pixel size for the image. The determine this, it is essential to consider the information provided in the report for each chunk and the scale at which the drawing will be produced.

On one hand, the ground resolution reported for each chunk is 1.00 cm/pixel for the aerial range, while the aerial close range offers a higher definition with a resolution of 0.263 cm/pix. Ground resolution indicates the smallest detectable details, meaning the model can recognize objects approximately as small as the reported value for each chunk. On the other hand, the scale at which the drawing will be produced is 1:50, which implies that the smallest clearly "legible" detail in the real world should measure around 5 cm. Considering these two parameters, a resolution of 2cm was selected for the aerial chunk used to export the top view, and a resolution of 2 cm was chosen for the facades.

54) Agisoft, 2024. *Op. Cit.*, p. 63.
55) Chiabrando, Filiberto, Elisabetta Donadio, and Fulvio Rinaudo. 2015. *SfM for Orthophoto to Generation: A Winning Approach for Cultural Heritage Knowledge*. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL-5/W7: 91-98. doi:10.5194/isprsarchives-XL-5-W7-91-2015.

Fig. 56A. North Façade Orthophoto.

Fig. 56B. South Façade Orthophoto.

Fig. 56C. East Façade Orthophoto.

Fig. 56D. West Façade Orthophoto.

Fig. 56E. Roof View Orthophoto (Aerial Range Chunk).

3.4 Step 9 – Exporting to Cloud Compare.

One of the primary outputs generated by Metashape is the dense point cloud. This part of the study will utilize these clouds to produce 2D documentation – namely, plans, elevations, and sections – through PointCap. Since PointCap only supports importing a single cloud per file, it is necessary to merge the three existing point clouds: The aerial and the aerial close-range clouds (processed by the authors) and the inner cloud (handled by the DIRECT team). To achieve this, all three clouds are imported into CloudCompare, where they merge into a single dataset, which is subsequently used in PointCap.

CloudCompare is an open software designed to handle 3D point clouds and related data. It allows users to import, visualize, and analyze dense point clouds generated by laser scanners, drones, photogrammetry cameras, or LiDAR. Consequently, the software serves as a tool to align multiple point clouds acquired through different capture methods, such as drone-based photogrammetry (used to obtain the aerial and aerial close-range cloud) and ground-based laser scanning (LiDAR) used for the interior of the church.

In this step the first thing that was manipulating the drone-based clouds as follows:

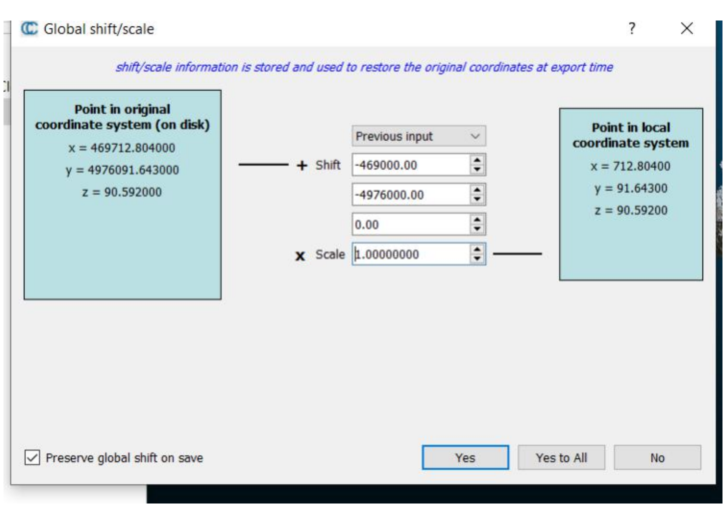
1. Global shift and scale
2. Cleaning the clouds
3. Merging and distance computation analysis.

3.4.1 Global shift scale

When importing the point cloud into CloudCompaere, the global shit/shift panel appears. This occurs because the dense point cloud is georeferenced, resulting in extremely large coordinates. As the software manual explains: The coordinates of points in georeferenced point clouds often have huge numeric values, typically on the order of millions (10^6). This is because they are expressed in the global reference systems, where points are located using absolute coordinates tied to their position on the planter[56].

CloudCompare uses a 32-bit system, which provides limited resolution for large numbers and, consequently, a reduced capacity to accurately represent decimals. As a result, when working with georeferenced clouds, positional precision can decrease to within 1 to 10 centimeters[57]. To address this inconvenience, the program offers the option to translate and rescale the data, allowing users to work with more manageable local coordinates while pre-

Fig. 57. Global shift/scale tab.

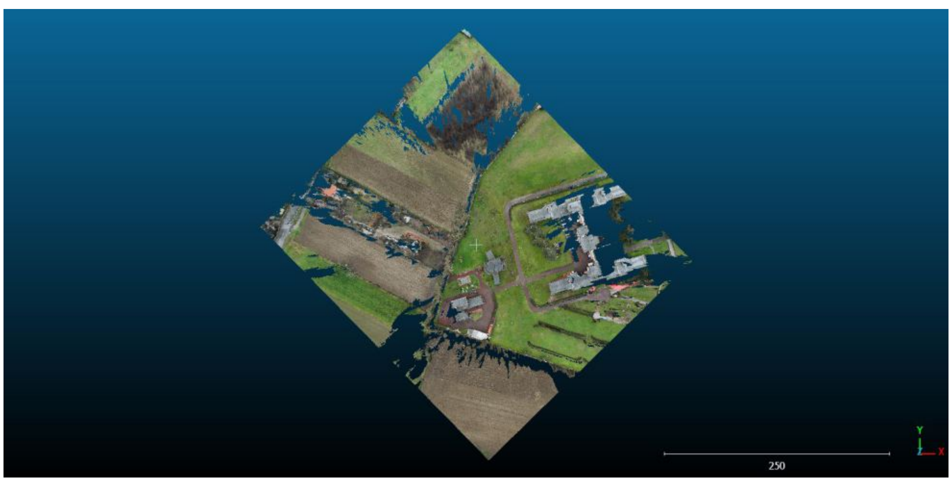


56) CloudCompare. n.d. *CloudCompare v2.6.1 - User Manual.* https://www.cloudcompare.org/doc/qCC/CloudCompare%20v2.6.1%20-%20User%20manual.pdf.
57) *Ivi.*

serving correct spatial relationships. This is achieved by applying a shift and a temporary rescaling, which can be reversed upon exporting the data. For the software to store and display the original coordinate system (rather than the local system) during the export, the "preserve global shift on save" checkbox must be selected, as seen in Figure 54.

The last figure explains the scaling process as follows:

-Original coordinates of a point (global system) – shift = local coordinates
Example with point X: 49712.804-469000.00=712.804
-Scale: 1.00 – means that the size and units have not been modified.



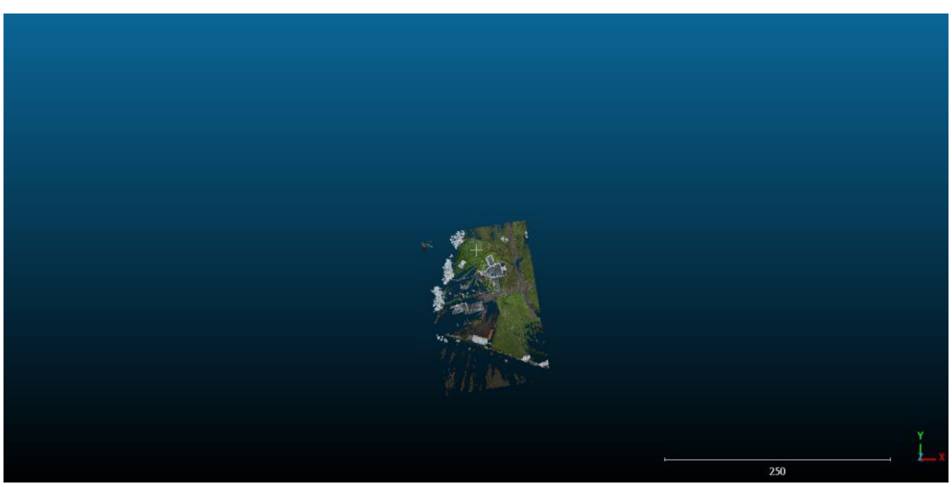


Fig. 58. Comparison between aerial and aerial-close range dimensions after being imported to CloudCompare.

3.4.2 Cleaning the Clouds.

The next step involves cleaning the point clouds, which entails removing unwanted or irrelevant points from each cloud. The goal is to enhance overall quality, facilitate analysis, and reduce the size of the processed data. Consequently, each cloud is first cleaned separately before being merged into a single dataset.

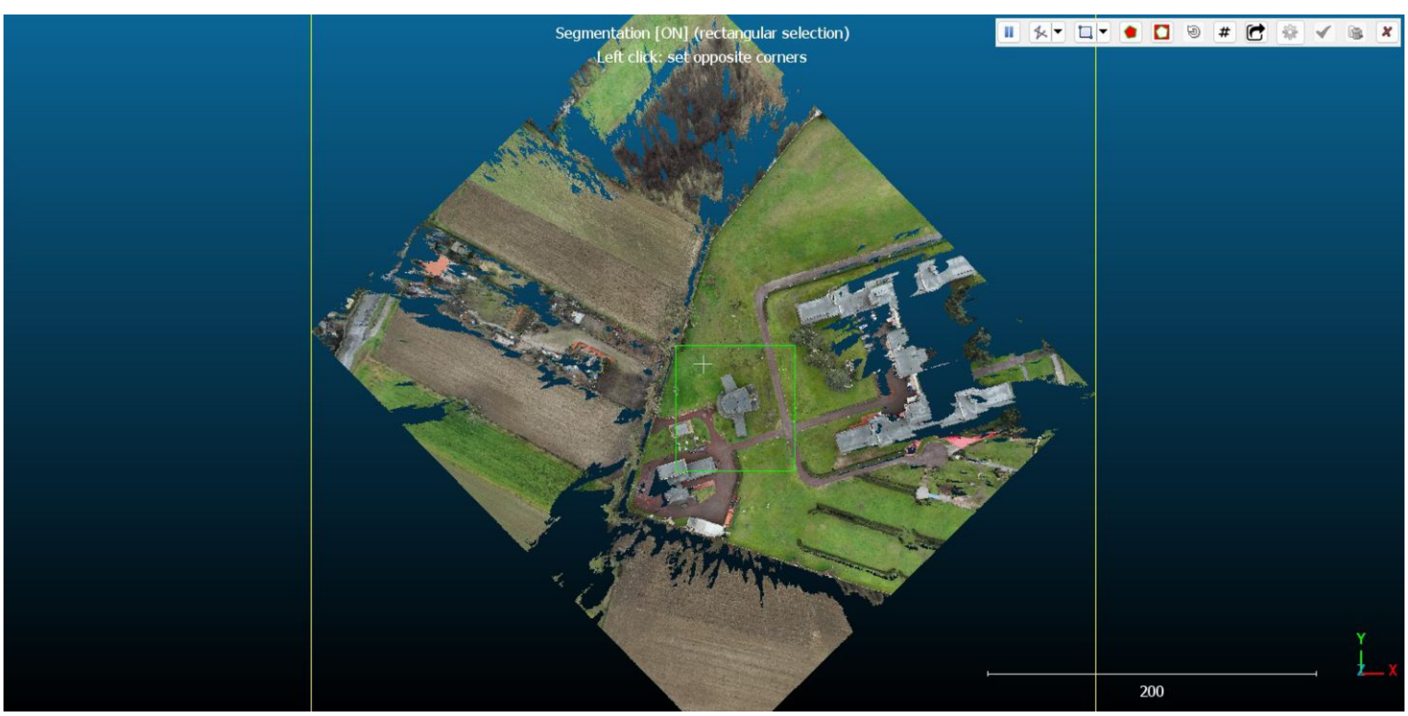
Several methods can be employed for cleaning a point cloud. In this process, the following techniques were used:

- Interactive segmentation: Allows users to manually select the areas by drawing a 2D polygon, then remove the point either inside or outside the region of interest.
- Remove duplicate points: Eliminates duplicate points based on a specific minimum distance between points in the cloud.
- Filter by value: Generates a distinction between points according to a specific range of scalar fields (elevation, intensity, position, etc).

Cleaning aerial range cloud

As can be seen, this point cloud contains information not only about the church but also about the grounds and surroundings of the Teresio Borsalino rehabilitation center. However, since this information is not relevant to the present study (since the site plan was created using the orthophoto form Metashape), the surrounding context is removed using the interactive segmentation tool. Subsequently, a duplicate-points cleaning procedure is performed to complete the cloud-cleaning process. Initially, the cloud had 16,895,879 points; after cutting the desired area it obtained 1,230,901 points and after cleaning duplicate points with a minimum distance of 1 mm, the cloud ended with 1,218,825 points.

Fig. 59. Creating a polygon (green) to segment the desired information on the current cloud (yellow).



As can be seen, this point cloud contains information not only about the church but also about the grounds and surroundings of the Teresio Borsalino rehabilitation center. However, since this information is not relevant to the present study (since the site plan was created using the orthophoto form Metashape), the surrounding context is removed using the interactive segmentation tool. Subsequently, a duplicate-points cleaning procedure is performed to complete the cloud-cleaning process. Initially, the cloud had 16,895,879 points; after cutting the desired area it obtained 1,230,901 points and after cleaning duplicate points with a minimum distance of 1 mm, the cloud ended with 1,218,825 points.

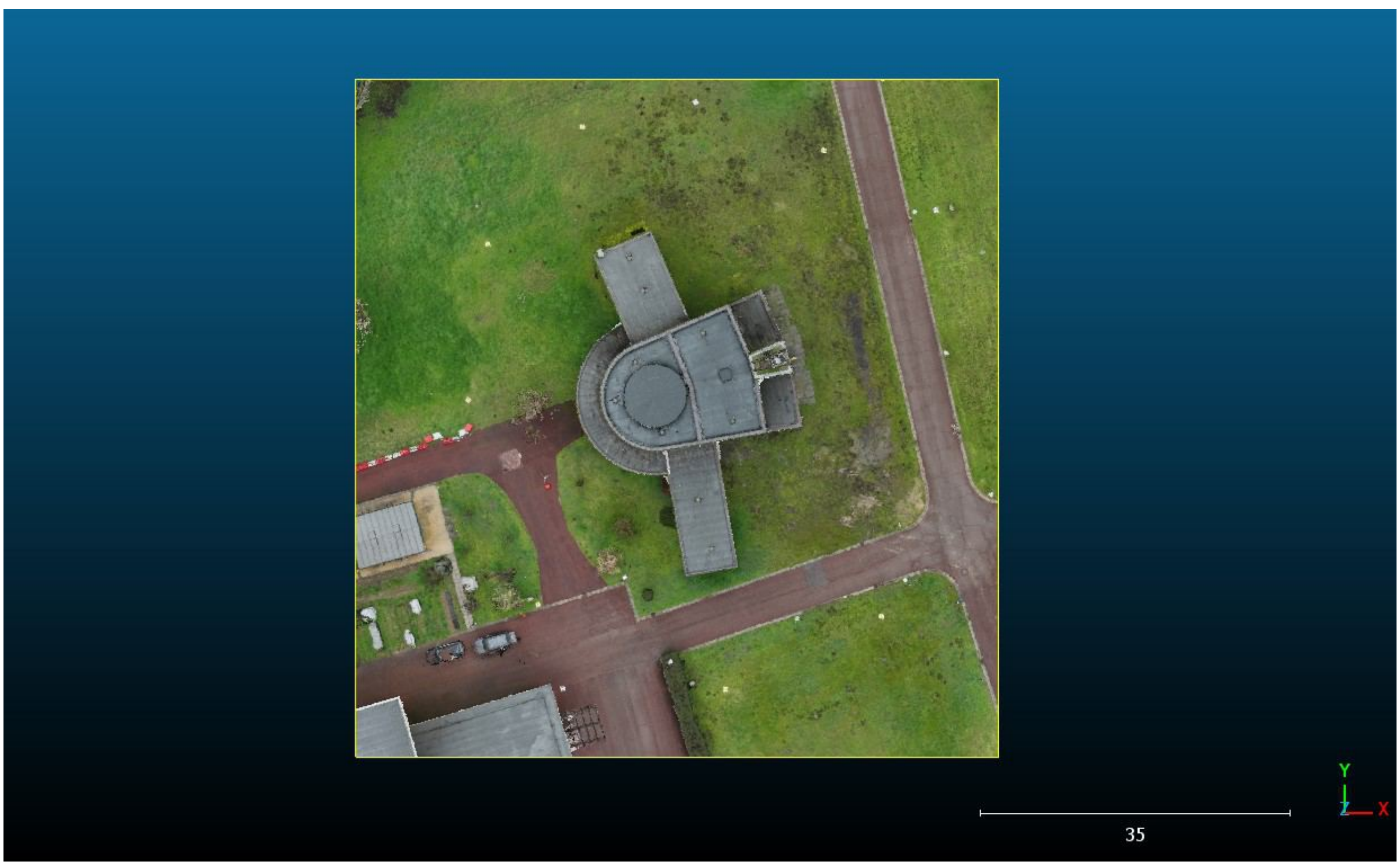


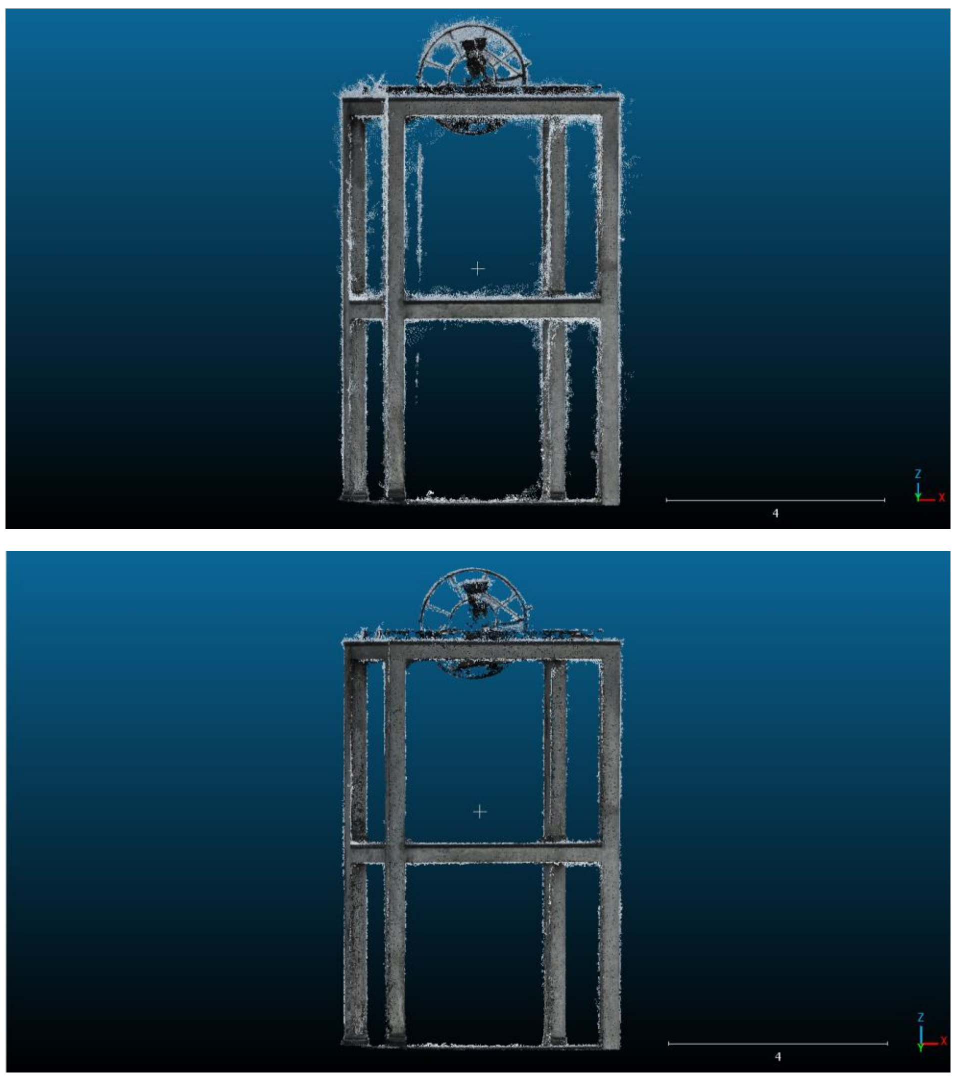
Fig. 60. Results of aerial range cloud with 1,218,825 points.

Cleaning aerial close-range cloud

Unlike the previous point cloud, the aerial-close range captures a smaller portion of the surrounding context. Nevertheless, the segmentation tool is also applied in this case to reduce the area of interest. Subsequently, a remove duplicate points procedure is executed, followed by a Filter by value operation to reach the final output. Initially, the point cloud contained a total of 45,742,592 points. After performing the cropping process to isolate the desired area, the number of points was reduced to 36,150,249. Following the application of the Remove duplicate points operation with a threshold of 1 mm, the point cloud was further refined to 29,796,730 points. Finally, additional cleaning processes were performed on the bell tower area, reducing the total number of points in the cloud to 29,478,753 points.

The Filter-by-value tool, combined with an additional segmentation process, was utilized to clean the sky region adjacent to the bell tower, as illustrated in Figure 61, Separating the bell tower into an independent point cloud was deemed necessary to prevent the unintentional removal of relevant points from the aerial close-range cloud. Once a point cloud containing only the bell tower was obtained, the first step was to utilize the Compute geometric features tool. This tool calculates various geometric descriptors for each point in a 3D point cloud. These features are derived from the local geometry surrounding each point and serve to enhance the understanding of the cloud's structural characteristics/ Furthermore, they facilitate the identification and removal of undesired points, thereby improving the overall accuracy and clarity of the dataset.

Fig. 61. Bell tower before (up) and after (down) cleaning process.



Structural geometric properties were utilized to differentiate between the points of the bell structure and the adjacent points (blueish points that seem like the sky) to reduce the second ones. Roughness measures the deviation of a point relative to its local surface; high values indicate noise or irregularities, while low values correspond to flat surfaces. Density evaluates the number of points in a local neighborhood, with metrics such as the number of neighbors and surface density. Points with low density typically represent noise or isolated points. Planarity assesses the flatness of a point's neighborhood, with high values indicating flat surfaces and low values suggesting edges or irregular points. Finally, Surface variation calculates local geometric changes; points with high variation are often indicative of noise or anomalies[58].

58) *Ivi.*

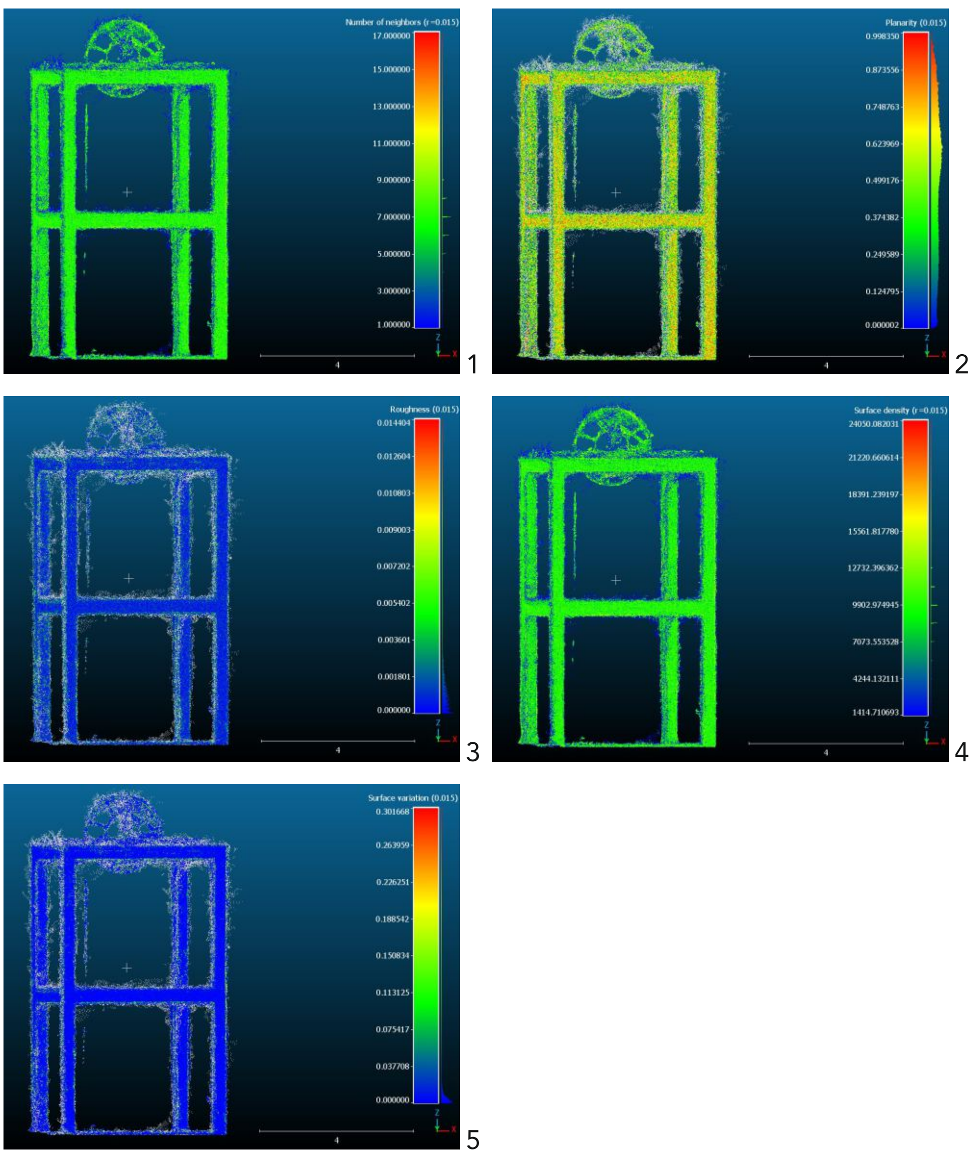


Fig. 62. 1. Number of neighbors, 2. planarity, 3. roughness, 4. surface of density, 5. surface variation.

For this process, a neighborhood radius of 0,015 was selected, yielding the results shown in Figure 63. After the analysis, and at first glance – merely by observing the images – it was established that the surface variation descriptor provided optimal results for the initial removal of sky points. The visualization of this result employed a color scale to represent the data, although many NaN points were observed; These points identified by the color gray and known as "Not a number", represent data with no associated value for this field. To remove these points Filter by value tool was applied, by defining a range that included only valid values within the color scale. As a result, gray points were excluded from the dataset, improving its overall quality and focusing on the tower.

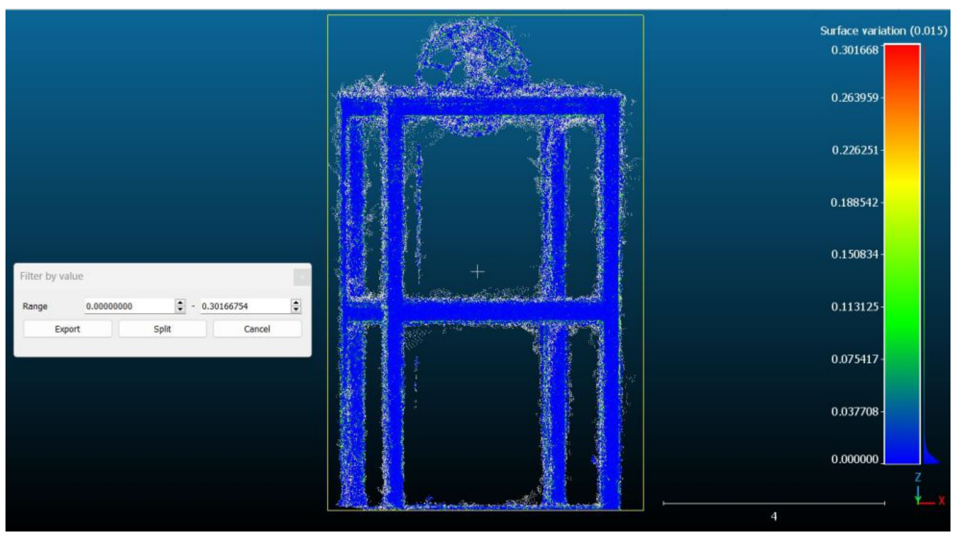


Fig. 63. Applying the Filter by value tool to the results obtained from surface variation.

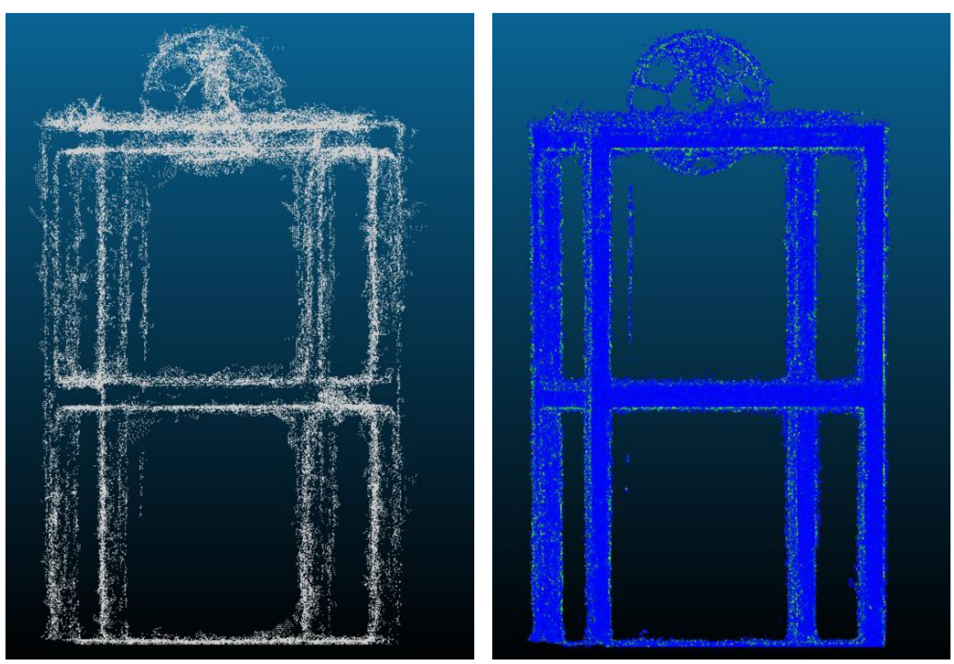


Fig. 64. Results from using the Filter by value on the surface variation results. From left to right: relevant points and irrelevant points.

The subsequent step in refining the tower's point cloud involved the use of the Number of neighbors metric, again applying the same neighbor radius of 0.15. In this case, no NaN points were observed. However, the color scale served as a reference to identify and define the desired range of valid points. This range facilitates the identification of undesired points, which were subsequently removed by applying the Filter by value tool. The final phase of the process included another pass with the Surface variation metric, followed by multiple manual adjustments using the Segmentation tool. This iterative and comprehensive approach ensured thorough cleaning of the bell tower's dense cloud. By the end of the process, the point cloud of the bell tower was significantly reduced, decreasing from an initial total of 820,930 points to 541,865 points.

3.4.3 Merging the Clouds

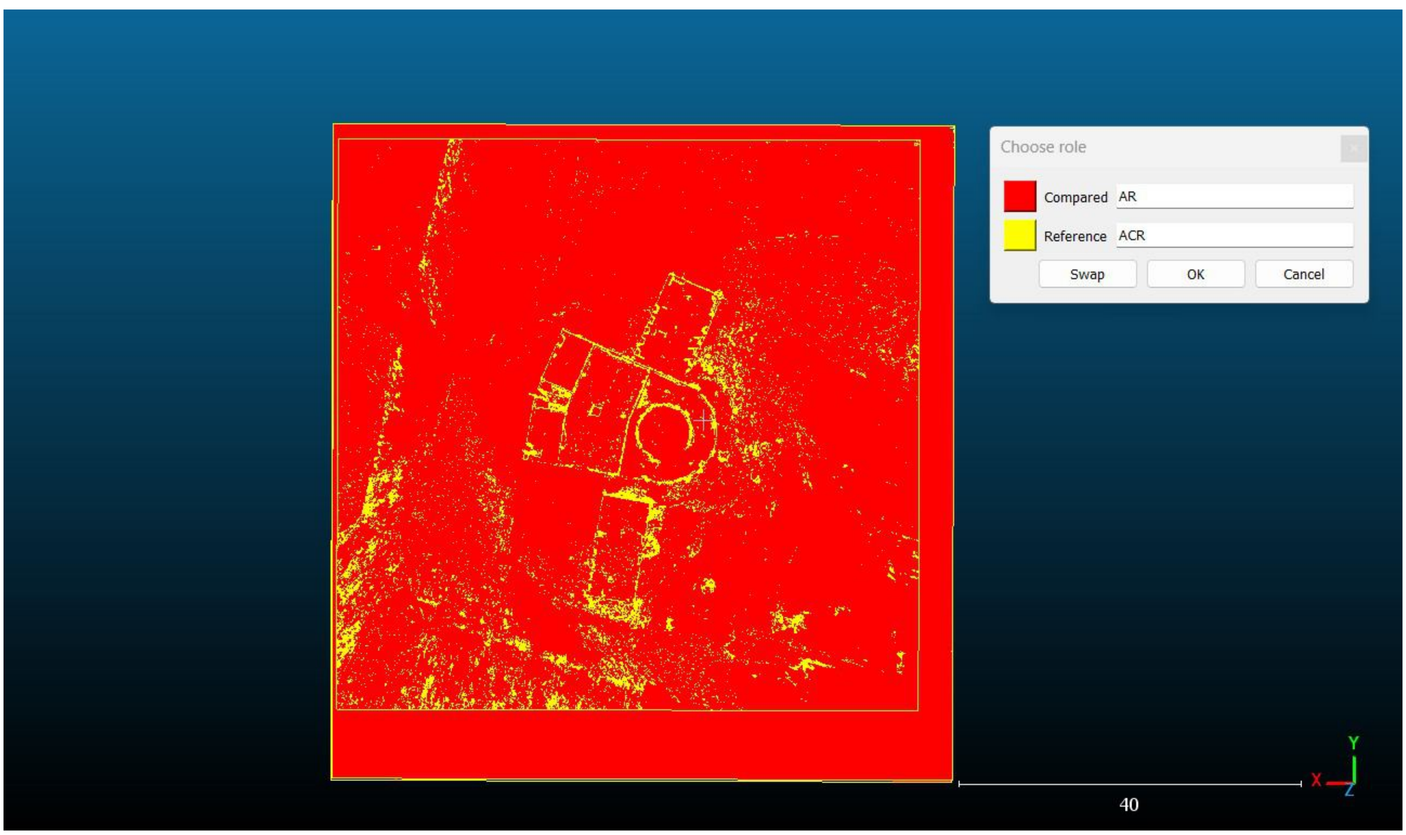
Once the point cloud of the bell tower was ready, the next step involved reintegrating it into its original point cloud (aerial close-range data). The tool designed to combine two or more entities into a single dataset is called the Merge tool. This gadget was indeed employed to unify the three individual clouds. It is important to highlight that the Merge tool, after completing the merging process, preserves various types of information, including scalar fields, RGB colors, and metadata.

Fig. 65. Alignment of the aerial close range with the aerial range cloud.

It is important to note that both point clouds generated through the photogrammetric process are georeferenced. Consequently, when imported into CloudCompare, and even after applying the shit process, the clouds are already aligned. However, before merging them, this statement was verified using the Cloud-to-cloud Computational Distance tool. This tool performs a comparison by calculating the nearest Euclidean distance between each point in the compared cloud and its closest corresponding point in the reference cloud, ensuring precise alignment verification.

The aerial range point cloud contains 1,218,825 points, while the aerial close-range point cloud consists of 29,478,753 points. Although the aerial range cloud encompasses a larger spatial extent, the aerial close-range cloud is significantly denser due to its higher point count. This difference is also evident upon visual inspection, as the texture of the aerial close-range cloud appears of superior quality. Consequently, the aerial close-range cloud was designated as the reference cloud, while the aerial range was treated as the compared cloud as illustrated in Figure 66.

Fig. 66. Compared cloud (red) and referenced cloud (yellow).



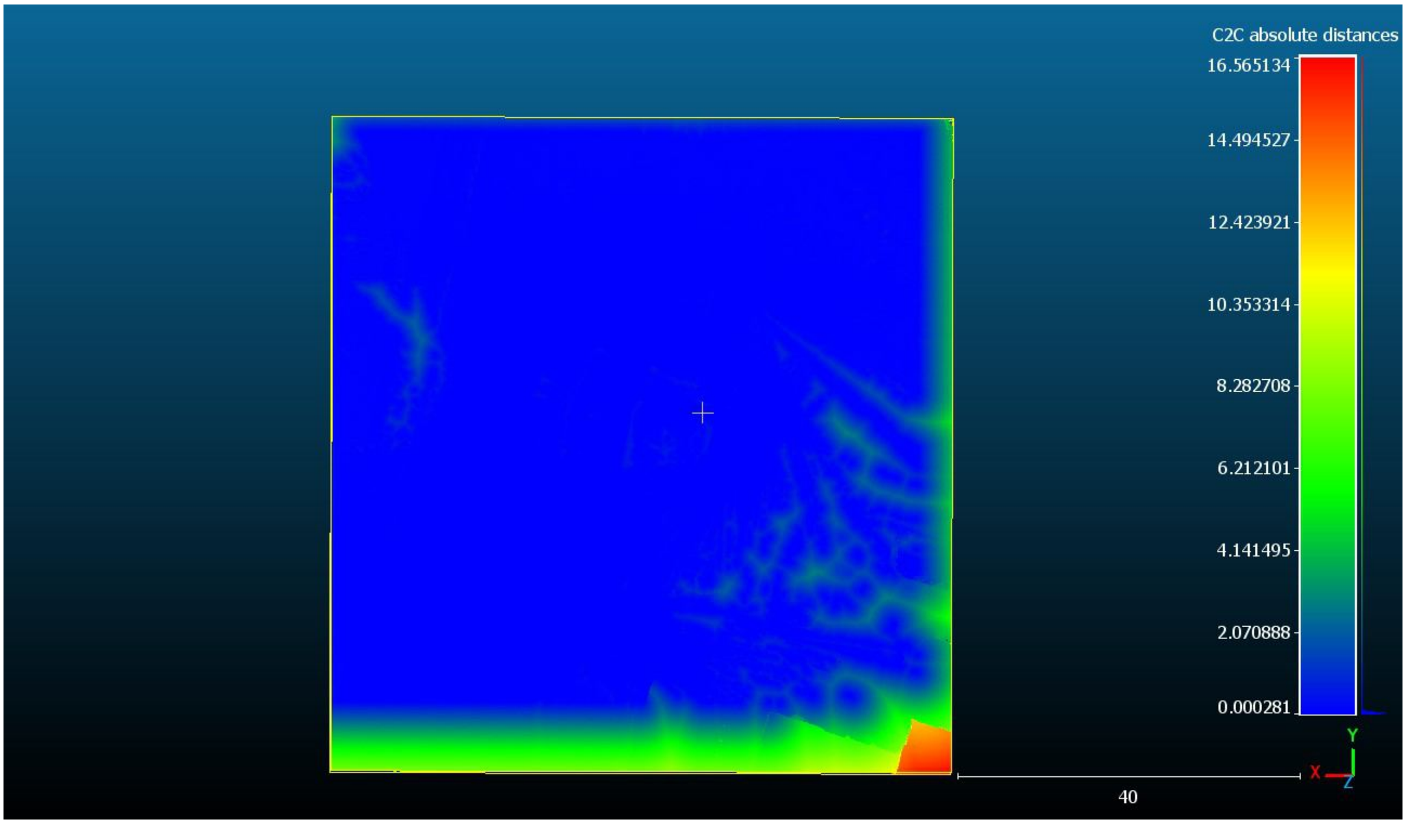


Fig. 67. Results of C2C absolute distance.

The third point cloud is the one that captured the building's interior. It was generated using a LiDAR scanner and in the same way as the previous ones, this one was georeferenced; the DIRECT team processed the data and delivered the scans already aligned to the authors; by saying "the scans," It means that they were not merged into a single point cloud but rather remained as independent point clouds. The remaining task was to merge these scans into a single unified dataset, referred to as "the inner cloud".

Ultimately, the "outside dense cloud" and the "inner dense cloud" were merged into a single, fully georeferenced point cloud, preserving their essential metadata, scalar fields, and RGB information, in this way the output is a complete and detailed digital representation of the building, which serves as a robust foundation for further analysis and documentation.

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Conclusion of 3D Survey Methods and Techniques

4. Conclusion of 3D Survey Methods and Techniques

3D survey methods have revolutionized architectural heritage documentation by providing precision in capturing complex geometries, surface details, and spatial representations. Unlike traditional techniques such as manual measurements and 2D drawings, advanced technologies like terrestrial laser scanners, and UAV-based photogrammetry, allow for the creation of highly detailed and accurate 3D models. These methodologies enhance structural analysis, future intervention planning and heritage conservation.

The 3D surveying process integrates various complementary techniques. Point cloud generation, as was already said, was achieved through laser scanning and photogrammetry, as an output they give a digital model that comprehensively documents the condition of the historic building, nevertheless, these were not the only tools used to achieve it. Georeferencing using GNSS and total stations ensures precise data alignment, guaranteeing spatial consistency and facilitating the integration of multiple datasets. In the case of the survey conducted on the church of Ignazio Gardella at the Teresio Borsalino rehabilitation center, the combination of these techniques has resulted in detailed and accurate documentation of the monument providing a fundamental basis for its monitoring and maintenance.

Beyond documentation and preservation, 3D surveying also plays a crucial role in heritage accessibility. The digital models generated can be used for virtual reconstructions and simulations, allowing remote access to historic structures and promoting these techniques not only ensures the conservation of tangible heritage but also strengthens its dissemination and understanding in the digital age.

In conclusion, 3D survey methods represent a significant advancement in architectural documentation, offering precise, non-invasive, and highly efficient tools for cultural heritage preservation. The combination of data acquisition, processing, and georeferencing techniques has proven essential for the long-term conservation of historic structures, ensuring their authenticity and accessibility for future generations.

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Part IV

Digital Plotting in 2D and 3D

2d plotting

1.1 Overview of Tools and Workflow

The production of accurate 2D documentation for the Church of Gardella exemplifies the integration of modern geomatics technologies and architectural drafting principles. This process focused on generating scaled plans, sections, and elevations, emphasizing precision and adherence to architectural and heritage standards. By leveraging on the software of PointCab and Metashape, the workflow facilitated the creation of drawings that accurately reflect the building's existing conditions and spatial characteristics.

The workflow began with the processed point cloud data, derived from the surveying techniques and workflow explained in the last chapter. This data served as a primary input for creating 2D drawings with the help of PointCab. This software helped to extract the plans and sections from the point cloud data, which was cleaned and merged using Cloud Compare. One of the biggest benefits of using PointCab is the interoperability with CAD software like AutoCAD, as it exports the extracted directly in the .dwg format which allows us to work in the same coordinates while creating scale drawings. This is a crucial step that ensures alignment with structural axes and facilitates an accurate representation of the interior spatial relationships.

For elevations, Metashape software was utilized to produce high resolution orthomosaics from photogrammetric imagery. These orthomosaics were georeferenced and imported in CAD software with the original coordinates and scale of the exported file, to ensure the precision and accuracy of the resultant drawings produced. These orthophotos not only captured the geometric accuracy of the façades, but also preserved the intricate details of surface textures and material conditions. This approach allowed for a seamless transformation of raw geospatial data to refined architectural drawings, ensuring that critical features on the façade are faithfully documented.

The integration of orthomosaics, into the drafting process for elevations, was particularly beneficial for analysing surface conditions. By mapping the details on the façades, it was possible to highlight areas of material degradation and structural wear. This dual-layered approach, combining geometric accuracy with visual texture enhanced the analytical value of elevations.

In summary, the 2D documentation of the church in Presidio Borsalino demonstrates a meticulous and methodical approach to architectural documentation. By utilizing the above-mentioned programs, the drawings have received a high level of accuracy and detail essential for understanding and preserving this culturally significant structure.

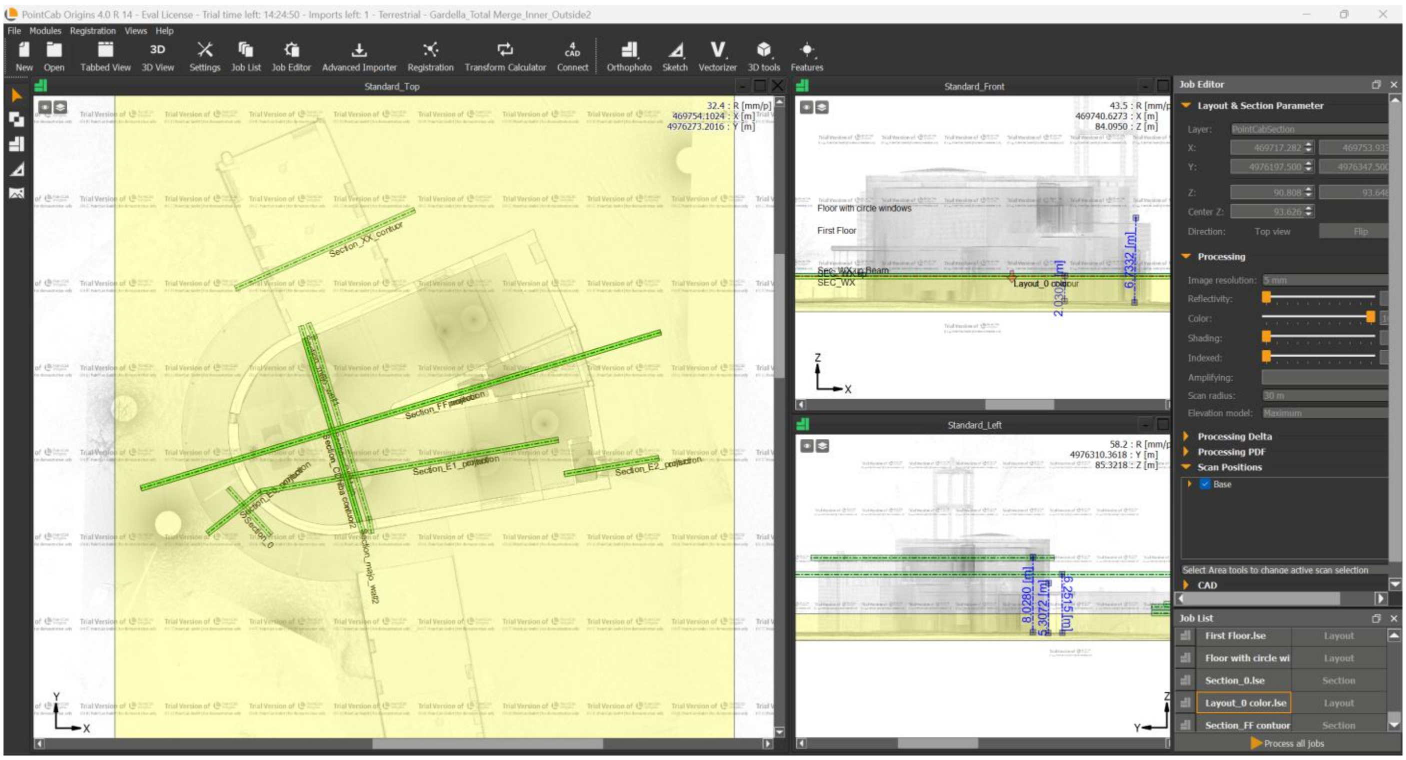
1.2 2 Digital Plotting using PointCab

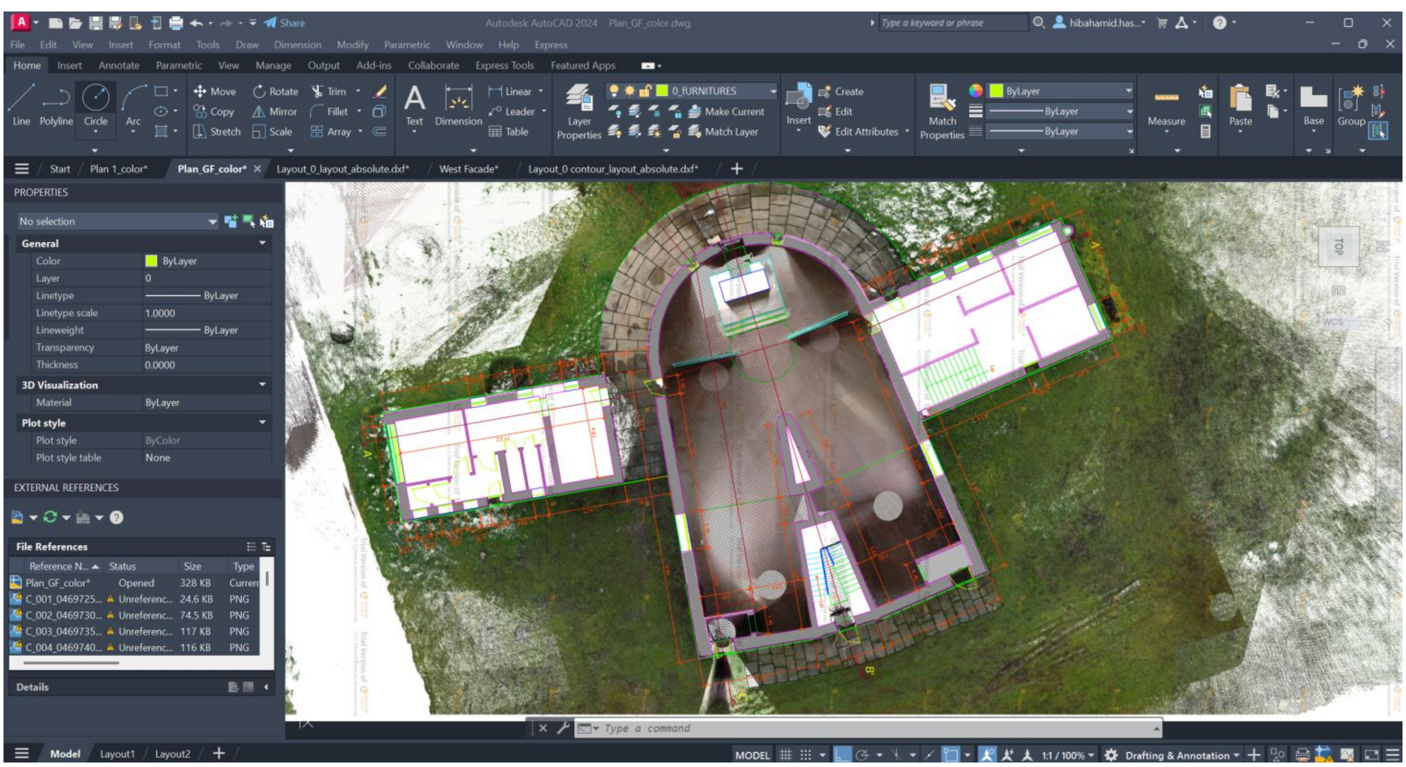
PointCab is specialized software designed to process and interpret point clouds, making it ideal for generating scaled 2D plans, sections, and elevations. It gives remarkable accuracy and as already mentioned, it uses the already georeferenced data obtained from original point clouds. For the purpose of our thesis, the interior point cloud obtained with LiDar and the exterior point cloud generated with the help of UAV survey were combined in the CloudCompare software and cleaned to export the SCENE in .e57 format which is interoperable with PointCab software. The integration of this data allowed us to create a single point cloud that served as a basis for digital plotting in both 2D drafting and 3D Scan to BIM processing.

The workflow begins with the importation of the unified point cloud into PointCab in the E57 format. Upon import, PointCab automatically organizes and processes the data, establishing a project environment that supports streamlined operations. The imported data is shown in Figure 1. Once the data is imported, PointCab automatically generates Standard Top, Standard Front and Standard Left views. The next step is to generate the "Layout Section" from the "Orthophoto" tab. This allows us to create the plans and sections from the standard views, based on required height or slice axes. The interface is very simple, it requires only a few adjustments in the settings of "Job Editor" tab which include image resolution, colour rate, reflectivity, shading and the file format of the jobs to be processed, in addition to where the files must be stored. Simply by clicking "Process all Jobs" at the bottom of the Job Editor tab, we can obtain the results in the CAD .dwg format. The software can give us the orthophotos both in Layout and Colour. The Layout is helpful in determining the exact angles and thickness of walls, while the colour exports help us with the materials, finishes and textures of the floors and walls. The example of CAD export is shown in Figure 2.

The exports from PointCab to AutoCAD are typically in the form of a mosaic of multiple pictures or datasets. To unify these multiple set of photos, Merger tool in PointCab Orthophots was used to export the view as a single dataset. This helps in simplifying workflows by eliminating the need to manage multiple files and ensures cleaner results. This tool enhances data quality by increasing point density and reducing noise, making it ideal for file optimization and time management.

After obtaining the results from PointCab, the plans and sections were drawn in AutoCAD with as much detail as possible. As obvious in the plan above, the interior scan of the church was done only in the central





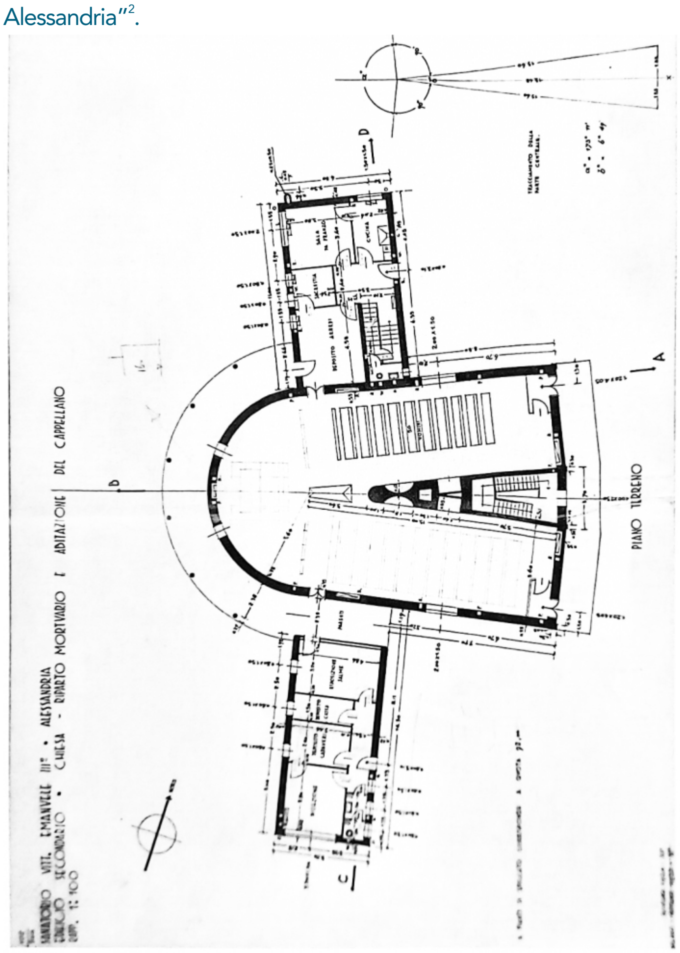
1) Di Franco, Andrea, Massimiliano Roca, and Guido Montanari, . 2008. *I Gardella ad Alessandria, 1900-1996: architetture*. Alessandria, Palazzo del Monferrato: S.l.: s.n..
2) Davio, Barbara, 1997, *Op. cit.*

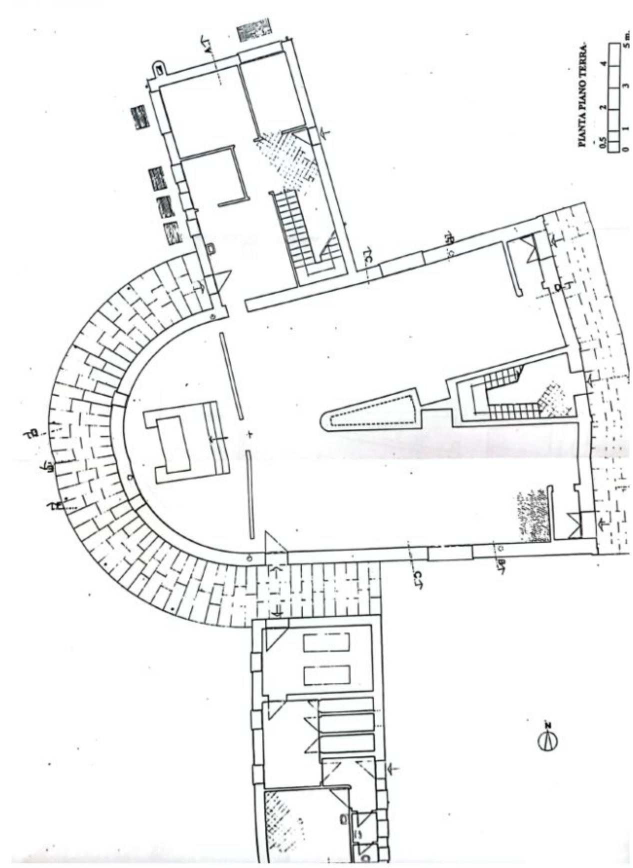
Fig. 1. PointCab interface, taking a Plan view at 2m height. This height was chosen because the sill level of windows in the naves have a higher sill level. This level ensured the sectional details of all the doors and windows on ground floor level. Source: Elaboration by Authors (previous page).
Fig. 2. AutoCAD Export from PointCab in Colour. Source: Elaboration by Authors (previous page).
Fig. 3. Left – Ground Floor Plan drawn by Ignazio Gardella 1934. Source: Archivio Gardella Oleggio AGO G3.san.V.E[1].
Fig. 4. Right – Excerpt from Thesis titled "La conservazione dell'architettura moderna: le opere di Ignazio Gardella in Alessandria"[2].

volume because the right and left wings are not accessible. The drawings of the internal distribution of these wings were produced with the help of the thesis of Barbara Davio done in 1997, at Politecnico di Torino under the supervision of Professors Luciano Re and Chiara Occelli. In addition, some archival drawings by Ignazio Gardella were found in the catalogue of exhibition titled "I Gardella ad Alessandria 1900-1996: Architecture" edited by Guido Montanari in 2008 in the library of BCA at Politecnico di Torino. The reference to these drawings has been shared in Chapter 2 in the section of Case Study. A few examples of these reference drawings are shown below.

The results from PointCAB were categorized by the authors in three categories to analyse different aspects of the buildings in plans and sections.

1. Contuor – This was done by taking a very small projection area of few centimetres to see the precise details of the section cut.
2. Projection – This was a larger projection area typically till the lowest level in terms of plans and till the depth of elevation in terms of vertical sections.
3. Colour – The purpose of coloured projections is to depict the material and texture of the walls, floors and other elements.





Below are some examples of the three types of results.

The second thing to be mentioned here is that the layout of the first floor was done with the help of two different section cuts from the PointCab software. This is due to the difference in level and heights of different structures. The sections AA' and CC' are stepped, which is due to the different angles of the building. They have been taken out from point cab at the desired angles as shown in Figure 13-15. Finally, the roof plan is done with the help of Metashape Orthomosaic. The procedure of exporting the



Fig. 5, 6, 7 (Left to right). Contour, projection, colour. Source: Elaboration by Authors.

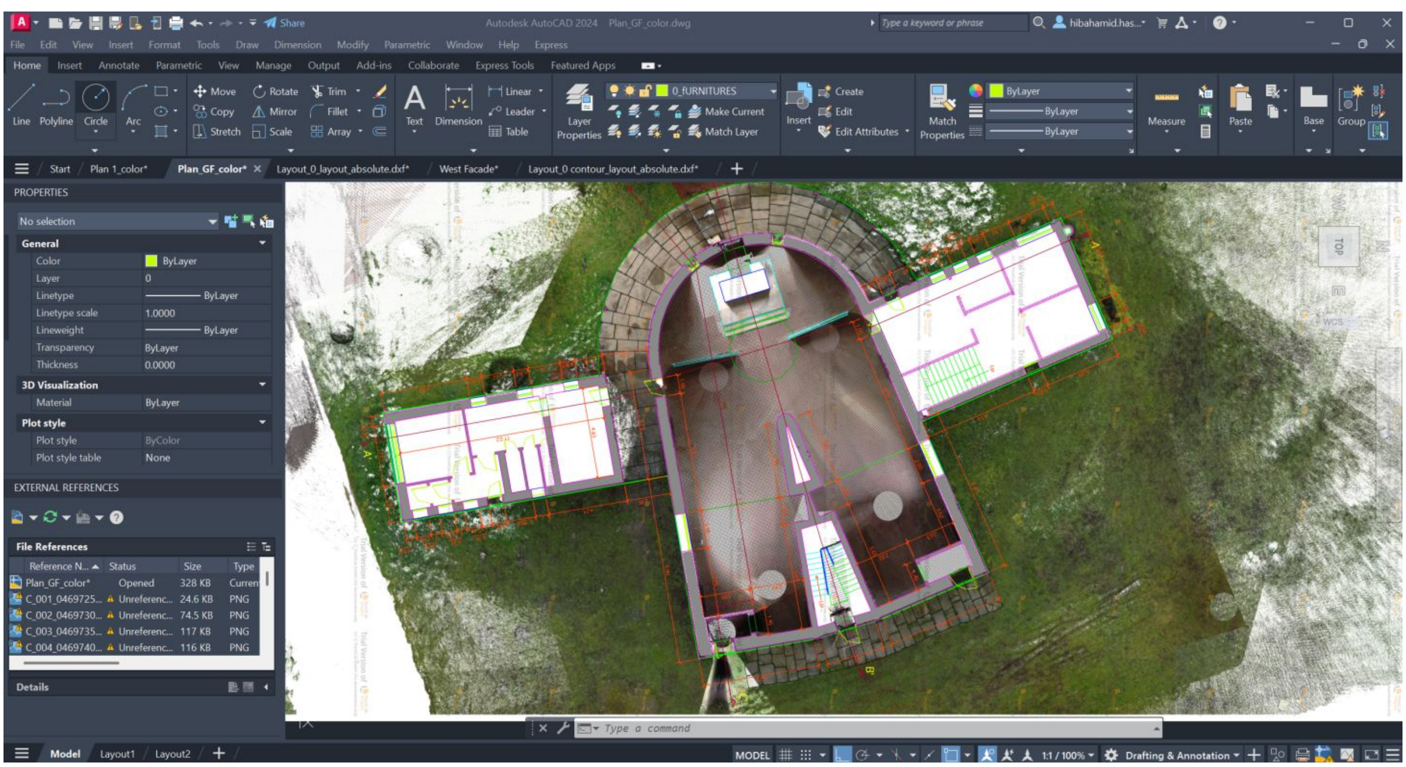


Fig. 8 (below). Digital documentation of plans – depicting the drawing of the layout. Source: Elaboration by the Authors.

Ortho mosaic has been explained in the previous chapter. It was because the higher quality of texture was required to do the roof layout and the point cloud done with Aerial range is more accurate for documenting the texture of the roof. The exported orthomosaic from Metashape is in .jpg or .tif format and it exports a file with coordinates and scale in .jgw format. This file contains the information provided in Table 1 in the same sequence. The reference figures are relevant to the orthomosaic of the roof plan.

1. Pixel Size in the X-Direction:	**0.02** (e.g. meters or feet per pixel)
2. Rotational Term:	**0** (along x-axis)
3. Rotation Term:	**0** (along y-axis)
4. Pixel Size in the Y-Direction:	**-0.02** (negative value if because the origin 0,0 is at the top-left corner in image coordinate system)
5. X-Coordinate of the Upper left corner:	**469708.787**
6. Y-Coordinate of the Upper left corner:	**4976317.362000001**

Tab. 1. The scale and coordinates of the Orthomosaic of Roof from Metashape.

This information helps in importing the orthomosaic in AutoCAD with scale and coordinate by adding the provided data in the .jgw file while importing. The process of this importation of image in CAD is very simple and explained below. First step is to ensure the desired units and limits for the project as a new AutoCAD templete is created for the orthomosaic. Then the image is inserted in the file with the ***Attach*** link in the Insert tab. At this point the .jgw file need to be referred to. While attaching, under the Scale tab, the box of Specify on-screen must be unchecked and the value of ***Width*** under Image size in pixels must be multiplied with the ***Pixel size in X-Direction***. This gives the correct scale of the image. Next, the ***X and Y coordinates*** given in the .jgw file must also be copied in the ***Insertion point*** to ensure the exact placement of the image as per the coordinates. This results in an accurately scaled image which can then be used for digitization. The example of this import is shown in Figure 9. The rest of the process is the same as followed for the rest of the 2D documentation.

1.3 Production of Scaled Drawings

The following section shows the results of the production of drawing is 2D with the help of the process explained above. These drawings are also attached to the Appendix of this thesis at a scale of 1:100. In the drawings where the dashed lines are seen in walls, roofs, floors, and other sectionally cut areas, they depict a hypothesis of those areas. Such as the interior of the two wings which have not been surveyed, the drawings of those parts are depicted in the manner explained above. They are explained in the legend next to the drawings.

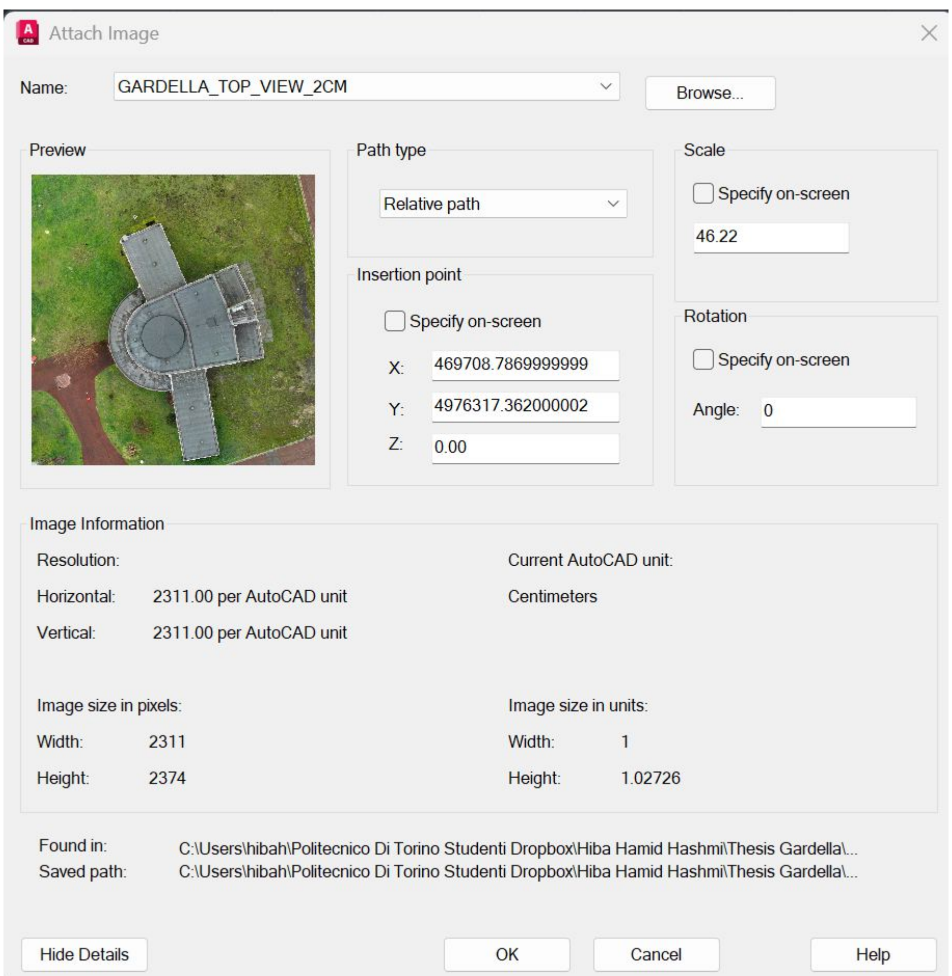


Fig. 9. This image shows the input values in the Attach Image tab while importing the orthomosaic.

Fig. 10. Ground Floor Plan. Source: Elaboration by Authors

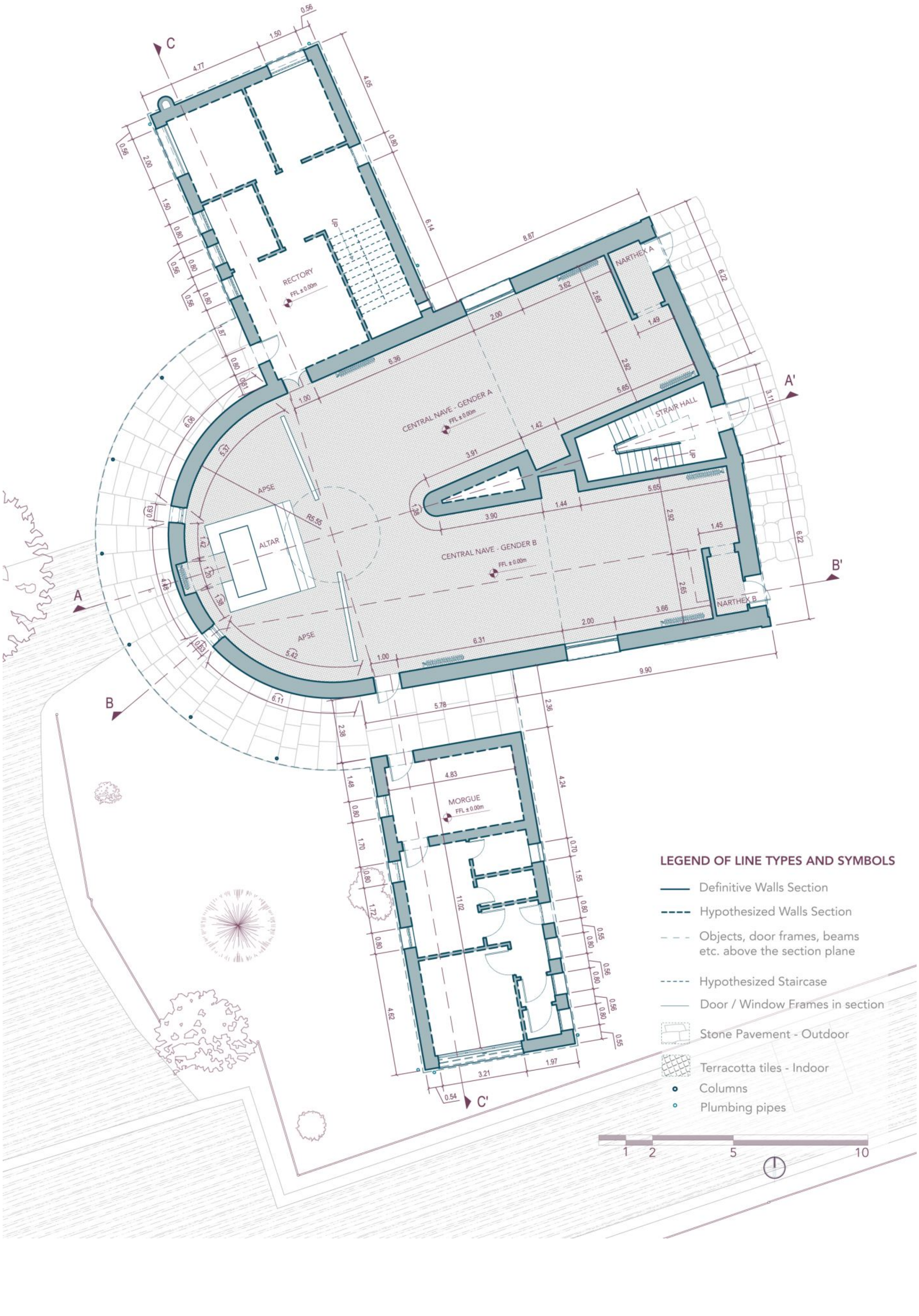


Fig. 11. First Floor Plan. Source: Elaboration by Authors

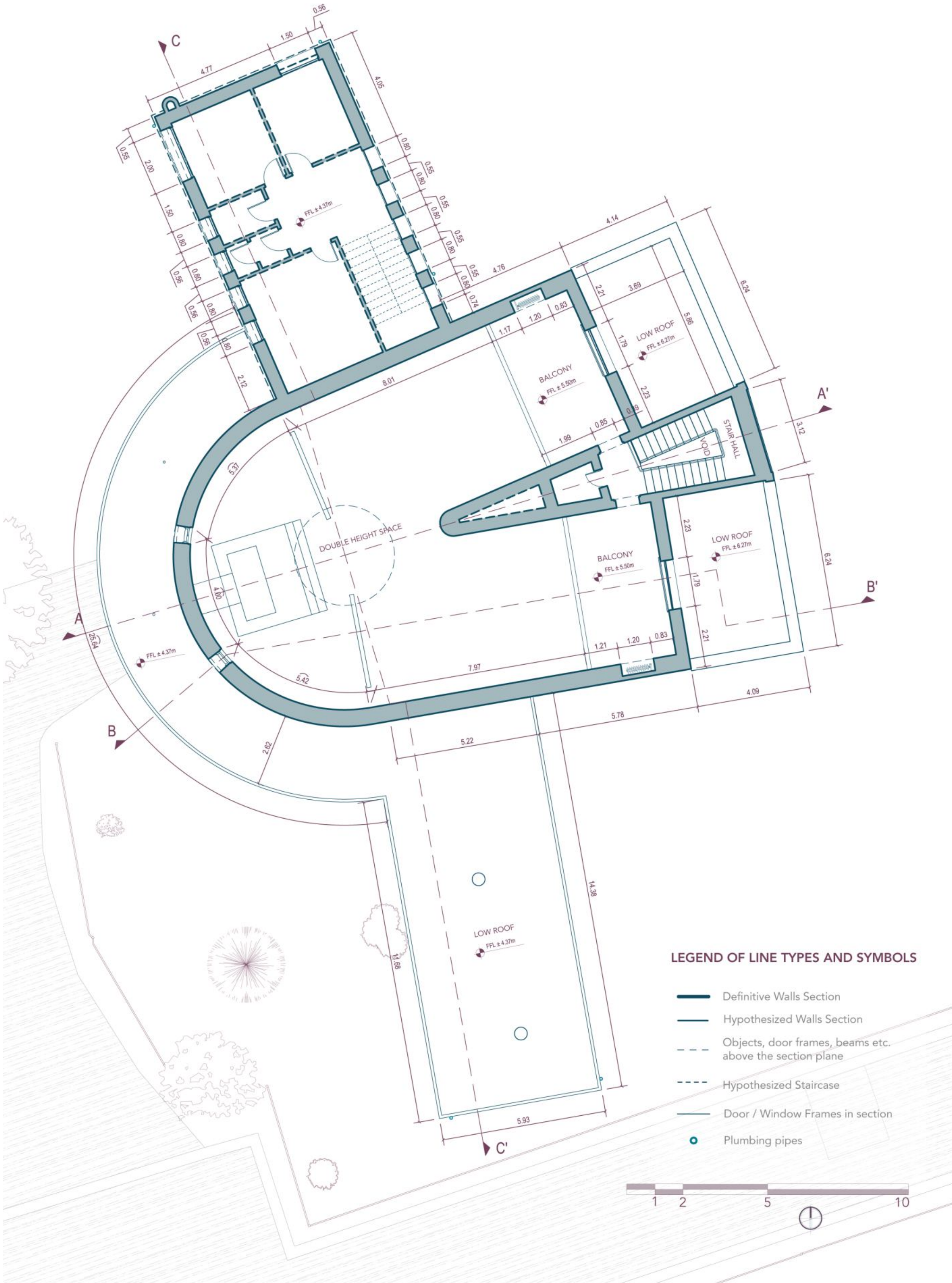


Fig. 12. Roof Plan. Source: Elaboration by Authors

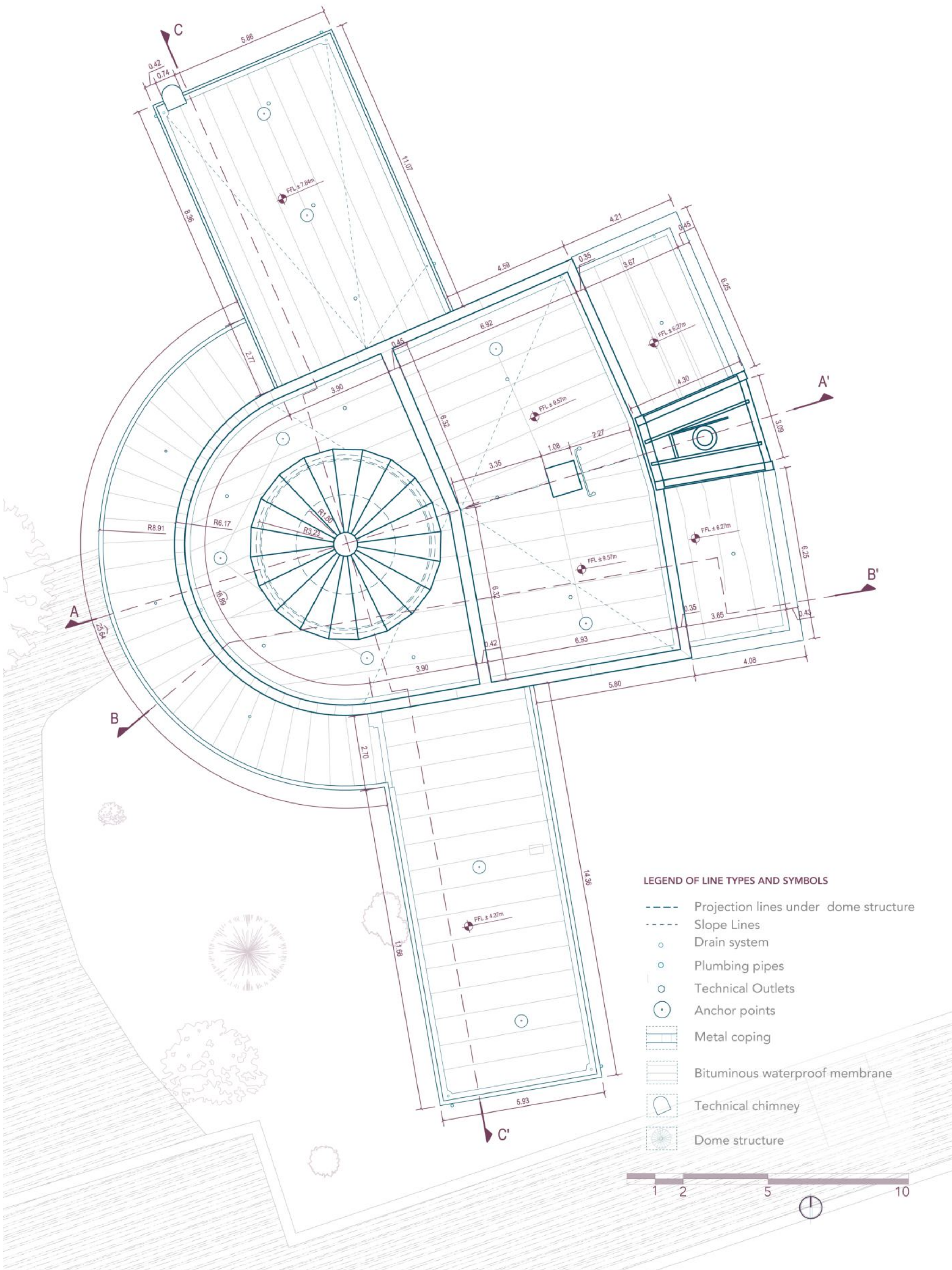


Fig. 13. Section A A' (above: Section from Point cab, below: 2D documentation). Source: Elaboration by Authors.

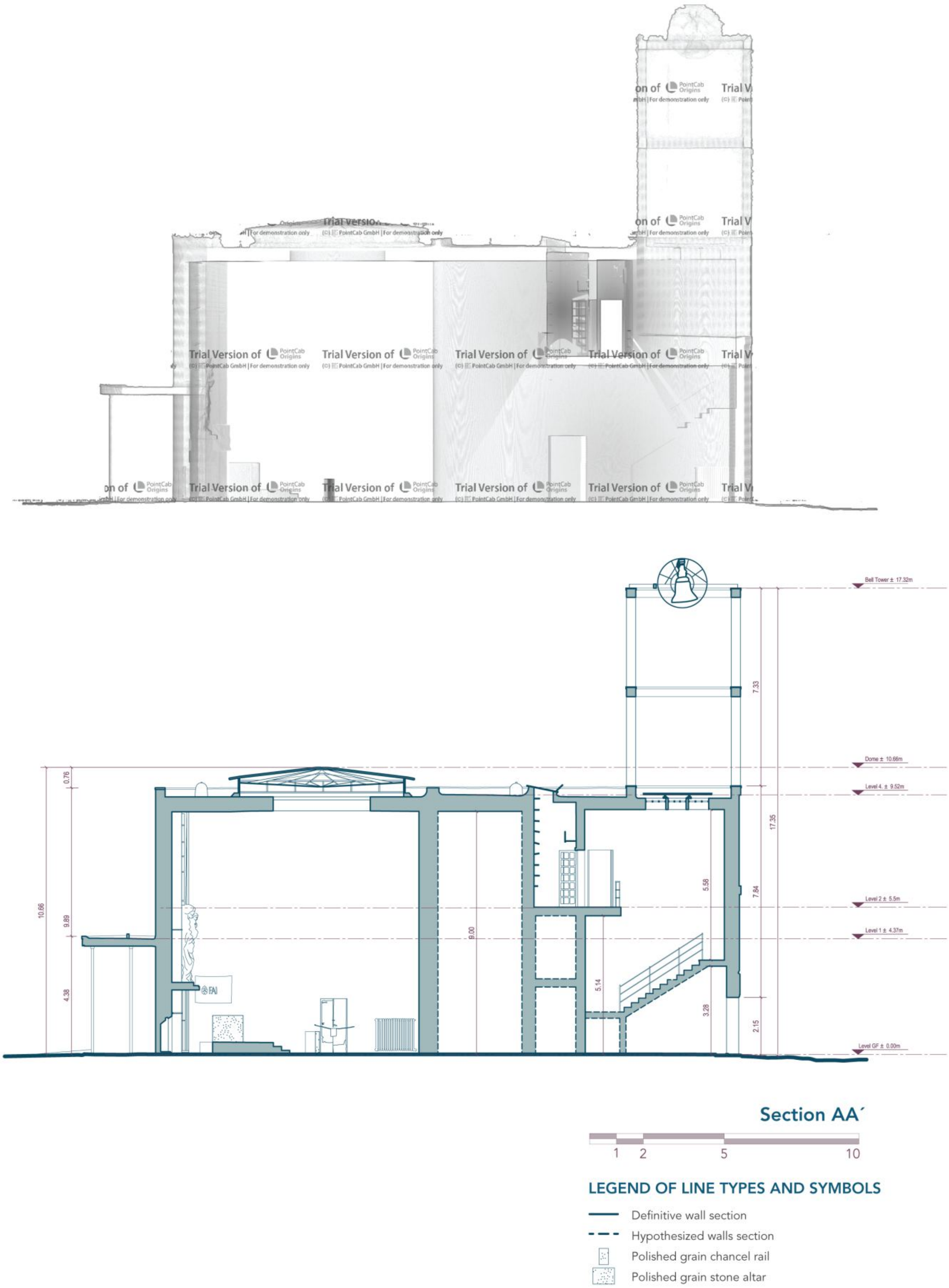


Fig. 14. Section B B′ (above: Section from Point cab, below: 2D documentation). Source: Elaboration by Authors.

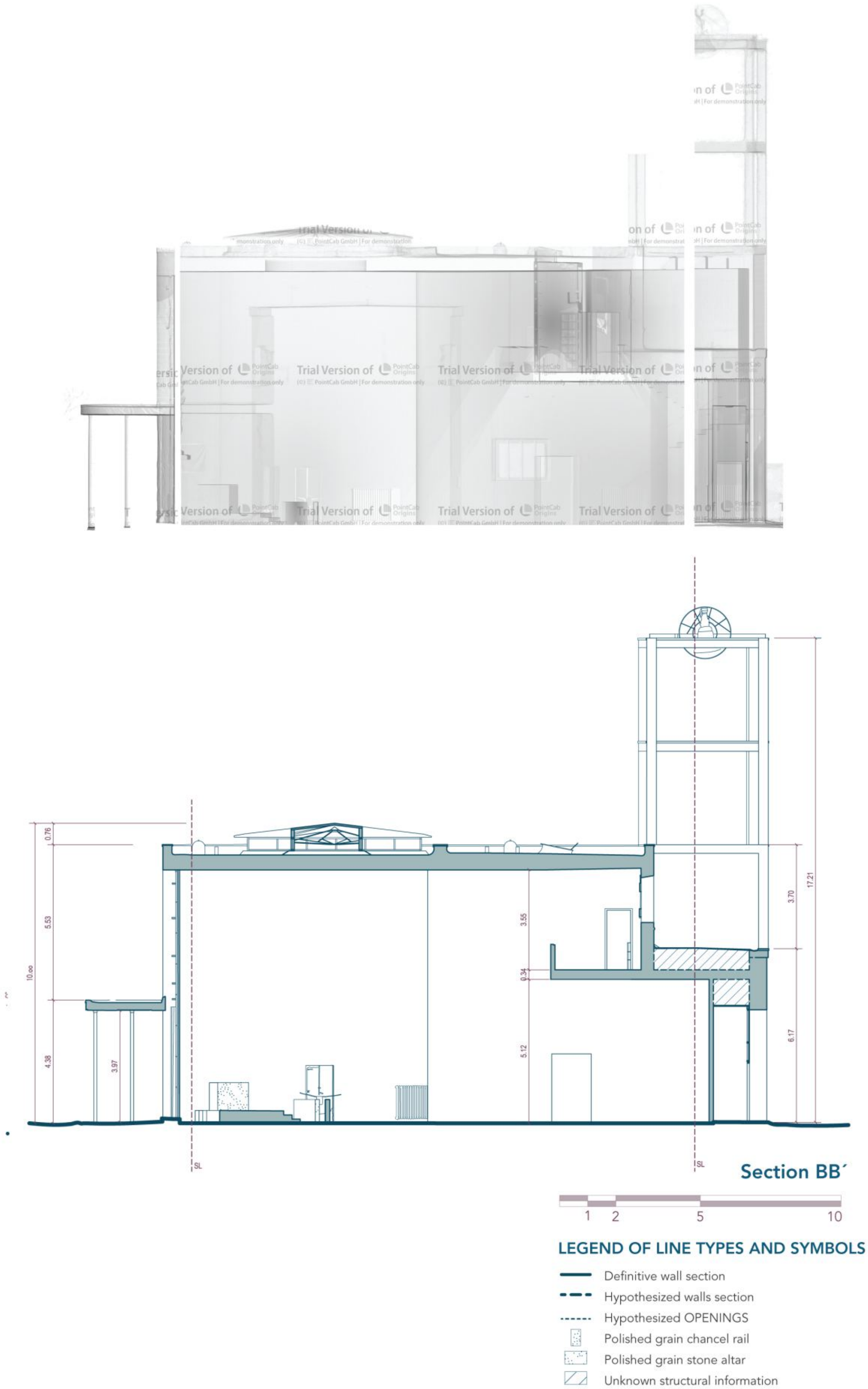
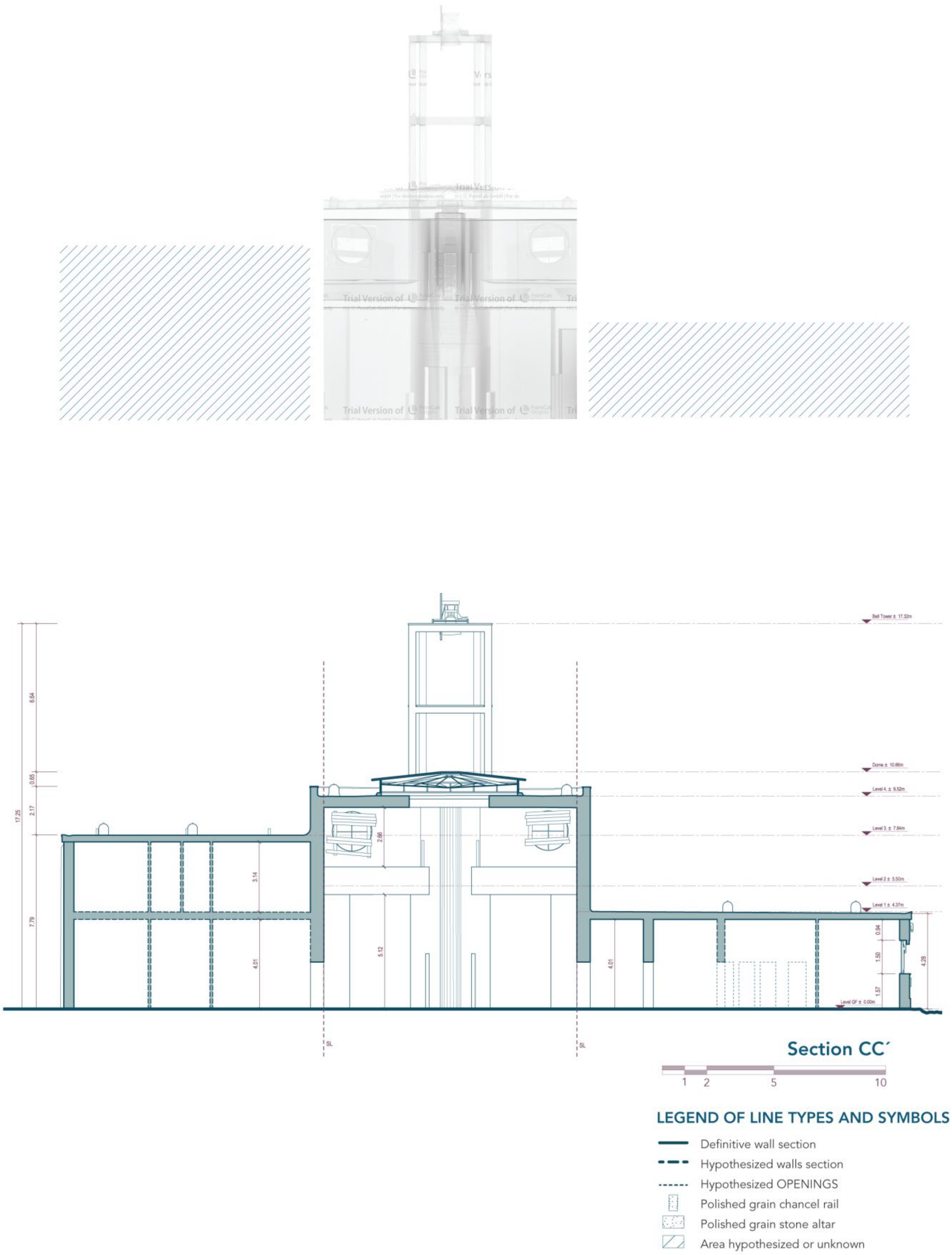


Fig. 15. Section C′ (above: Section from Point cab of the central part, below: 2D documentation). Source: Elaboration by Authors.



3D Modelling with Scan-to-BIM Approach

This section focuses on the Scan-to-BIM approach applied to the creation of a precise and close to accurate HBIM model for Gardella's church. Building on the survey data captured earlier, it highlights the challenges and solutions encountered during the digital modelling of this historically and culturally significant modernist structure. The chapter emphasizes how the unique geometry, and structural complexities of the church were documented and modelled to meet the specific needs of restoration and conservation.

The discussion begins by introducing HBIM and its relevance to restoration projects, particularly in addressing the challenges of capturing irregular geometries and integrating historical material data into a digital format. It then evolves into detailing the methodology, workflow, and technological underpinnings of Scan-to-BIM approach. It will examine the benefits (e.g., precision, data integration, and long-term asset management) and challenges (e.g., data complexity, technical limitations, and cost) of this approach.

The discussion later focuses on how varying Levels of Development (LOD) have an impact on the usability of BIM models. The LOD (100-500) are examined along with their comparison to the Italian LOD standards LOD A-G, providing insight into the alignment of national and international practices. These frameworks are pivotal in determining the resolution and specificity of BIM models, particularly for restoration projects that require a high degree of accuracy.

A critical component of this section is the practical model creation workflow of the Case Study of Gardella's Church. It offers a detailed explanation of how the model of the church was constructed and which plugins were utilized to integrate 3D survey data into a digital 3D model. Key architectural features creation in the model are further explained to illustrate the intricate modelling process.

Finally, the section concludes by presenting the completed 3D model and evaluation of its Level of Accuracy. This evaluation ensures that the digital representation reflects the building's actual condition with precision, aligning with international and local standards. This model not only serves as a detailed archive of the structure but also as a tool for facilitating future restoration work. Through this comprehensive approach, this chapter demonstrates how Scan-to-BIM plays a transformative role in preserving architectural heritage while supporting sustainable restoration practices.

2.1 Definition and Evolution of BIM

Building Information Modelling (BIM) is a transformative process for creating, managing, and sharing data across a building's lifecycle using digital tools and platforms. Modern definitions, such as the one provided by the International Organization for Standardization (ISO 19650-1, 2018) describe BIM as:

"The use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable bases for decisions"[3]

This highlights its role as a collaborative methodology rather than merely a technological tool. To fully understand its evolution, it is useful to compare the current understanding of BIM with earlier definitions, such as the one established by the National Standard-United States Project Committee (NBIMS-US) organization. The NBIMS defined BIM as:

"a digital representation of physical and functional characteristics of a facility, serving as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle, from its inception to demolition"[4]

This definition reflects BIM's evolution into a collaborative framework across disciplines in architecture, engineering and construction (AEC), emphasizing not only the creation of 3D models but also the integration of multidimensional data to streamline decision-making, improve efficiency, and reduce errors.

2.1.1 Foundations of BIM

The origins of BIM date back to the 1970s, when Charles M. Eastman proposed the concept of parametric modeling and object-based building databases. His groundbreaking research about Building Description systems envisioned an environment where different stakeholders could collaborate using shared digital models that automatically updated across all views when changes were made[5]. However, the technological limitations of the time prevented the widespread adoption of these concepts.

3) ISO 19650-1–Part 1. 2018. *ISO 19650 Building Information Modelling (BIM).* British Standards Institution: London, UK. Accessed January 10, 2025. https://www.bsigroup.com/en-VN/bim---building-information-modelling---iso-19650/.

4) NBIMS-US. n.d. *National BIM Standard-United States® Version 3.*, National BIM Standard - United States. Accessed January 2025, 10. https://www.nibs.org/nbims/v3.

5) Eastman, Charles M. 1975. "The Use of Computers Instead of Drawings in Building Design." AIA Journal 63: 46-50.

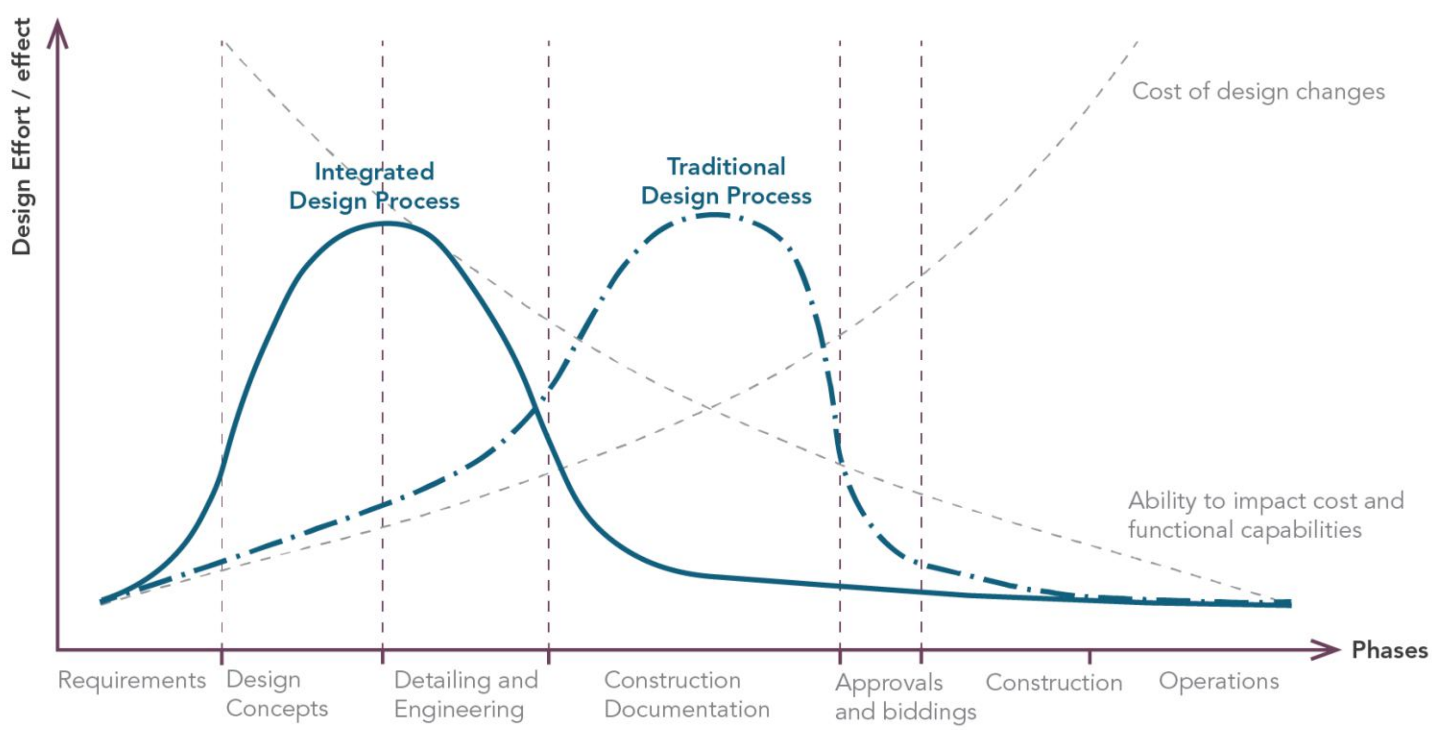
6) Wierzbicki, Madalina, Clarence W. de Silva, and Don H. Krug. 2011. "BIM – HISTORY and TRENDS." International Conference on Construction Applications of Virtual Reality. Weimar: CONVR2011.
7) *Ivi*.

The practical implementation of BIM became feasible in the late 1990s and early 2000s with advancements in computational power and software design. A pivotal moment in BIM's evolution was the release of ***Autodesk Revit*** in 2000, which introduced parametric modeling capabilities and real-time updates across all design views. However, Graphisoft ArchiCAD was one of the pioneer BIM software across the AEC industry[6].

Revit's parametric building components enabled users to create data-rich libraries, allowing integration of material properties, construction schedules, and cost estimates. Furthermore, Revit's compatibility with open standards such as Industry Foundation Classes (IFC) fostered interoperability, enabling seamless Interoperability with other software supporting IFC[7]. This adaptability solidified Revit's role as a core BIM tool in the AEC industry.

The advantages of shifting to BIM were famously highlighted by Patrick MacLeamy of HOK in 2004 through a diagram of an "Effort Curve" demonstrating how the early implementation of BIM shifts critical decision-making to the initial design stages. This proactive approach, according to the curve, minimizes costly changes during later stages of construction when adjustments are more expensive. They emphasized that by resolving design conflicts early and streamlining workflows, BIM not only lowers overall project costs and timelines but also supports lifecycle management, ensuring long-term value in building operations and maintenance.

Fig. 16. The first solid curve shows the itegrated BIM design process, whereas the second dashed-dot curve shows the traditional approach. Source: Patrick MacLeamy 2004, Presentation HOK.



2.1.2 Tools and Applications

Beyond Revit, other BIM platforms have become essential in addressing specific needs withing the AEC industry such as construction, operation and maintenance. Modern BIM platforms integrate diverse datasets, such as energy performance metrics, material specifications, cost schedules, into a single shared model.

Other than Revit, Key BIM tools/software include.

1. **Graphisoft ArchiCAD**: With an intuitive interface and robust capabilities, it excels in creating detailed models and facilitating collaboration among architects and engineers.
2. **Bentley OpenBuildings Designer**: Aimed at infrastructure projects, this tool supports complex, multidisciplinary workflows for large scale developments such as bridges and railways.
3. **Trimble Tekla**: Primarily used in structural engineering, Tekla provides precise modelling capabilities for structural systems in steel, timber or concrete.
4. **Navisworks**: A widely used BIM tool for construction scheduling, Clash detection in shared model, and 4D / 5D simulations.
5. **Dassault Systèmes CATIA**: Originally developed for the aerospace industry, CATIA's parametric design and simulation tools have found applications in Architectural modelling, especially for complex geometries.

BIM has also expanded into new domains such as Historic Building Information Modelling (HBIM), where technologies like LiDAR and photogrammetry are used to document and restore historical structures. Applications of HBIM enable precise modelling of irregular geometries and integration of heritage data, bridging the gap between traditional conservation practices and modern technology.

2.2 Historic Building Information Modeling (HBIM)

Historic Building Information Modeling (HBIM) is a specialized adaptation of BIM, tailored to the documentation, analysis, and preservation of historical buildings. It integrates advanced digital technologies like terrestrial laser scanning, LiDAR, or photogrammetry to create highly detailed as-built 3D models of heritage sites enriched with semantic data about a structure's materials, historical transformations, and condition. HBIM goes beyond visual representation to incorporate non-geometric information, such as material degradation and construction techniques, into parametric object libraries, enabling a comprehensive understanding of historic assets[8].

8) Murphy, Maurice, Eugene McGovern, and Sara Pavia. 2013. *Historic Building Information Modelling – Adding intelligence to laser and image based surveys of European classical architecture.* ISPRS Journal of Photogrammetry and Remote Sensing 76: 89–102. doi:10.1108/02630800910985108.

9) Murphy, Maurice, Eugene McGovern, and Sara Pavia. 2009. *Historic building information modelling (HBIM).* Structural Survey 27 (4): 311-327. doi:10.1108/02630800910985108.

10) Ávila, Fernando, Álvaro Blanca-Hoyos, Esther Puertas, and Rafael Gallego. 2024. *Review HBIM: Background, Current Trends, and Future Prospects.* Applied Sciences 14 (23): 11191. doi:10.3390/app142311191.

11) *Ivi.*

12) Bruno, Nazarena, and Riccardo Roncella. 2019. *HBIM for Conservation: A New Proposal for Information Modeling.* Remote Sensing 11 (15): 1751. doi:10.3390/rs11151751 .

Key challenges in the implementation of HBIM include the lack of standardized guidelines for HBIM workflows, limited parametric object libraries for heritage-specific elements, and the need for multidisciplinary collaboration to handle complex datasets. However, HBIM's ability to combine historical accuracy with modern technological precision makes it an indispensable tool for the preservation of cultural heritage, ensuring its relevance for future generations.

2.2.1 Early Development

HBIM was first conceptualized by Maurice Murphy et al. in 2009 with a publication on Historic Building Information modelling[9]. This publication defined HBIM as a system for documenting historic structures using 3D surveying methods as opposed to traditional survey methods especially for historical sites. Early applications of HBIM included Murphy's 2012 PhD dissertation on cultural heritage buildings in Ireland, which developed interactive parametric 3D object libraries with detailed construction and material information[10].

During the 2010s, other researchers also explored HBIM techniques, including reconstructing, architectural geometry, creating parametric object libraries for classical architecture, and developing software for processing parametric data. By 2015, interest in HBIM surged, driven by the need for heritage conservation, advances in 3D modeling, and growing recognition of HBIM as a tool for managing, analyzing, and preserving built heritage[11].

2.2.2 International and Italian Implementation of HBIM

The implementation of HBIM is underpinned by international standards that ensure interoperability, data accuracy and consistency in heritage documentation and management. For this, IFC Industry Foundation Classes, an open standard developed by buildingSMART International, play a great role in the exchange of BIM data across different software platforms.

The ISO 19650 series, which provides global standards for managing information over a building's lifecycle, is widely used in HBIM projects. Although ISO EN 19650 was developed with contemporary BIM in mind, its principles have been adapted for heritage contexts, particularly for managing complex datasets and ensuring traceability of historical information.

Implementation in Italy has been a leader in HBIM innovation, leveraging it vast architectural heritage and legislative frameworks. The ***UNI 11337:2017 standard***, an extension of ***ISO 19650***, introduced specific Levels of Development (LOD) tailored for Heritage buildings[12].

For example:

LOD F: focuses on documenting as-built conditions, including management and maintenance plans

LOG G: Captures the evolution of heritage assets over their lifecycle, incorporating data on maintenance, restoration, and structural decay.

(More on LOD and their concepts will be discussed in the next topic)

These levels provide a theoretical framework for heritage asset documentation, but specific guidelines for descriptive fields and implementation are still under development[13]. Discuss that the Italian researchers have also worked on ontologies and shared libraries for classical architectural elements, such as Romanesque buildings, to standardize heritage modeling practices. However, there are still challenges to overcome for the full implementation of HBIM and Italy is one of the countries trying to advance in this research.

13) *Ivi.*

14) Bruno, Nazarena, and Riccardo Roncella. 2018. *A Restoration Oriented HBIM System for Cultural Heritage Documentation: The Case Study of Parma Cathedral*, ISPRS TC II Mid-term Symposium. Riva del Garda, Italy: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. doi:10.5194/ISPRS-ARCHIVES-XLII-2-171-2018.

15) Lin, Guiye, Guokai Li, Andrea Giordano, Kun Sang, Luigi Stendardo, and Xiaochun Yang. 2024. *Three-Dimensional Documentation and Reconversion of Architectural Heritage by UAV and HBIM: A Study of Santo Stefano Church in Italy*. Drones 8 (6): 250. doi:https://doi.org/10.3390/drones8060250.

2.2.3 Case studies

a.Cathedral of Parma, Italy

In a study by[14], the HBIM modeling process is utilized for the study of Parma Cathedral. They have utilized an integrated methodology to address its historical complexity, structural issues, and material decay. The first step involves surveys combining terrestrial laser scanning, photogrammetry, and topography for detailed data acquisition, with TLS as the primary method and orthophotos linked for façade mapping. A hybrid modeling approach in Autodesk Revit balanced precision and efficiency, using parametric modeling for standard elements and mesh integration for irregular details, with degradation data and orthophotos directly linked to the model.

Metadata played a critical role in, with a customized database documenting survey method, modeling accuracy, and historical data, ensuring transparency and supporting conservation planning. A Revit plug-in (name not mentioned) enabled 2D and 3D thematic mapping, enriching the model's use for material decay and restoration analysis.

While it is a novel approach to map decay, it works for 2D details better than 3D and does not work well with curved or irregular surfaces.

b.Santo Stefano Church, Voltera, Italy

A case study done by[15] represents a landmark application of HBIM in creating a detailed 3D model for heritage conservation. This project utilized cutting-edge Unmanned Aerial Vehicles UAVs for photogrammetric data acquisition and integrated it with HBIM processes to develop a comprehensive digital twin of the structure. The “close + surround” oblique photography technique was employed, allowing the team to generate an extensive 3D point cloud model of the church.

The resulting HBIM model incorporates not only geometrical data but also incorporates historical references, parametric libraries, and material information to enrich the digital representation. The digital twin was further integrated into a virtual reality VR environment, enabling immersive visualizations that enhanced both conservation planning and public engagement. This innovative approach facilitated a highly accurate reconstruction of the church's original appearance, while preserving key architectural elements and spatial relationships.

The authors conclude that the integration of UAV photogrammetry and HBIM offers an efficient, cost effective, and non-invasive solution for heritage conservation. The project demonstrated HBIM's potential to merge accurate documentation with historical interpretation, offering a comprehensive framework for preserving and digitally reconstructing endangered heritage sites.

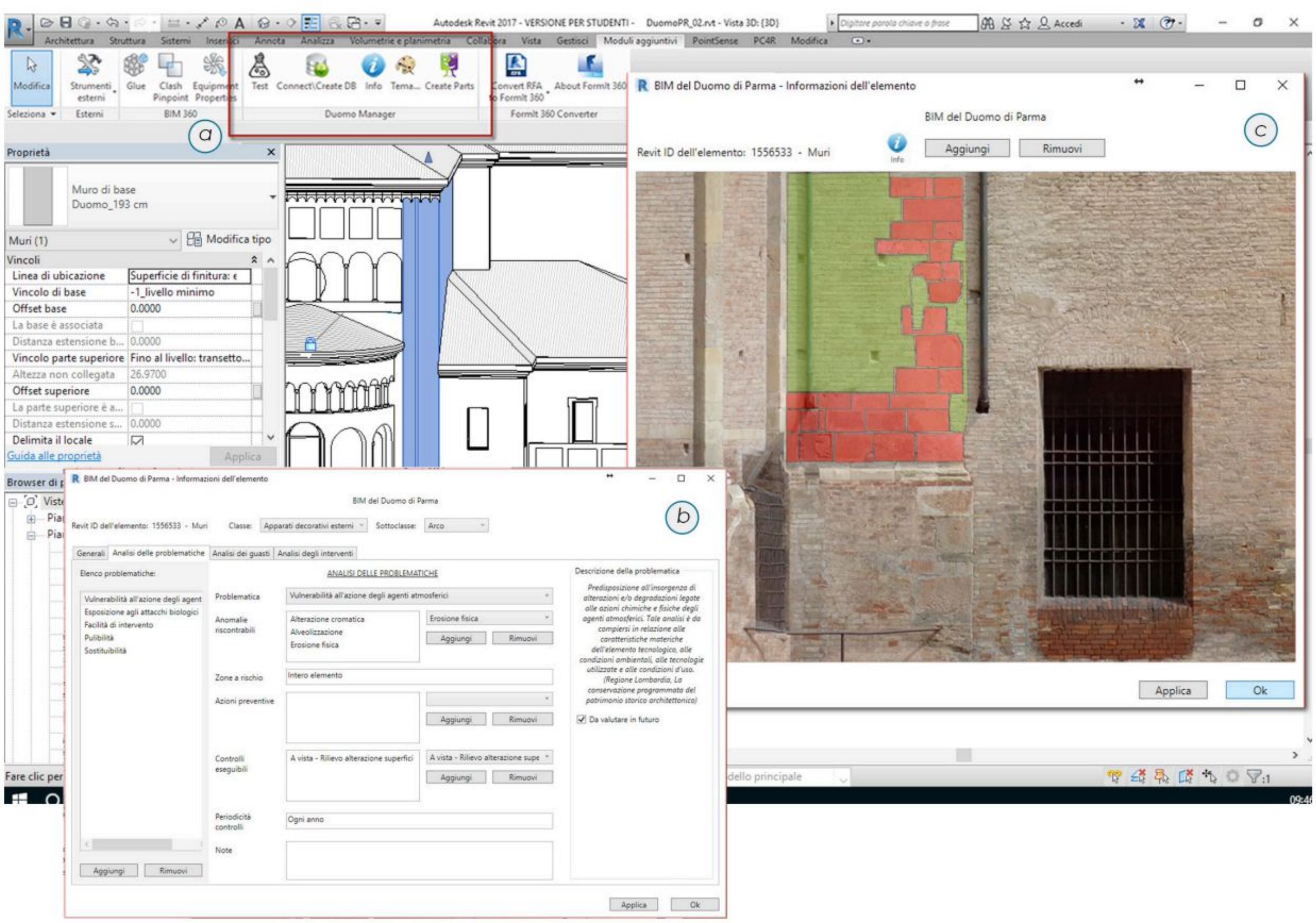


Fig. 17. Case Study of Parma Cathedral - Implemented interfaces. a. Revit ribbon panel with additional features, b. Consultation of data associated with the BIM element, c. Creation of material-pathological mappings (in 2D).
Source: Bruno & Roncella, A Restoration Oriented HBIM System for cultural heritage documentation: The Case Study of Parma Cathedral 2018.

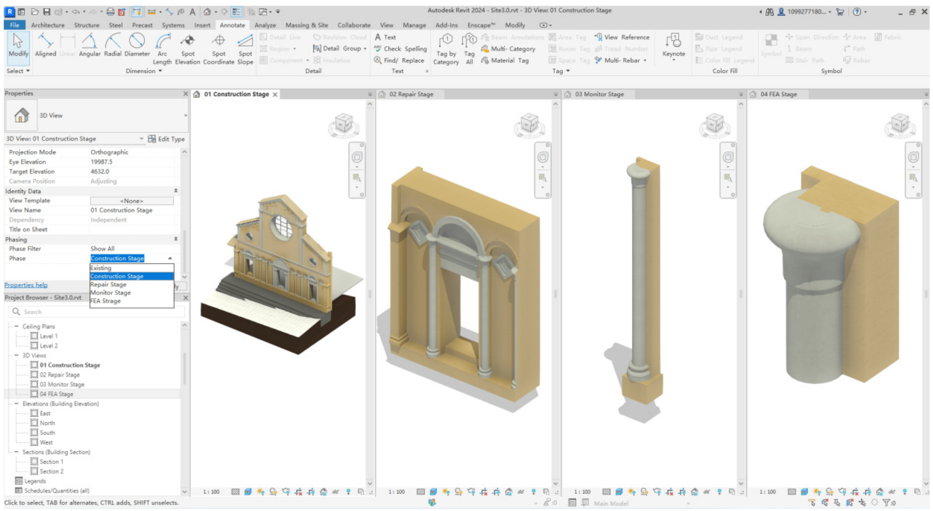
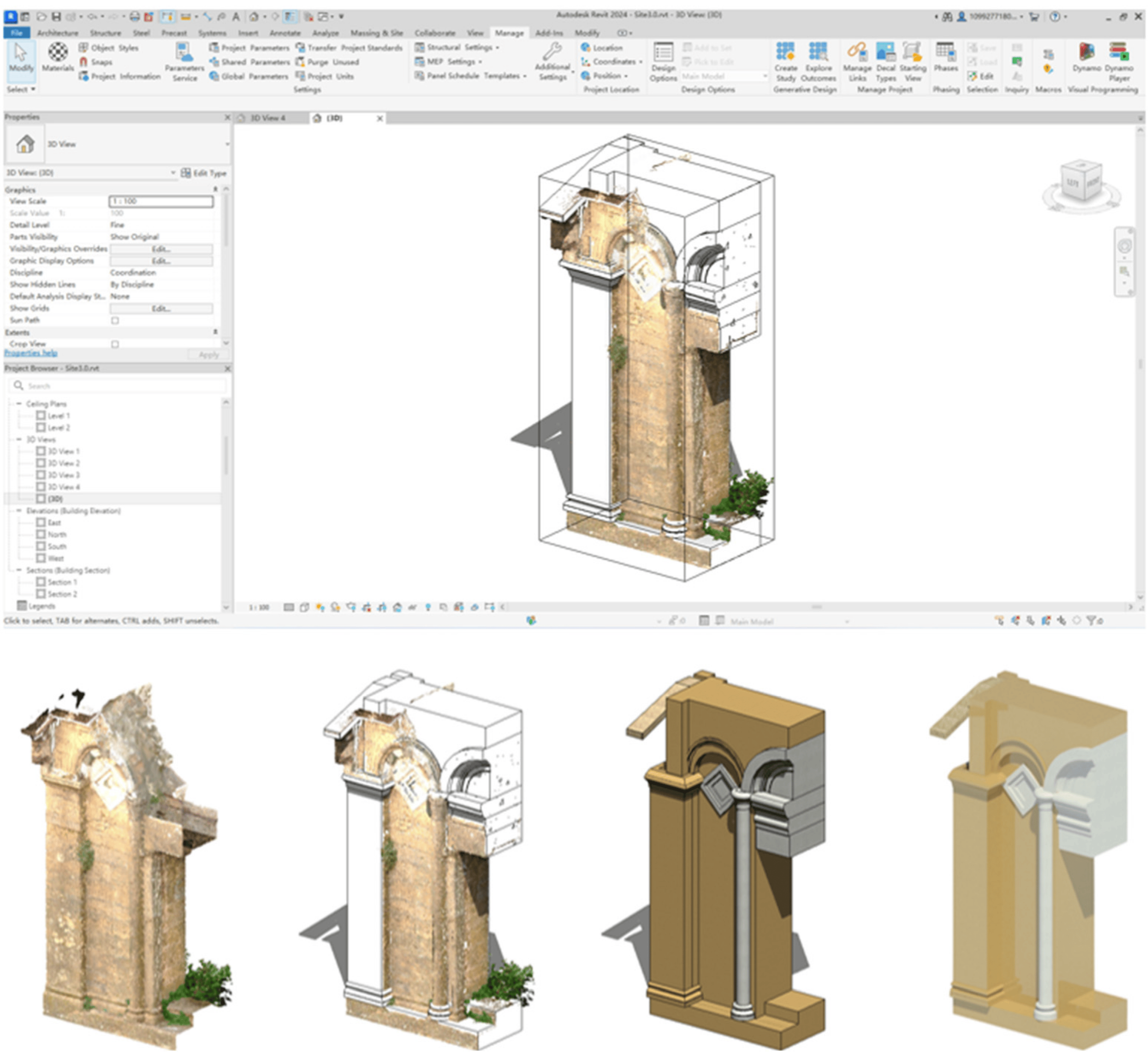


Fig. 18. Santo Stefano Church, Voltera – This image shows an idealized repair process. The phases parameter has been added to the project properties.

Fig. 19 (below). HBIM family library of the Santo Stefano Church. Sources Figure A & B : Lin, Guiye, Guokai Li, Andrea Giordano, Kun Sang, Luigi Stendardo, and Xiaochun Yang. 2024. *Three-Dimensional Documentation and Reconversion of Architectural Heritage by UAV and HBIM: A Study of Santo Stefano Church in Italy.*



16) Valero, Enrique, Frédéric Bosché, and Martin Bueno. 2022. *Laser Scanning for BIM*, Journal of Information Technology in Construction (ITcon) 27: 486-495. doi:10.36680/j.itcon.2022.023.
17) Angeloni, R., C. Mariotti, L. Petetta, and L. Coppetta. 2023. *Enabling Scan-to-BIM Workflow For Heritage Conservation And Management Process.* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLVIII-M-2: 79–86. doi:10.5194/isprs-archives-XLVIII-M-2-2023-79-2023.
18) Badenko, V., A. Fedotov, D. Zotov, S. Lytkin, D. Volgin, R. D. Garg, and Liu Min. 2019. *Scan-to-BIM Methodology Adapted for Different Application.* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII-5/W2: 1-7. doi:doi.org/10.5194/isprs-archives-XLII-5-W2-1-2019.

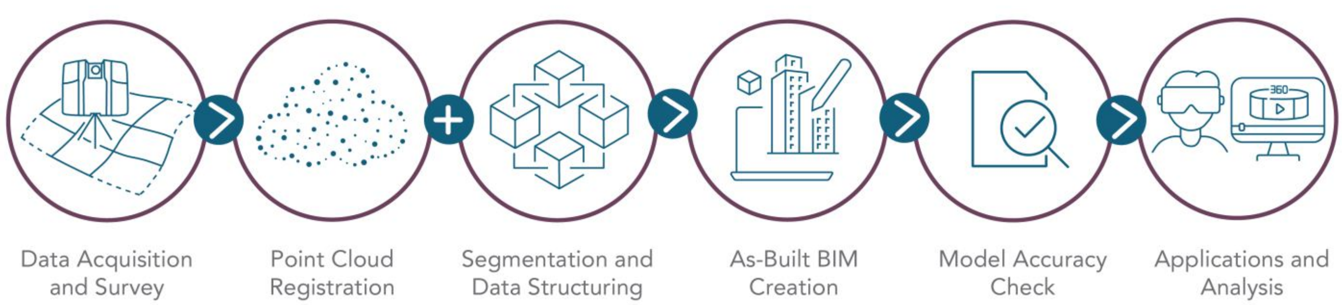
2.3 Concepts of Scan-to-BIM

Scan-to-BIM refers to a systematic process of capturing the existing / as-built conditions of a building or structure through advanced 3D scanning technologies and converting the resulting data into a detailed Building Information Model. This is carried out with the help of point clouds imported in the BIM software and using that as a reference for 3D model generation. At present, the practice of Scan-to-BIM is mainly manual, however, there has been research to automate the process[16]. This can be seen with the advancement of Plugins for Revit, such as the As-Built modeler, which somehow automates the process of creating elements. However, it still lacks a greater library of architectural elements and works mostly with simpler details, such as walls (straight), doors, and windows. It does not provide much flexibility in automated workflow but works well if the building geometry is simpler.

The process of Scan-to-BIM integrates digital survey data, semantic annotations, and information modeling to enable precise conservation and management processes for architectural heritage. Several approaches have been utilized and proposed by researchers to streamline the data enrichment of historic buildings especially in form of annotations or queries[17]. The as-built models created using the Scan-to-BIM approach are highly accurate, often reaching millimeter precision, which is essential for both historical and industrial applications. These techniques facilitate in the creation of digital twins for existing assets, which serve as comprehensive repositories of geometric and attribute data for future use[18].

Despite these advantages, the process is labor-intensive and often requires substantial manual intervention, particularly during data post-processing and model creation. Challenges such as interoperability between software platforms and the need for high computational resources are significant barriers. However, its application in a heritage project bridges the gap between traditional documentation methods and advanced digital tools, ensuring the heritage assets are faithfully represented and digitally archived for future generations.

Fig. 20. Typical Workflow of Scan-to-BIM approach. Source: Elaboration by Authors.



2.3.1 Overview of the Workflow

A typical Scan-to-BIM workflow follows a structured sequence of stages ensuring that the transition from raw scan data to a functional BIM model is efficient and accurate. Based on various methods described in literature, the stages mentioned here are based on the studies by Angeloni, et. al. and Badenko *et. al.*. However, it is also clear from different publications that every researcher has used their own method. Some typical steps are mentioned below.

1. Data Acquisition

Digital survey carried out by integrating different data capturing technologies such as Laser Scanners, UAV based photogrammetry, LiDAR etc. This step ensures comprehensive coverage of the structure, including hard-to-reach or deteriorated areas.

2. Point Cloud Registration and Cleaning

This step involves merging multiple scans into a unified point cloud. This alignment ensures that the individual datasets from different scan positions are accurately combined. As in our case, it was done using Cloud Compare.

3.Segmentation and data structuring

This is a critical step, which can be useful in large or complex projects. It is the segmentation of a unified point cloud into meaningful components corresponding to building elements, such as roof, walls, floors, windows etc. It is also the conversion of the coordinate system into a required coordinate system. This process can simplify or streamline the process.

4.As-Built BIM Creation

The unified point clouds or the segmented component of the point clouds are imported into BIM software, where they are used to create parametric objects that represent the building's physical and functional components. Semantic information is also added here, such as historical records, material properties, degradation patterns etc.

5.Validation and Accuracy Checks

To ensure the fidelity of the model, the BIM is validated against the original point cloud through a deviation analysis. This gives us the accurate level of accuracy in the model

6.Application and Analysis

The finalized HBIM can be used for a wide range of applications, such as restoration planning, simulating interventions, analyzing sustainable strategies etc. It can also be employed for public engagement through VR and AR platforms.

2.3.2 Level of Development and its Role in BIM

Level of Development LOD

The Level of Development (LOD) in Building Information Modeling is a structured system used to define the maturity, detail, and reliability of elements in a digital model. Introduced by the American Institute of Architects (AIA) in 2008, and further refined by BIMForum, LOD serves as a standardized framework ensuring consistency in information exchange across different stakeholders. LOD is essential for managing the progressive evolution of BIM elements, from conceptual design to construction and facility management[19].

LOD integrates two fundamental aspects:

Level of Geometry LOG: Defines the graphical complexity and visual representation of a BIM element at different stages of development. It ensures that the level of graphical detail matches project requirements[20].

Level of Information LOI: Encompasses non-geometric data, such as material properties, maintenance schedules, costs, and historical information. LOI enhances the model's functionality, making it useful beyond construction for asset management and facility operations[21].

Together, LOG and LOI create the LOD system, which defines both graphical detail and associated metadata required at different project phases.

It must be noted that the LOD Frameworks have variations in different countries. The US uses AIA/BIMForum Level of Development system which is from LOD 100 – LOD 500. Whereas the United Kingdom uses BS 1192 and PAS 1192 Level of Detail which is from LOMD 1 to LOMD 7. In Italy. The classification is based on UNI 1137 standard which is from LOD A – G.

While these frameworks share common principles, each country has adapted LOD classifications to suit regional standards, industry needs, and regulatory environments.

Role of LOD in BIM

a.Standardized Communication and Coordination

LOD serves as a unified reference framework that ensures all stakeholders – architects, engineers, contractors, and facility managers – are working with consistent expectations about the accuracy, completeness, and usability of BIM elements. This eliminates miscommunication, aligns project objectives, and enhances collaboration throughout the building life cycle[21].

b.Improved Design Accuracy and Clas Detection

As LOD progresses, LOG becomes increasingly refined, improving spatial accuracy and enabling clash detection in multi-disciplinary models. By LOD 350, detailed connections between structural, architectural, and MEP (Mechanical, Electrical, Plumbing) elements are defined, minimizing conflicts before construction begins.

19) Gigante-Barrera, Angel, Darshan Ruikar, Soroosh Sharifi, and Kirti Ruikar. 2018. *A grounded theory based framework for level of development implementation within the information delivery manual*. International Journal of 3-D Information Modeling 30-48. doi:10.4018/IJ3DIM.2018010103.

20) Brumana, R., S. Della Torre, M. Previtali, L. Barazzetti, L. Cantini, D. Oreni, and F. Banfi. 2018. *Generative HBIM modelling to embody complexity (LOD, LOG, LOA, LOI): surveying, preservation, site intervention—the Basilica di Collemaggio (L'Aquila)*. Applied Geomatics 10: 545-567. doi: https://doi-org.ezproxy.biblio.polito.it/10.1007/s12518-018-0233-3.

21) *Ivi*.

22) Alshorafa, Raif, and Esin Ergen. 2021. *Determining the level of development for BIM implementation in large-scale projects - A multi-case study*. Engineering, Construction and Architectural Management 28 (1): 397-423. doi:10.1108/ECAM-08-2018-0352.

c.Improved Cost Estimation and Scheduling (5D BIM)

By integrating LOD with 5D BIM, cost estimation becomes more accurate. LOD 300-400 allows for detailed quantity take-offs, enabling precise budgeting and efficient construction scheduling. This progressive approach reduces financial risks and enhances project planning[23].

d.Lifecycle and Facility Management (6D & 7D BIM)

At LOD 500, BIM models serve as digital twins, incorporating as-built geometry and enriched information for facility management and maintenance planning. As the study by Charef, Alaka and Emmit[25] suggests that this allows building owners to:

- Track component lifespan and replacement schedules
- Improve energy efficiency and sustainability monitoring
- Optimize long-term asset management
- Building performance monitoring

The diagram below shows the Dimensions of BIM which are widely recognized all over the world. These are spread across all the Level of Developments and provide a multi-dimensional ecosystem to incorporate project's geometry, schedule, cost, sustainability, asset and facility management. While expanding beyond these dimensions incorporating safety, light construction and AI or automation.

23) Alshorafa, Raif, and Esin Ergen. 2021. *Determining the level of development for BIM implementation in large-scale projects - A multi-case study.* Engineering, Construction and Architectural Management 28 (1): 397-423. doi:10.1108/ECAM-08-2018-0352.

24) Wood, Jamin, and Kriengsak Panuwatwanich. 2014. *Using LOD in Structural Cost Estimation during Building Design Stage: Pilot Study.* Procedia Engineering 85: 543-552. doi:https://doi.org/10.1016/j.proeng.2014.10.582.

25) Charef, Rabia, Hafiz A. Alaka, and Stephen Emmitt. 2018. *Beyond the Third Dimension of BIM: A Systematic Review of Literature and Assessment of Professional Views.* Journal of Building Engineering 19: 242-257. doi:10.1016/j.jobe.2018.04.028.

26) BIMForum. 2024. *Level of Development (LOD) Specification.* BIMForum.org. Accessed 1 10, 2025. https://bimforum.org/resource/lod-level-of-development-lod-specification/.

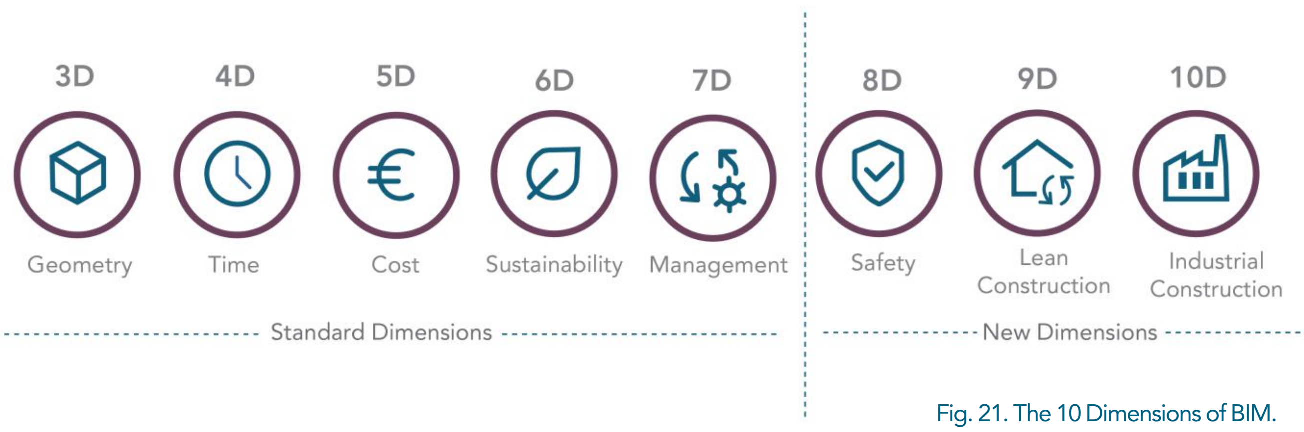


Fig. 21. The 10 Dimensions of BIM.

2.3.3 Explanation of LOD Stages

Levels of Development are divided into various stages and there are different frameworks developed by regions based on local requirements.

LOD Stages in the US (AIA/BIMForum)

It consists of six progressive levels defining the accuracy, geometry, and metadata of BIM elements. The following are the explanations as per the[26].

1. **LOD 100 (Conceptual Design)** – Basic volumetric representations without specific details of dimensions
2. **LOD 200 (Schematic Design)** – Approximate information regarding dimensions, placements (location), quantity, shape and orientation are included. They include correct positioning of the fixtures.
3. **LOD 300 (Detailed Design)** – an as designed model, it has the precise geometry with measurable information regarding quantity, size, shape, location and orientation. These should fully convey the design intent of the project
4. **LOD 350 (Coordination and Connections)** – As-Designed geometry, and similar components to LOD 300 with the addition of detail that supports construction-level coordination and includes interfaces between building components.
5. **LOD 400 (Fabrication and Assembly)** – Model containing sufficient details for fabrication. They are developed including the details up to the level of shop drawings.
6. **LOD 500 (As-Built Model and Facility Management)** – Fully verified model reflecting actual construction for lifecycle maintenance

LOD Stages in Italy (UNI 11337:2017 – LOD A-G)

Italy's LOD classification integrates European Union regulations and historical conservation needs. Unlike the US and UK, Italy's LOD system is highly tailored for heritage and adaptive reuse projects. The explanations below are adapted from the presentation of Alberto Pavan and from the BIM guide from ACCA website.

1. **LOD A (Symbolic Object)** – Graphical representation of a geometric system or a generic representation, without geometric constraints. The quantitative and qualitative characteristics are like LOD 100
2. **LOD B (Generic Object)** – Entities are virtually realized in generic or geometric system with approximated size, shape, performance, location, orientation etc.
3. **LOD C (Generic defined object)** – The entities are visually represented as a structured geometric system. Their quantitative and qualitative attributes – such as performance, size, shape, location, orientation, and cost – are defined in a standardized manner, ensuring compliance with current legislation and relevant technical standards.
4. **LOD D (Detailed Items)** – Virtual representation of entities in a geometric system with attributes of quantities and qualities specified for a defined set of similar products. Comparable to LOD 300 - 350

5. **LOD E (specific Object)** – Entities with qualitative and quantitative characteristics specific to a single production system linked to the defined product. It contains the details related to manufacturing, assembly and installation.
6. **LOD F (Object as Executed)** – The objects represent a verifies virtualization of the specific production system as executed or constructed (as-built). Their quantitative and qualitative characteristics - such as size, shape, location, orientation, and cost - correspond to the exact specifications of the installed or placed product. For each individual product, management, maintenance, repair and replacement actions are defined to be carried out throughout the entire life of the project.
7. **LOD G (Updated Object)** – Objects represent the updated virtualization of an entity's actual state at a specific point in time. This serves as a historical record of the lifecycle of a given production system, reflecting modifications from it originally executed, constructed, or installed state.

All quantitative and qualitative characteristics are updated in accordance with lifecycle and previous conditions.

Each significant repair, maintenance or replacement etc. performed over time is documented in the virtual environment – making the model it a digital twin.

27) Abualdenien, Jimmy, and André Borrmann. 2022. *Levels of Detail, Development, Definition, and Information Beed: A Critical Literature Review*. Journal of Information Technology in Construction (ITcon), Special issue: *The Eastman Symposium* 27: 363-392. doi:10.36680/j.itcon.2022.018.

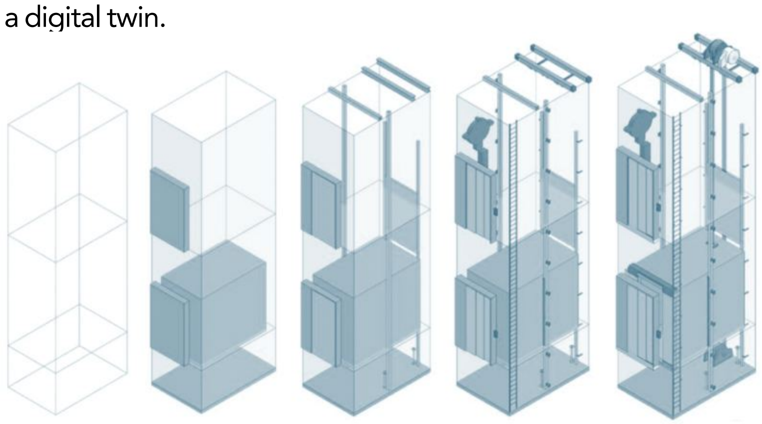


Fig. 22. Progress of Design across AIA LODs taking the example of an elevator. An adaptation modeled according to the BIMForum's Specifications by Abualdenien and Borrmann[27].

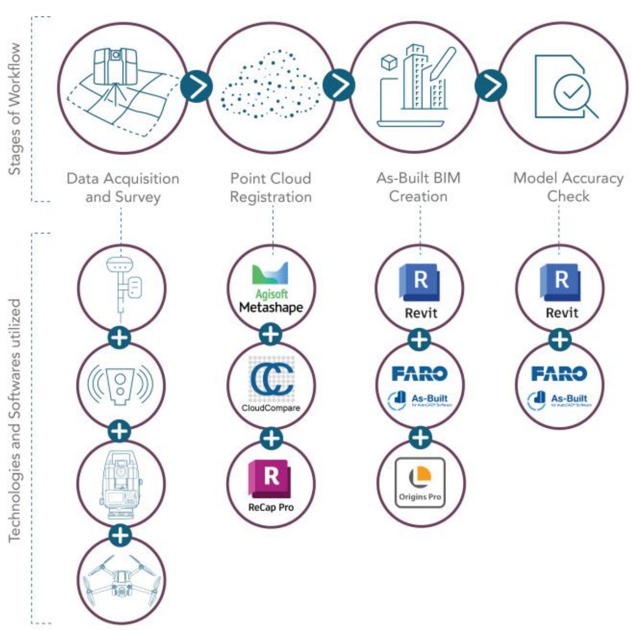
	LOD A	LOD B	LOD C	LOD D	LOD E	LOD F	LOD G
Geometry of Vertical or pseudo-vertical architectural element	Element represented by a 2D symbol	Generic solid for representation of vertical or pseudo-vertical architectural element with shape, thickness and approximate	Element was represented with dimensions calculated according to the technical regulation	Element represented by a solid with real dimensions. Modeled stratigraphies	Element represented by a solid with real dimensions. Including stratigraphies specific data on materials and finishes.	Wall object	Wall object
Object	2D graphic	3D solid	Structured 3D solid	Complex 3D solid	Complex 3D solid	Solid complete wall	Solid wall
Characteristics	Approximate positioning	Simple overall dimensions	Thickness, length, width, volume, definition of materials	Definition of detailed stratigraphies thicknesses, structure, insulation, inner tube	Internal and external finishing type, internal and external finishing surface	Maintenance manual, Classification (UNI 8290, CSI, etc.), Product certification	Maintenance data

Fig. 23. Level of Development UNI 11337 – 2017. Source: Modified by Alberto Pavan.

Fig. 24. Scan-to-BIM Workflow for the Case Study (demonstrating the stages of Workflow and the tools utilized, from 3D surveying to HBIM). Source: Devised by the Authors.

2.4 Model Creation Workflow

The process of creating the 3D in HBIM requires a well-structured workflow that integrates point cloud data, modelling software, and specialized plugins to ensure accuracy and historical fidelity. For this project, **Autodesk Revit 2024** was chosen as the primary modelling tool due to its versatility in architectural modelling and ability to integrate point cloud data efficiently. However, given that Revit does not support all the point cloud formats, additional software tools were used to facilitate data conversion and enhance the modelling process.



The point cloud data, initially processed in **CloudCompare**, however, the formats of export from this software are not interoperable with Revit. For this reason, the Autodesk ReCap Pro software was used to export the integrated and clean point cloud in a format compatible with Revit. This conversion allowed for a smooth transition and interoperability between various programs used.

Once the point cloud was successfully integrated into Revit, the next step involved modelling the structural and architectural components of the building. The building geometry is simple, however, the complexity of this church lies in its architectural elements, for that matter, a combination of automated and manual techniques was used to ensure accurate as-built model. To streamline the extraction of wall thicknesses, floor levels, and openings, the **FARO As-**

Built plugin was installed within Revit. This plugin is specifically designed for point **cloud-to-BIM** conversion and provided semi-automated extraction tools for identifying walls, doors, and windows within the scanned data. Using FARO As-Built, wall thicknesses were precisely measured, and major openings (doors and windows) were correctly placed based on the point cloud reference. The created 3D model was then overlapped with the 2D documentation, which was done with the help of **PointCab Origins**, to verify any discrepancies. Some of the details were adjusted in 2D documentation as the 3D model shows more accuracy being able to check precise details of point cloud at each level.

Despite its capabilities, FARO As Built has several limitations when applied to heritage modelling. While it proved useful for defining major architectural elements, it was not effective for modelling minute details or lacks diverse library of families for HBIM such as for windows, coping profiles, dome or columns. As a result, these elements had to be manually modelled using Revit's family editor and parametric modelling tools. For instance, **window families** were created from scratch, referencing orthophotos, the **dome** was created using recent and historical photographs and the top of **bell tower** was also created in the similar way. The **staircase** for the bell tower was half scanned in the survey and the rest of the staircase was modelled by taking reference from the videos and photographs available online, since that area was not allowed to be visited.

It is very challenging to define a typical LOD for this project, since all the elements have been developed with different levels of detail. For example, the walls have LOD E, as their stratification was visible through the deterioration of the walls. Floors and the roofing details are a hypothesis hence they can be loosely categorized in LOD D. The system of the dome, although not very precise, but contains the structural system very close to the built structure, hence this can be categorized between LOD D-E. This is the personal interpretation of the authors, as the subject requires much more study and detailed elaboration of HBIM in its LOG and LOI, but the limitations of lack of all the information available regarding the material and structure of the building hinders this step.

After modelling the primary architectural and ornamental elements with as much detail as possible, a **validation process** was conducted to ensure that the HBIM accurately reflected the original point cloud, cross checking dimensions, and making necessary refinements to ensure accuracy. This was carried out using **As-Built Deviation Analysis** tool with 2cm accuracy. Additionally, the semantic properties of some of the model elements were assigned based on the historical, visual and 3D survey. And later the analysis of degradation of one façade was carried out, which will be explained in Part V.

The resulting HBIM successfully captures the highly accurate geometric details of the building with a hypothesis of non-geometric information. The workflow highlights that the HBIM process has a need to integrate multiple software tools and balance automation with manual detailing. This is a starting point to develop a restoration project for the church of Gardella in real context.

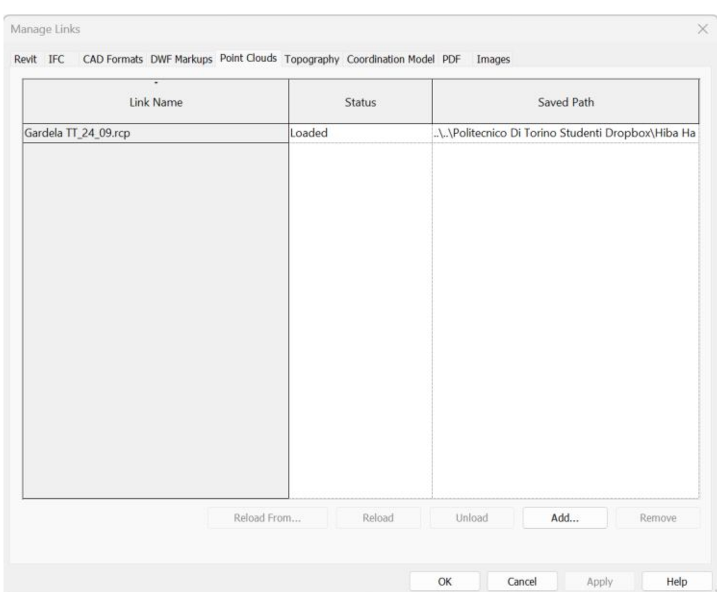
Creation of the HBIM Model

3.1 Point Cloud Import to Revit

The point cloud from Agisoft Metashape is exported in **.las** format for further working into the Cloud Compare software. The process has been explained in Part III (3.4). The file format of Cloud Compare is .bin and the software exports the clouds in **.las**, **.e57**, or **.ptx formats**, none of which are interoperable directly with Revit. Hence, to make the point cloud interoperable with Revit, the **.e57** (merged cloud) file was imported into the **Autodesk ReCap Pro** software, a software designed for processing and converting point cloud data into a format compatible with Autodesk products. From there the point cloud was converted into **.rcp** format, which was then imported into Revit to serve as the base reference for modelling the building's geometry and architectural features.

The option to import point cloud in Revit was set to Center to Center to ensure that the point cloud is placed close to the point of origin 0.0 in Revit. However, the problem faced with the point cloud was that it was not placed at level 1 and was below this level, this issue was manually fixed. To verify that the Revit model coordinates match the 2D coordinates of AutoCad, the AutoCAD exports of layout from PointCab origins were linked into the Revit model with the option Center to Center, and then the point cloud was manually aligned with the layout from PointCab. This was an optional step for the purpose of verifying the model accuracy with the 2D layout and the 3D model generated directly with the point cloud.

Fig. 25. Imported Point Cloud in. rcp format.



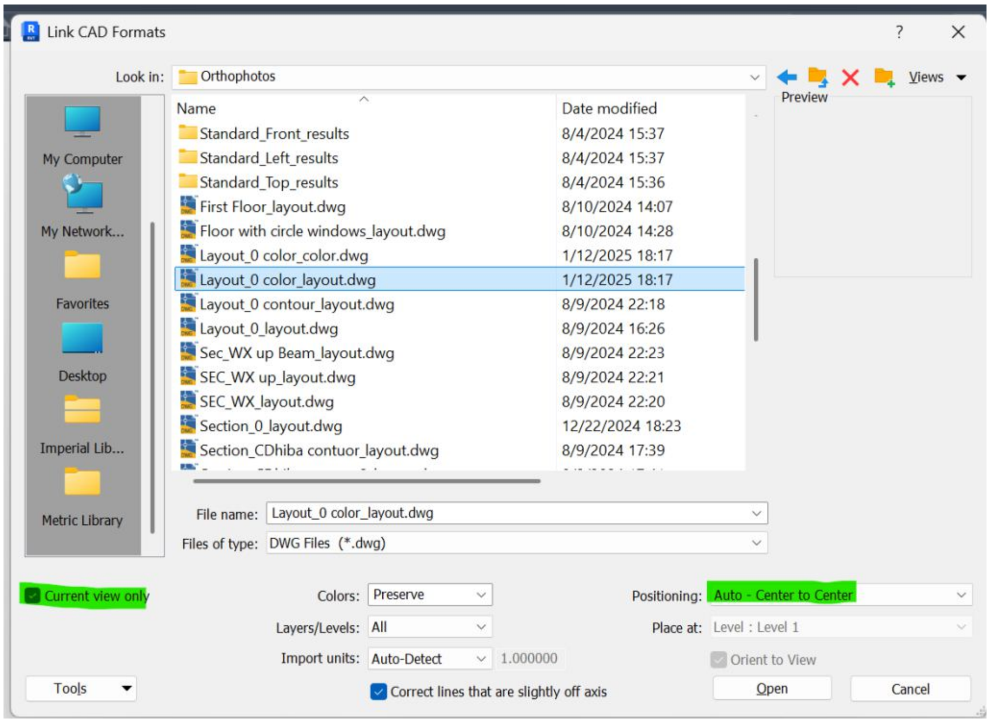


Fig. 26. Imported Point Cloud in .rcp format.
Fig. 27. Imported Point cloud with point of origin 0.0 seen in blue circular cross. Source: By authors – done in Autodesk Revit 2024.

3.2 Creating Levels

The second and the most crucial step was to create the levels. As the church has multiple levels which do not correspond to others, it was necessary to create a level based on the height of each block, to ensure maximum accuracy in the model. This is also the part where the HBIM accuracy exceeds that of 2D documentation. A total of eight levels were created based on the heights of eight different structures of the building. However, two of the levels were considered mezzanine based on a shorter height distance in reference to the preceding level. These are level 1.5 and level 2.5, as can be seen in Figure 4 and 5.

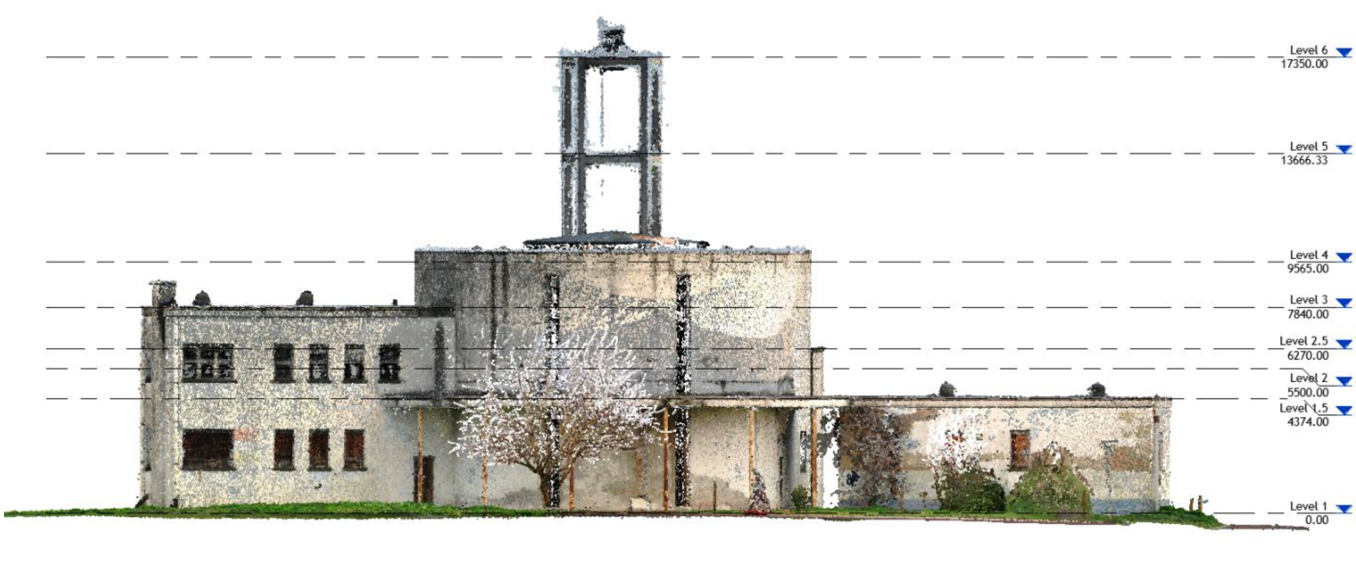


Fig. 28 (up). Levels shown on East Elevation (Not to Scale). Source: By authors – done in Autodesk Revit 2024.
Fig. 29 (below). Levels shown on West Elevation (Not to Scale). Source: By authors – done in Autodesk Revit 2024.

3.3 Building Walls, Floors and Roofs

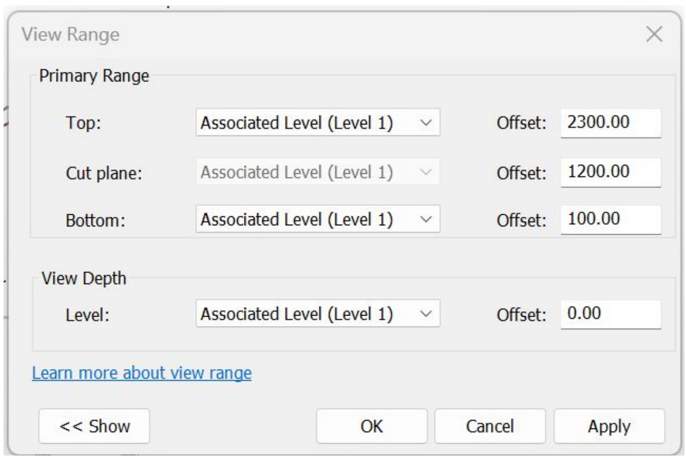
These components are categorized and modeled as System Families. According to Autodesk, System Families consist of fundamental building elements that are assembled on-site during construction. For example, structural components like walls, roofs and floors, mechanical elements such as ducts and pipes or system settings that define project parameters, including levels, grids etc.

In this project, system families are used to model walls, floors and roofs because the photogrammetric documentation does not show any major structural deviations, hence it is possible to achieve accuracy with this method. Semantic information has been added (as much as possible) to ensure the completeness of the model.

For model creation, once the levels are set, it is required to set the View Range for each level to have a clear view of the point cloud for creating the elements. Since the heights of each level vary, it was not possible to set a standard rule for the view range. Hence, each floor has its own rule for defining view range for the best results.

After setting the view ranges, the model building was done with the help of FARO As-Built plugin for Revit. This plugin proved to be extremely useful for noticing the right thickness of walls. Walls were created using the command Fit Walls, and then two points on the planar walls were selected. The plugin determined the thickness of the walls automatically, which were then re assessed with Wall thickness tool. Overall, the perimeter wall thickness varies from 52 cm to 60cm. Materials were assigned to the walls based on the visual hypothesis and by consulting the document UNI_TR_11552:2014.

The roofs and the floors were created by taking reference to their depth from the sections created in Revit. The material and structural details in the section are hypothesized since there are no published documents available on the structural survey of the church. Some of the materials were created by the authors to create layer stratification of parameters in floors and roof. Those are also hypothesized based on the analysis of the architecture of twentieth century (see Part V – 2.2). Below are the elaborations of the system family parameters and the results of the model. The drawings and 3D models are not to scale. They are attached to the appendices at 1:100 scale.



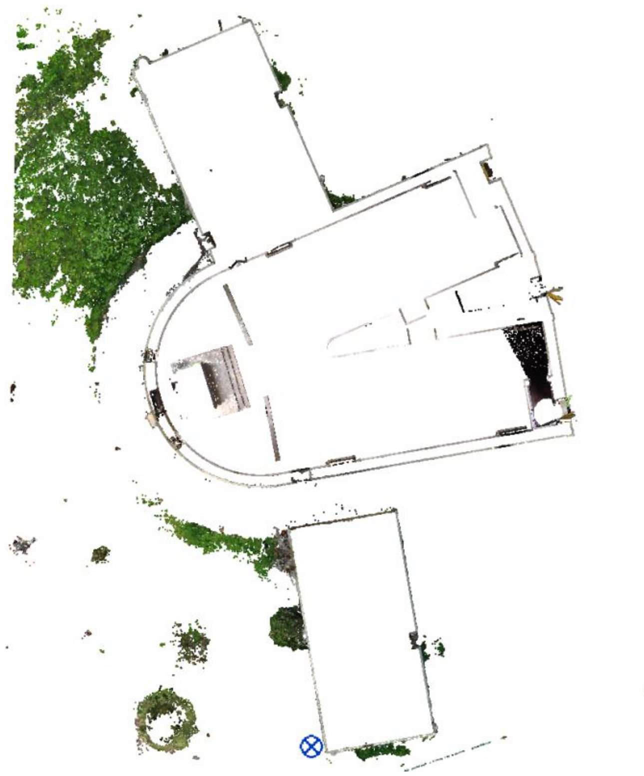
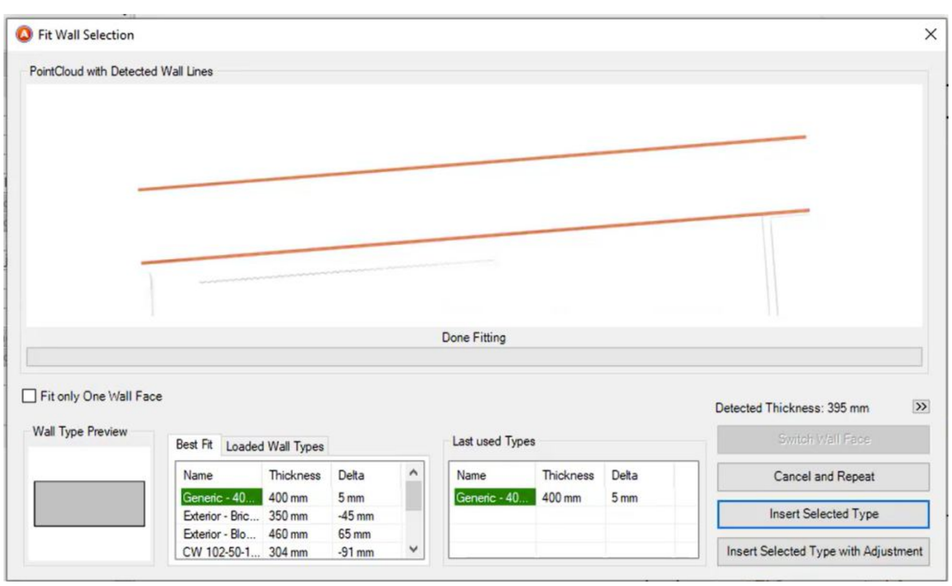


Fig. 30 (up). Left: View Range Parameter of Level 1 adjusted to +100 to achieve clear view of the wall thickness.
Fig. 31 (right). Right: Result of the adjusted View Range of Level 1 (Out of Scale).
Fig. 32 (below). Fit Wall command application in FARO As – Built. The plugin gives multiple options and suggests the Best Fit based on the geometry it assesses in the point cloud.



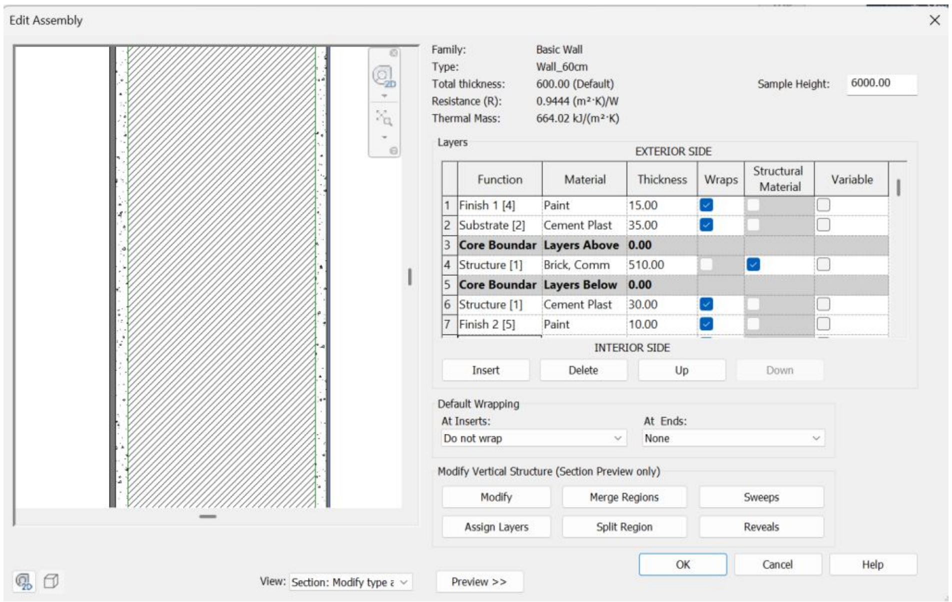


Fig. 33. Layer stratification of 60cm Basic Perimeter Wall.

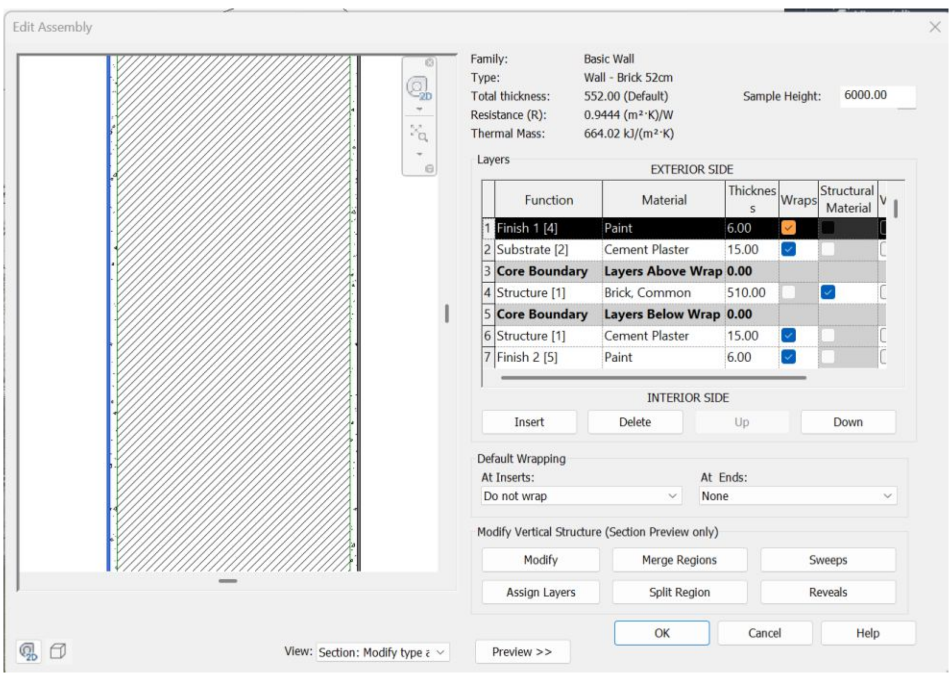


Fig. 34. Layer stratification of 52cm Basic Perimeter Wall – The hypothesis is that the walls have undergone degradation hence the layers of exterior and interior plaster and finish are thinner.

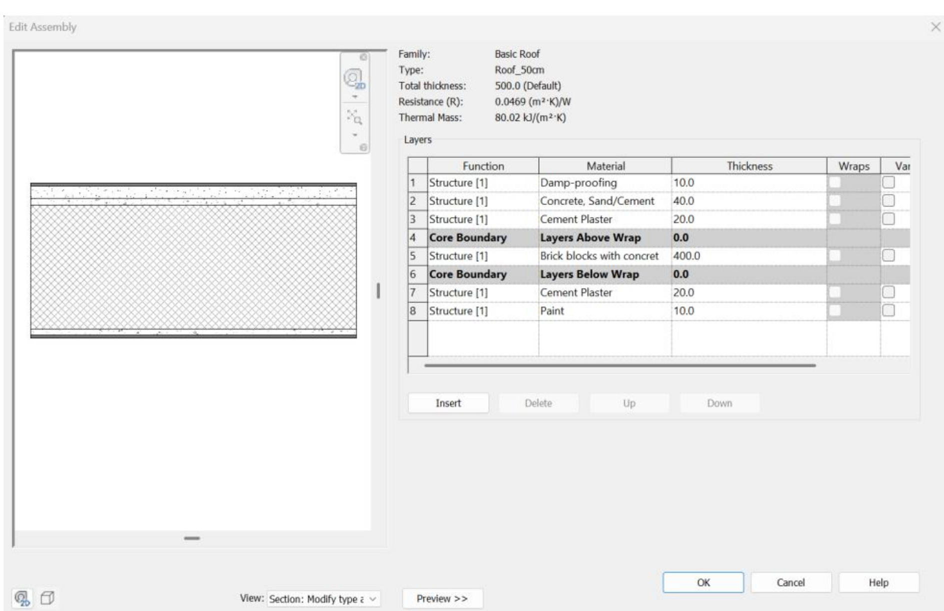
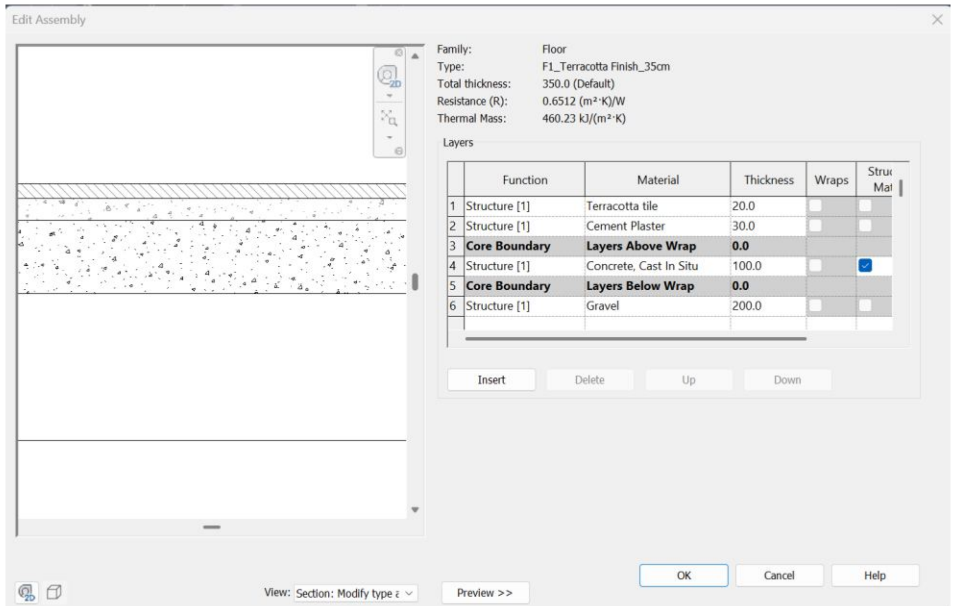


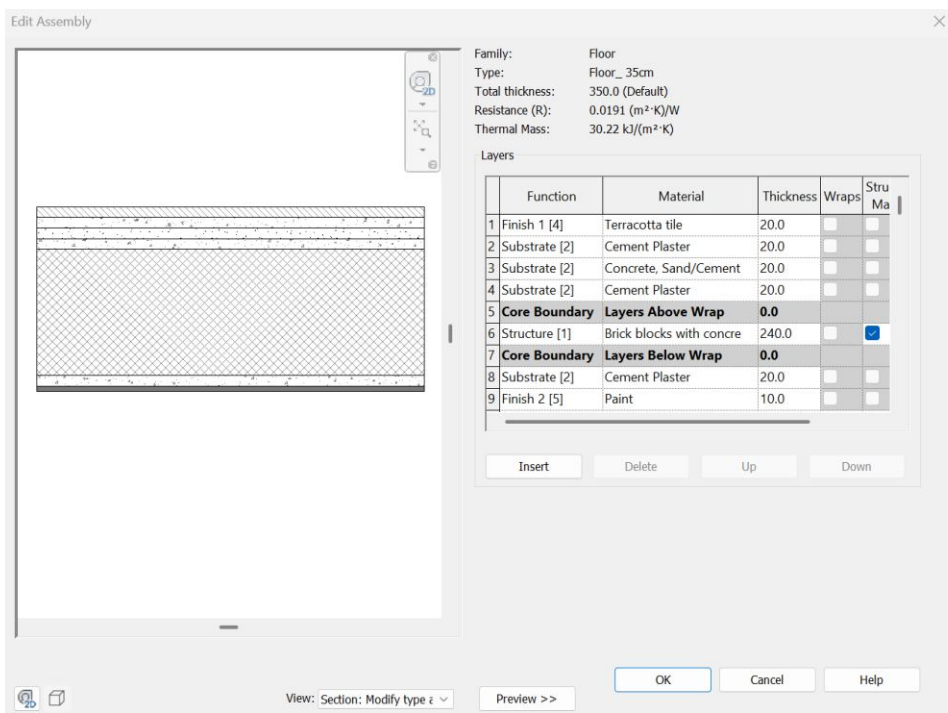
Fig. 35. Layer stratification of 50cm Roof- The depth of the roof is certain however the structural system is hypothesized to be Brick blocks with Reinforced concrete.

Fig. 36. Layer stratification of 35cm Floor (Level 1 – Ground) – The hypothesis is based on the Abacus of UNI/TR 11552:2014.

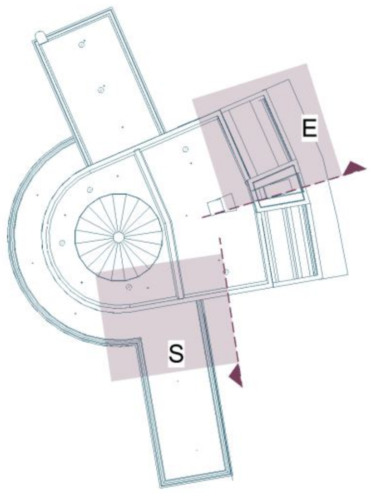


	Function	Material	Thickness	Wraps	Struc Mat
1	Structure [1]	Terracotta tile	20.0	☐	☐
2	Structure [1]	Cement Plaster	30.0	☐	☐
3	**Core Boundary**	**Layers Above Wrap**	**0.0**		
4	Structure [1]	Concrete, Cast In Situ	100.0	☐	☑
5	**Core Boundary**	**Layers Below Wrap**	**0.0**		
6	Structure [1]	Gravel	200.0	☐	☐

Fig. 37. Layer stratification of 35cm Floor (Level 2 – Intermediate) – The hypothesis is based on the Abacus of UNI/TR 11552:2014.



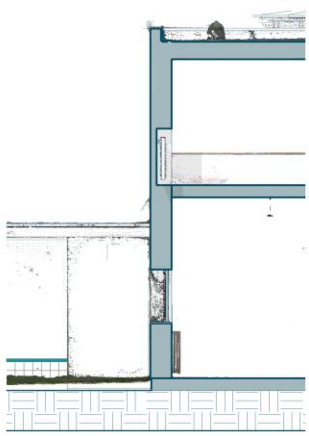
	Function	Material	Thickness	Wraps	Stru Ma
1	Finish 1 [4]	Terracotta tile	20.0	☐	☐
2	Substrate [2]	Cement Plaster	20.0	☐	☐
3	Substrate [2]	Concrete, Sand/Cement	20.0	☐	☐
4	Substrate [2]	Cement Plaster	20.0	☐	☐
5	**Core Boundary**	**Layers Above Wrap**	**0.0**		
6	Structure [1]	Brick blocks with concre	240.0	☐	☑
7	**Core Boundary**	**Layers Below Wrap**	**0.0**		
8	Substrate [2]	Cement Plaster	20.0	☐	☐
9	Finish 2 [5]	Paint	10.0	☐	☐



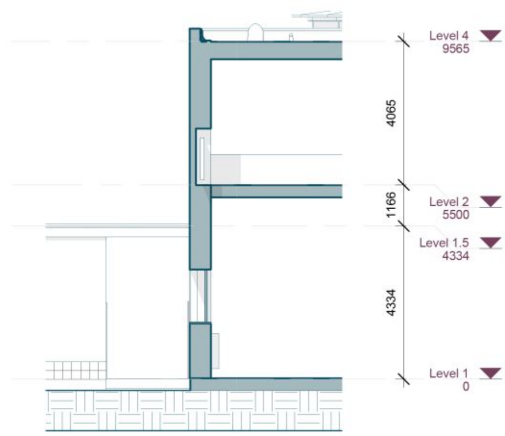
K01 Key Plan_East & South
1 : 400

Fig. 38. Left: Key Plan 01 showing section line and Area highlighted in Pink to show 3D section area. Below: Section of South Walls in 2D and 3D – Showing overlap with the Point Cloud.

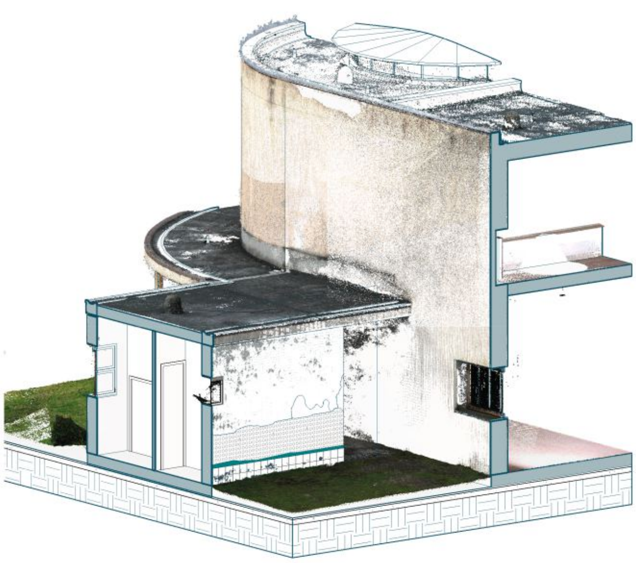
Fig. 39 (next page). Section of North Walls in 2D and 3D – Showing overlap with the Point Cloud – (Area of Stair hall has been partly hypothesized since the area was partly scanned with LiDAR).



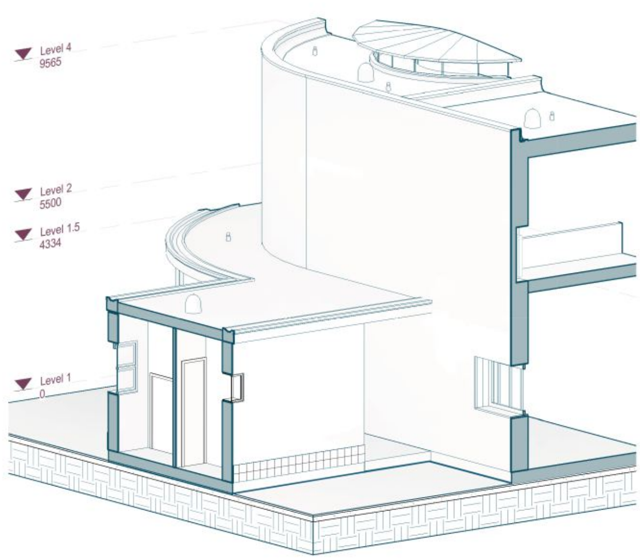
S01 South Wall Section_Point Cloud
1 : 100



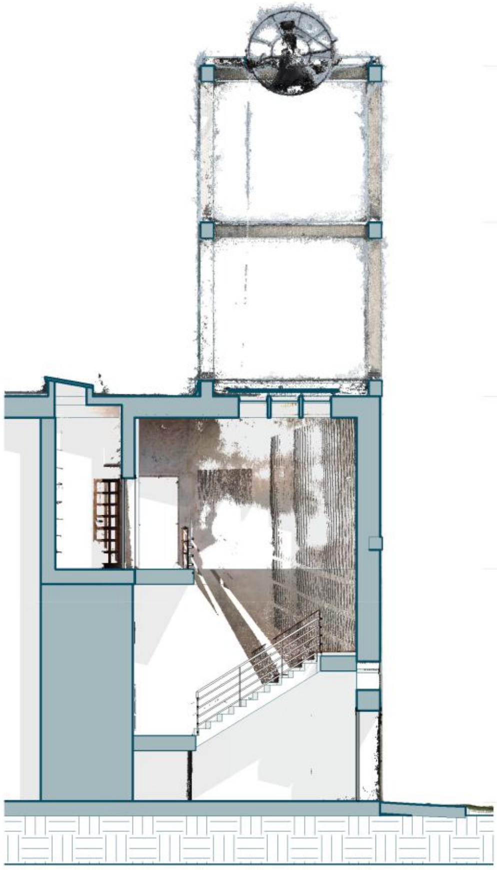
S02 South Wall Section
1 : 100
0m 1m 2m 3m 4m 5m



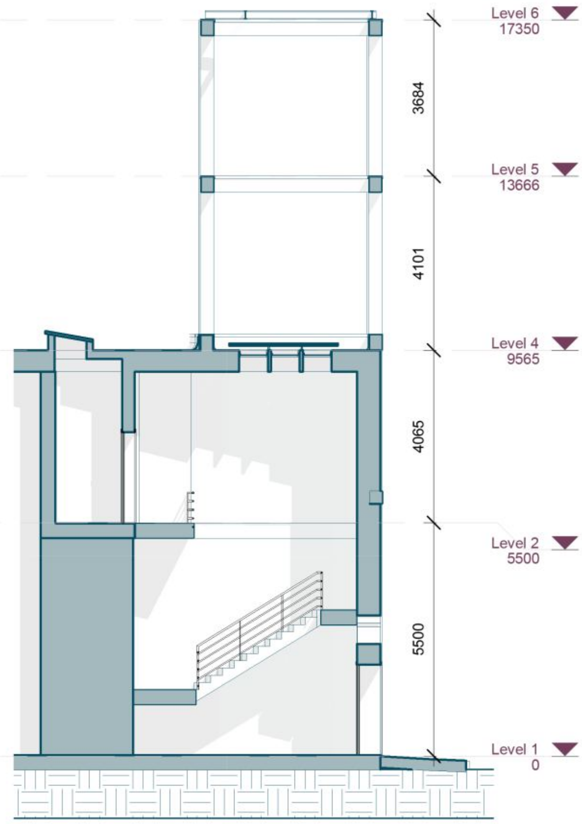
S03 South Walls_3D+Point Cloud



S04 South Walls_3D



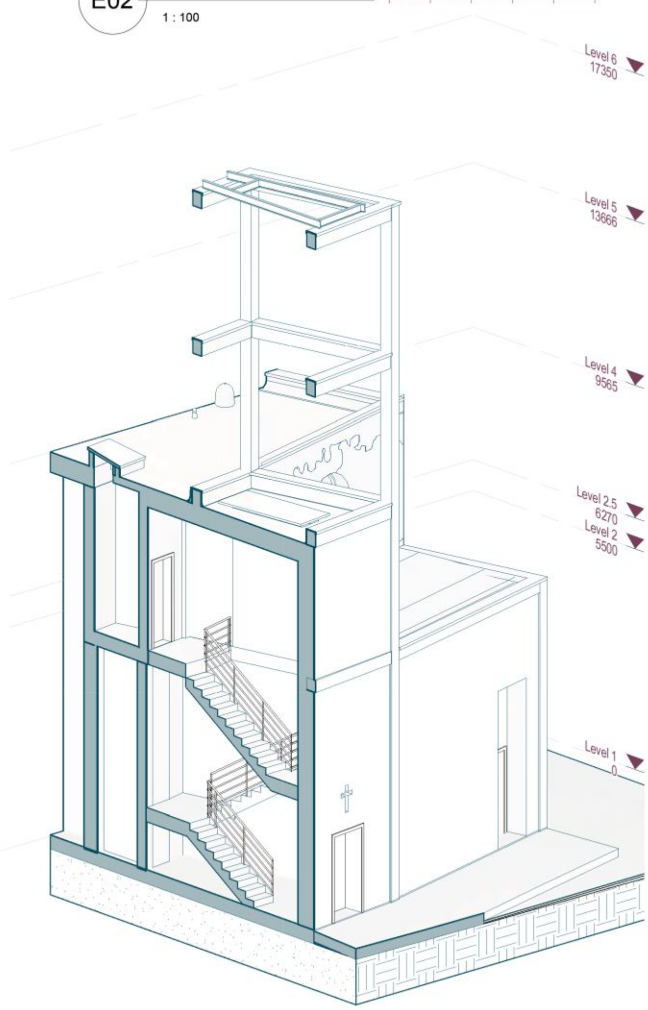
E01 East Wall Section_Point Cloud
1 : 100



E02 East Wall Section
1 : 100

0m 1m 2m 3m 4m 5m

E03 East Walls_3D+Point Cloud

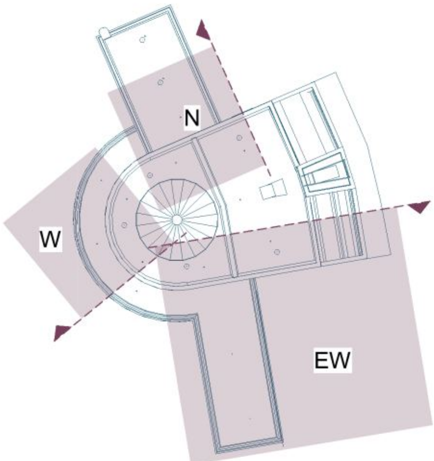


E04 East Walls_3D

Fig. 40. Left: Key Plan 02 showing section line and Area highlighted in Pink to show 3D section area. Below: Section of West Walls in 2D and 3D – Showing overlap with the Point Cloud.

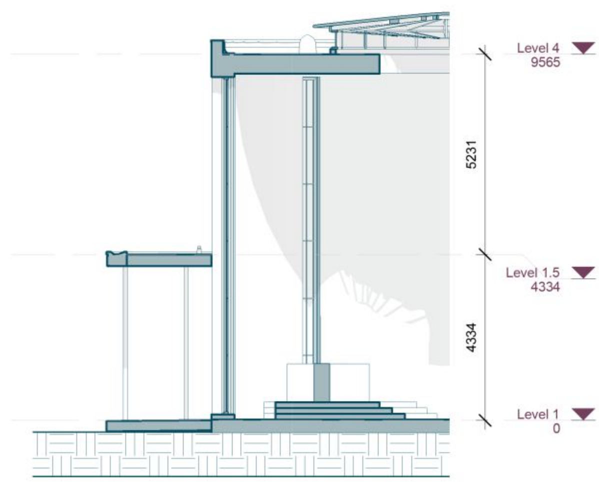
Fig. 41 (next page, up). Section of North Walls in 2D and 3D – Showing overlap with the Point Cloud.

Fig. 42 (next page, below). 3D Section in East West Orientation – The fill in Pink signifies the area without any structural information.



K02 Key Plan_East, West & North
1 : 400

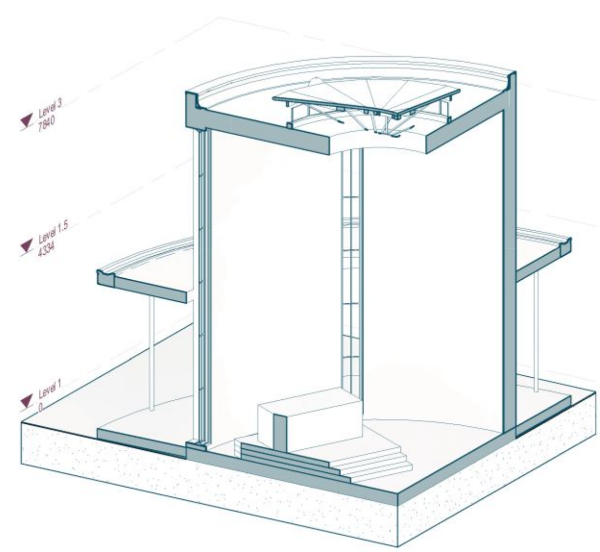
W01 West Wall Section_Point Cloud
1 : 100



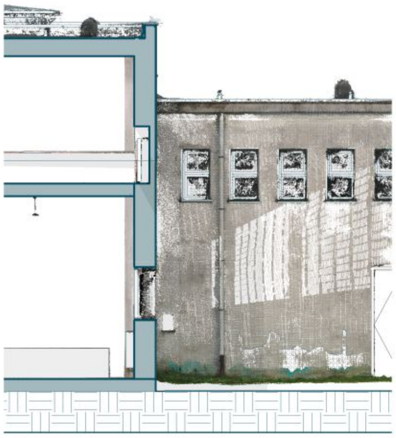
W02 West Wall section
1 : 100

0m 1m 2m 3m 4m 5m

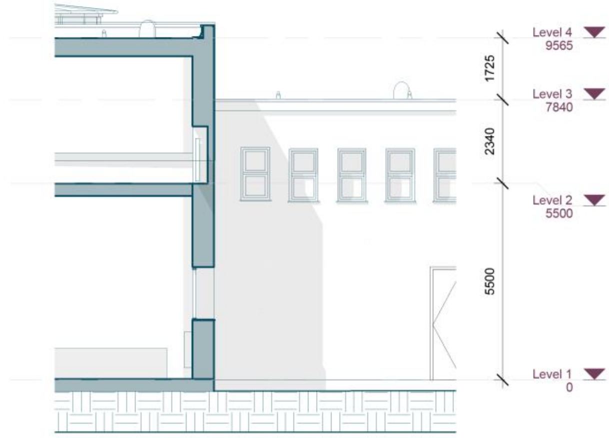
W03 West Wall_3D+Point Cloud



W04 West Wall_3D

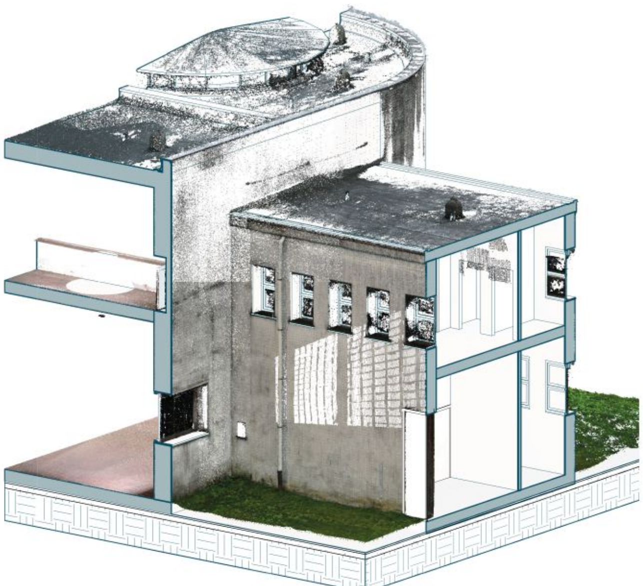


N01 North Wall Section_Point Cloud
1 : 100

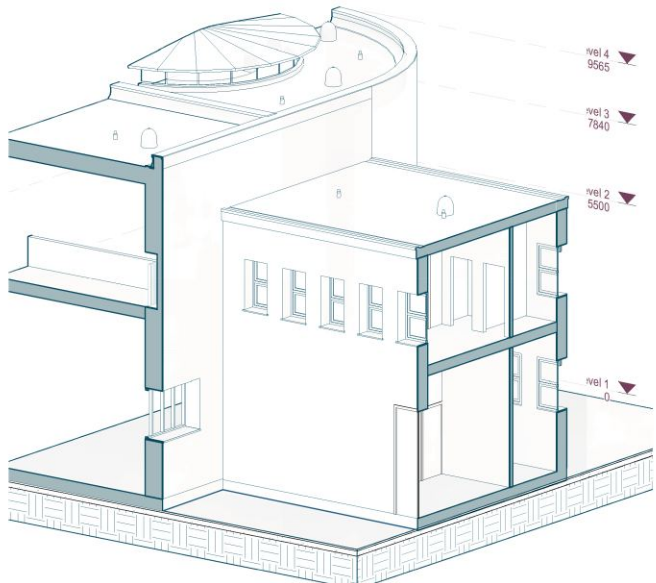


N02 North Wall Section
1 : 100

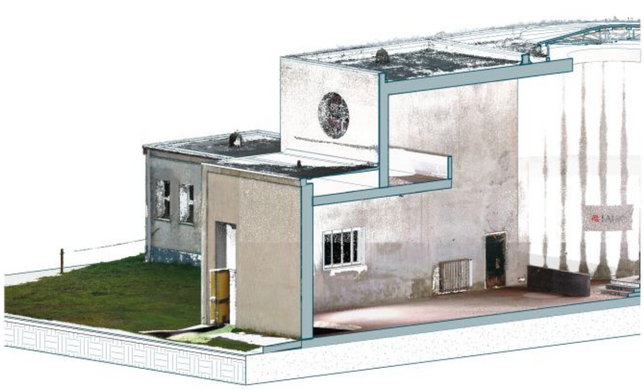
0m 1m 2m 3m 4m 5m



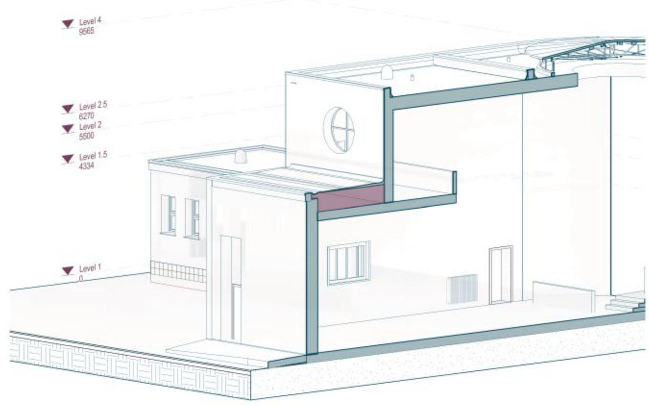
N03 North Wall_3D+Point Cloud



N04 North Wall_3D



EW01 East West_3D+Point Cloud



EW02 East West_3D

3.4 Window Families

Windows are created as both ***Loadable Families*** and In-Place Families. As per Autodesk, Loadable Families are used to create various buildings and system components including windows, doors, casework, furniture etc. While ***In-Place Families*** are unique elements created specifically for a particular project. These components are designed to adapt to project geometry, resizing or adjusting as needed.

Before modeling the families, the openings for each window and door were created using As-built plugin. This gave a clear idea on the size of the openings and helped analyzing the windows in terms of their design, sizes and shapes. Most of the windows in the North and South wing are similar and hence they were repeated as a module. Even though the South wing windows were closed with wooden planks, however, similarity in opening size helped determining the design. There are a total of 7 typologies of windows, out of which Window Type 6 and Window Type 7 have been modeled as In-Place families. Family of Window Type one has two modules. The ones on the East façade are without the window shutter, which is evident from the north wing façade, whereas the window 1 typology on South Façade has shutters. All the window families have been assigned Type parameters that can be adjusted according to the height or width of the opening or positioning of the shutter.

3.5 Dome Family

The Dome has a complex ribbed shape and multiple components. For this reason, it has been modeled as a Metric Generic Model Family. To create the family, first the 2D section and plan of the dome were imported into the Generic family to have the exact angles of the dome. As the point cloud did not show a higher level of detail for the dome, most of the modelling was done based on the estimates from the photographs. Once the 2D drawings were imported, it was placed in the plan and section windows of the generic family keeping the center of the dome at the central axis. After this the outline for the plan of the dome was drawn as an Inscribed Polygon with 20 sides. Then to create the dome deck, it was necessary to use Revolve sweep by drawing the section profile in the section window (in reference to the 2D CAD import) and revolving it around the central axis. This gave a smooth and accurate outer shape of the dome.

To create the structural profiles of wood and steel, Array tool was used. First, the compression ring node was created right below the roof of the dome and then the profiles of both steel and wooden components were created using Sweep blend and then they were arrayed around the central axis of the dome ensuring their placement at the meridional lines and connecting them to the central compression ring and outer tension ring, both of which were extruded as shapes. Finally, the metal/steel connections were created to form a structural node, which connect the meridian ribs (in steel) to the compression ring at the top.

3.6 Coping, Chimney and Anchor points

All the parapets of the walls and the beams of the Bell tower are covered with ***Metal Coping***. On the parapets, there is also an added bituminous layer, which is a recent addition, and this layer connects the coping at the edges. The overall detail is not very clear in the scan however, it has been modeled with as much detail as possible. They have been modeled as Generic In-Place component, by creating a section profile of the coping and sweeping it along the path of the parapet. ***Chimney*** is another In Place component but in this case as a Wall, for future material and other properties assignment. Simple extrusion of Solids and Voids have been used to model this component. Lastly, the small components on the roof like ***Anchor points*** or the air outlets, have been modeled as Metric Generic Families using the Revolve tool, since the model In-Place was not forming exact geometry due to the complexity of angles in the building.

The following pages will show the results of the realized models of the above-mentioned components and families.

Windows – Loadable and Generic Model Families

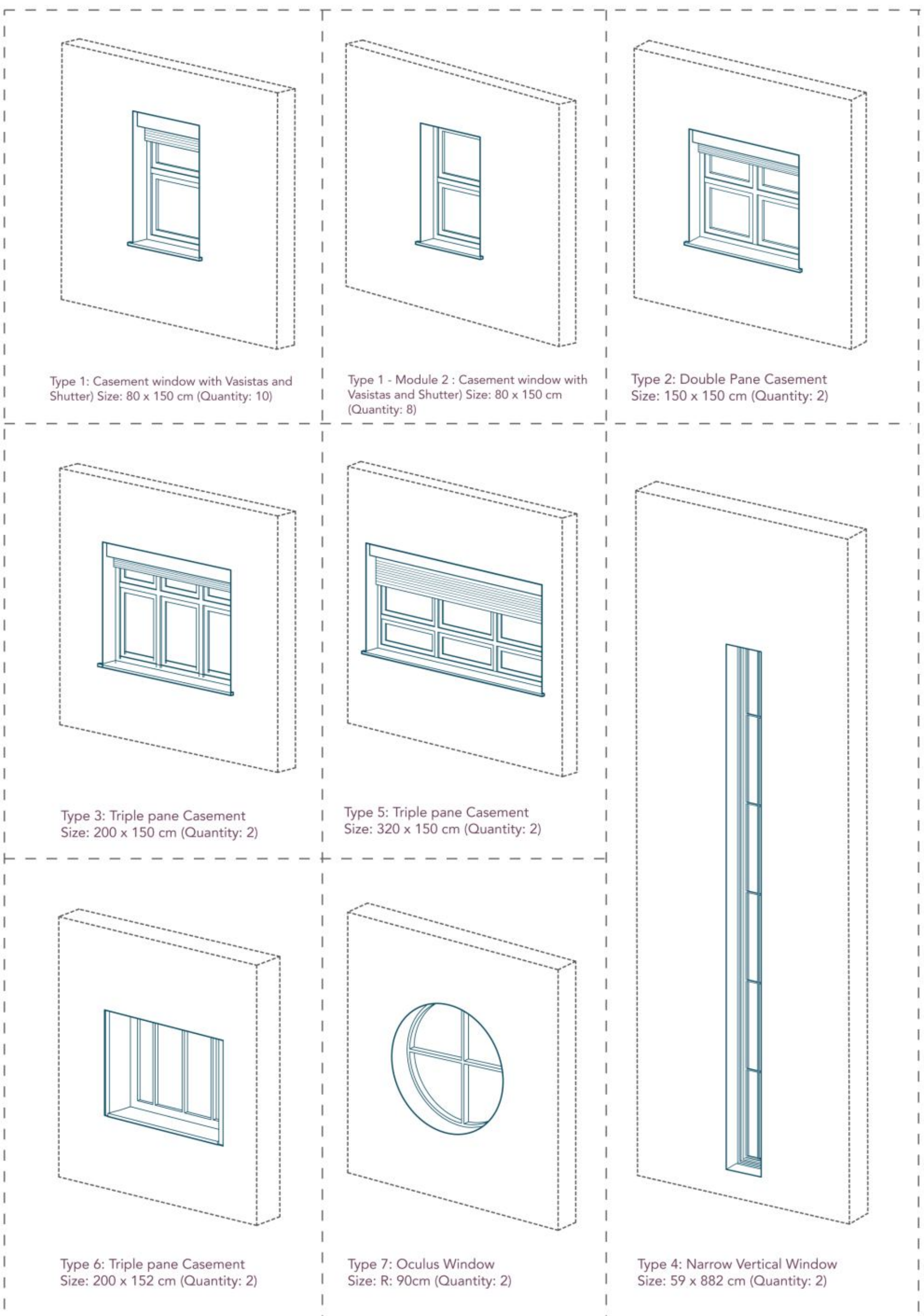
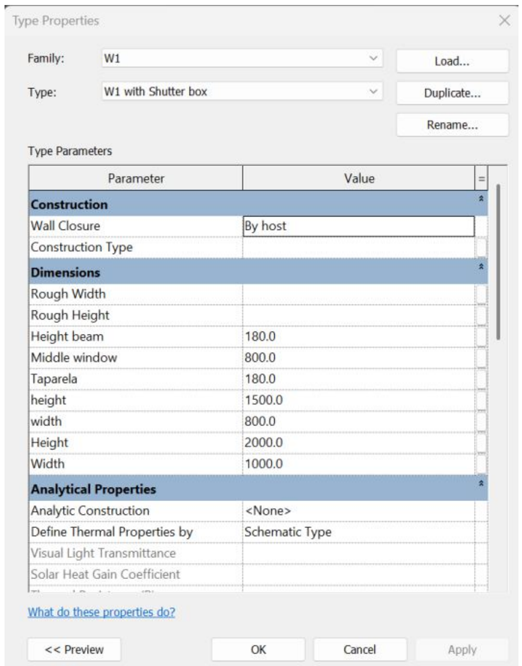


Fig. 43. Abacus of all window families.

Window Family Parameters



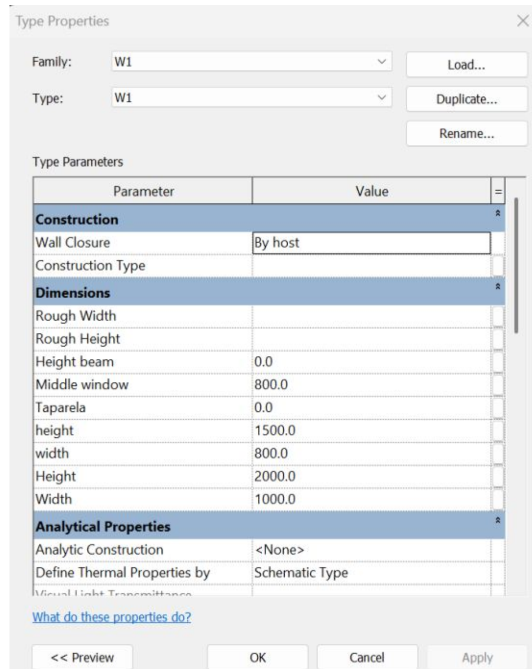
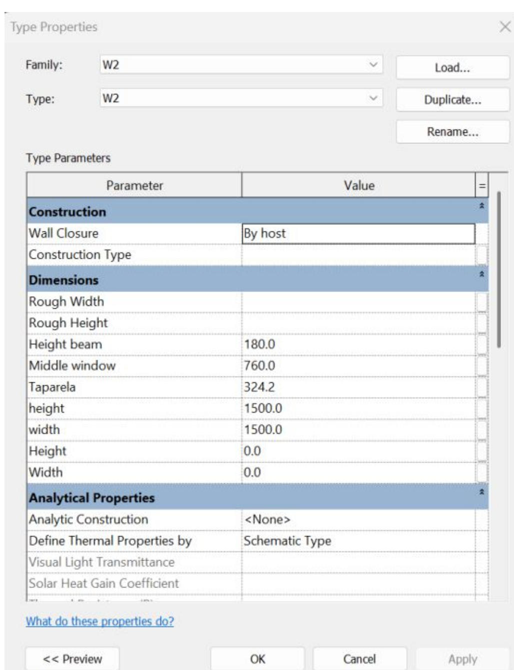


Fig. 44. Left – Window Type 1, Fig. 45: Right – Window Type 1 – Module 2.



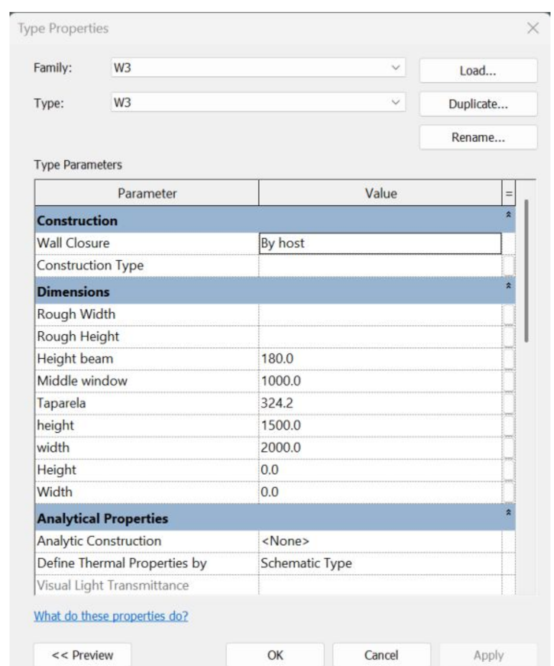
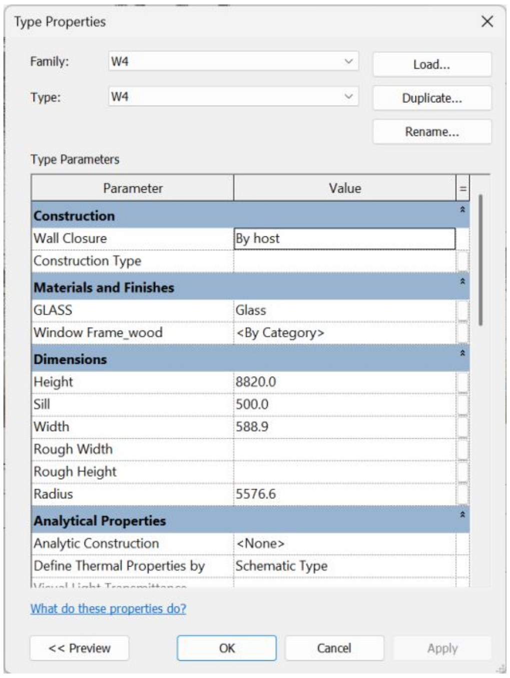


Fig. 46. Left - Window Type 2, Figure 47: Right - Window Type 3



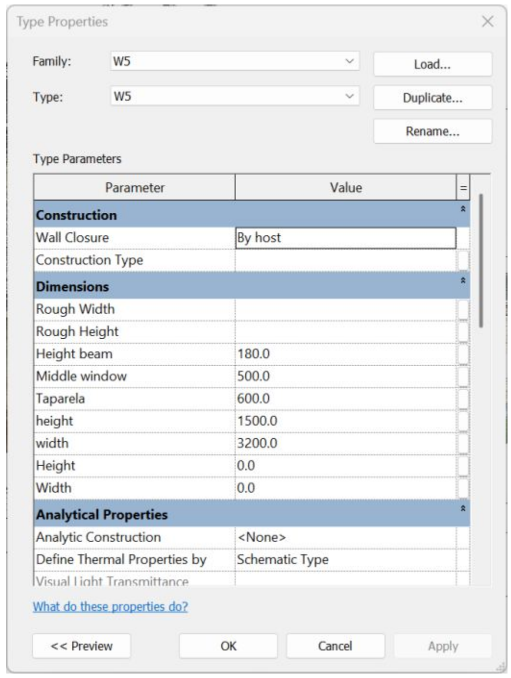
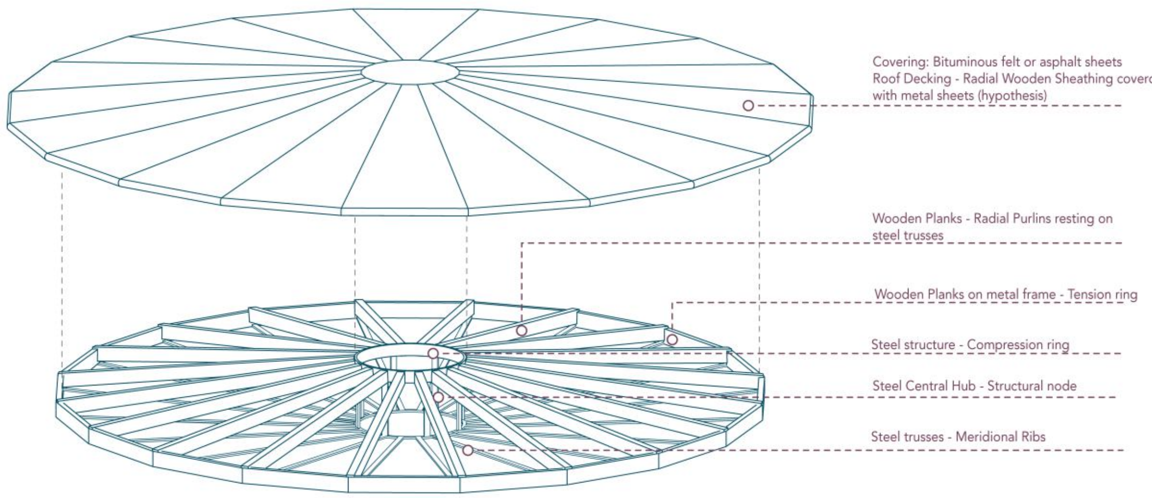


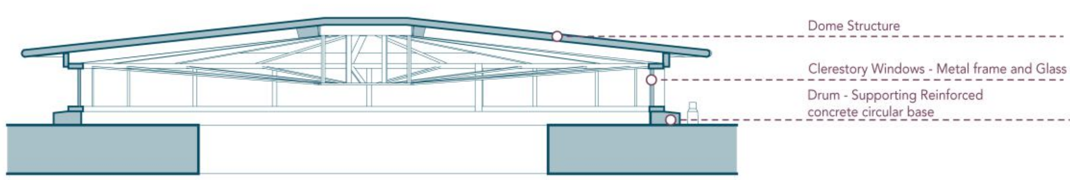
Fig. 48. Left – Window Type 4, Fig. 49: Right – Window Type 5.

Fig. 49. Top – Exploded Axon of the Dome. Bottom – Dome Section (not to scale).

Dome Family Model

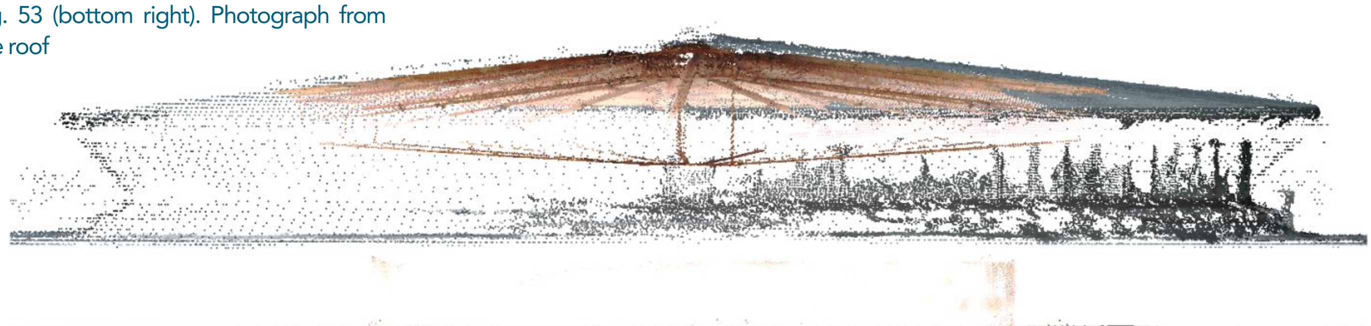


Dome Exploded Axonometric showing Structural components

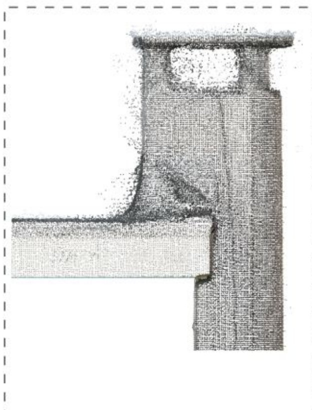


Dome Section

Fig. 50. Point Cloud of the Dome
Figure 52 (bottom left). Photograph from the indoor Alter.
Fig. 53 (bottom right). Photograph from the roof



Coping, Chimney and Anchor point Models



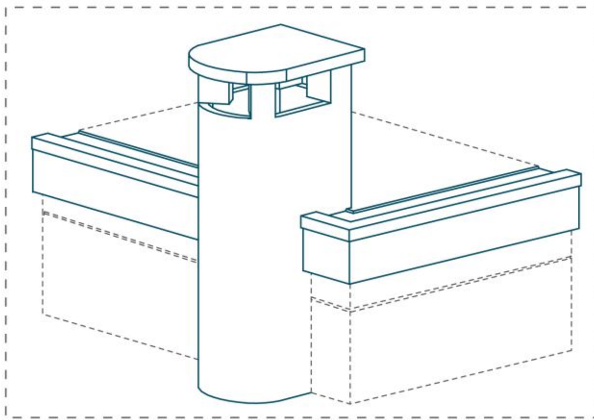
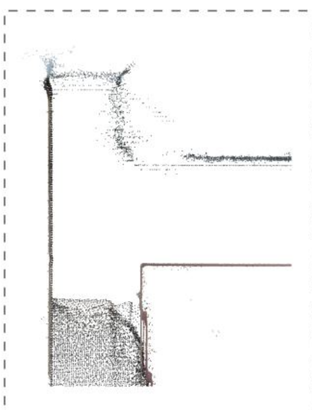


Fig. 54A (left). Point Cloud of Chimney.
Fig. 54b (right). 3D Model of the Chimney.



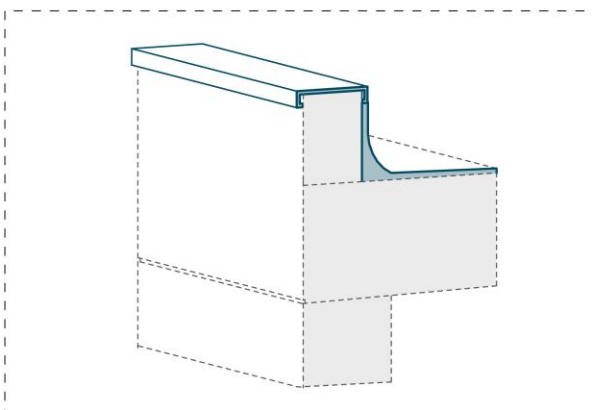
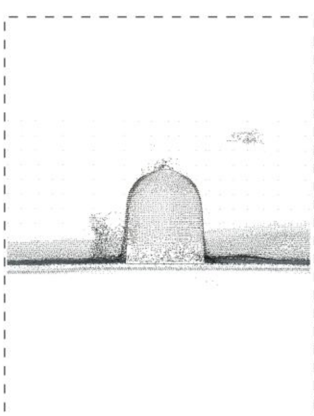


Fig. 55A (left). Point Cloud section of the parapet.
Fig. 55b (right). 3D Model of the Coping and the Bitumen layer.



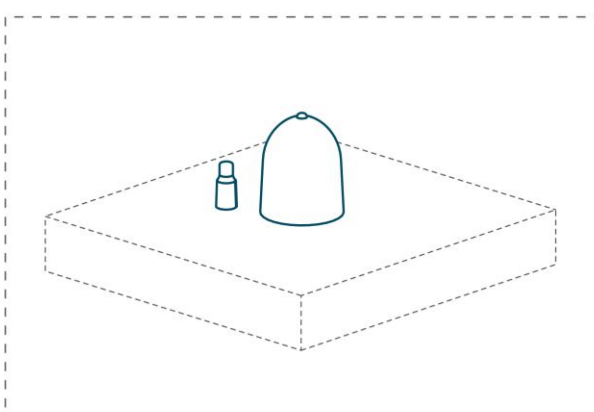
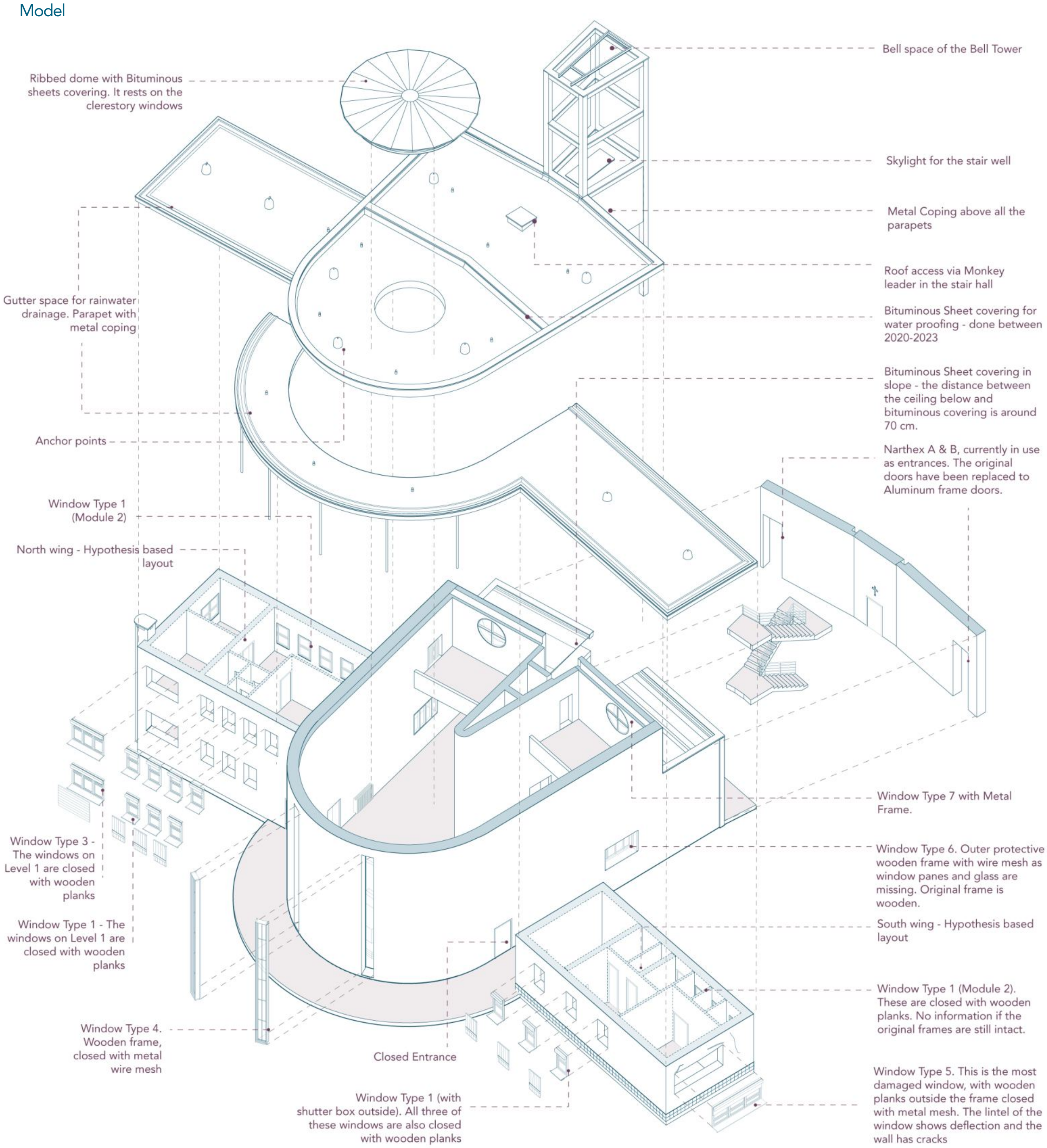


Fig. 56A (left). Point Cloud section of anchor point.
Fig. 56b (right). 3D Model of the anchor point and the air outlets.

3.7Final HBIM Model

Fig. 57. Axonometric showing building components of the Definitive HBIM Model



Model Accuracy Check

After completing the HBIM model creation in Revit, a model accuracy check was conducted using the As-Built plugin to verify the deviation between the as-built conditions (point cloud data) and the Revit model. This step is crucial to ensure that the 3D model precisely reflects the existing conditions of the structure and meets the required level of accuracy (LOA) for heritage documentation and restoration. The analysis was carried out by comparing the modeled surfaces with the original point cloud data, measuring discrepancies and categorizing deviation using a color-coded deviation map.

The analysis was done using the Surface Analysis tool, which computes the differences between the HBIM model geometry and the reference point cloud. The process involved setting a grid size, which in this case was set to 50 mm to balance computational efficiency and precision. A smaller grid would have increased accuracy, but it could significantly extend the processing time. Next, a maximum surface distance of 300mm was set to detect major deviations, ensuring the any significant misalignments can be captured. Lastly, each façade was analyzed separately to detect localized deviation in walls, openings and structural elements.

The results are displayed using U.S. Institute of Building Documentation USIBD Level of Accuracy Ranges (LOA) for represented accuracy. Once the analysis is done, the results are automatically displayed using a gradient color scale indicating the magnitude of degradation. The results can be read in the following way:

- Green (LOA 50 & 40: 0-5mm deviation) → Highly accurate areas
- Yellow (LOA 30: 5-15 mm deviation) → Acceptable minor deviations
- Orange (LOA 20: 15-50 mm deviation) → Moderate deviations, requiring attention.
- Red (LOA 10: >50mm deviation) → Significant inaccuracies and potential modeling errors or misalignments
- Blue (negative values) → indicate undercut regions, while positive values (red tones) represent protrusions in the modeled surface compared to the point cloud.

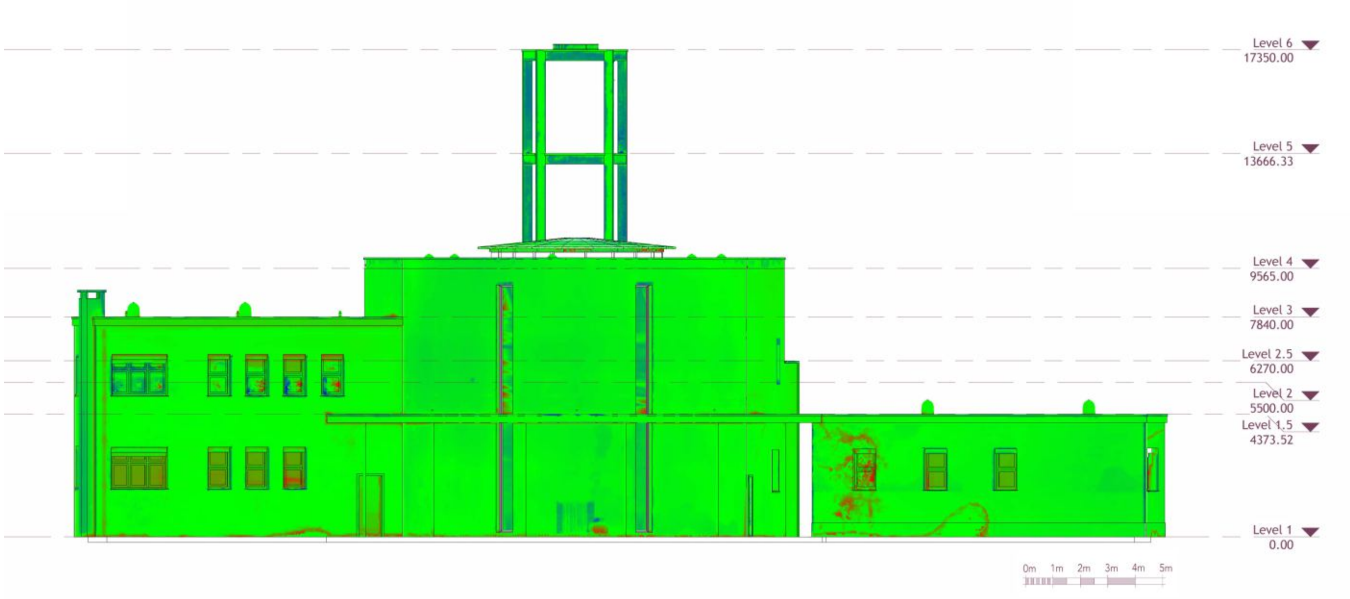
The analysis results of all the facades indicate that HBIM model aligns exceptionally well with the point cloud, with most of it surfaces falling within the LOA 50 (0-1mm) and LOA 40 (1-5mm) accuracy ranges. This means that majority of the building elements were modeled within a very high precision margin. Some localized discrepancies are seen around windows and doors, likely due to the misalignment of opening or placement of window components. Higher deviation in blue and red spots are seen on the parapet and the bell tower and a rectangular area in blue is seen on the South and the North façade. Some of these deviation issues were fixed in the model, however, there were some issues that could not have been resolved due to lack of information in those areas. Red areas can also be seen at the base of the structure, which are not related to accuracy issues, but are related to the topography which was not modeled based on the survey.

To conclude, this process of accuracy verification ensures that this HBIM model is precisely documented to a high degree. While it still needs improvements and a much further Level of Development, it can set a strong stage for further research.

Results of Level of Accuracy (LOA) analysis

Fig. 58. East Façade LOA.

Fig. 59. South Façade LOA.



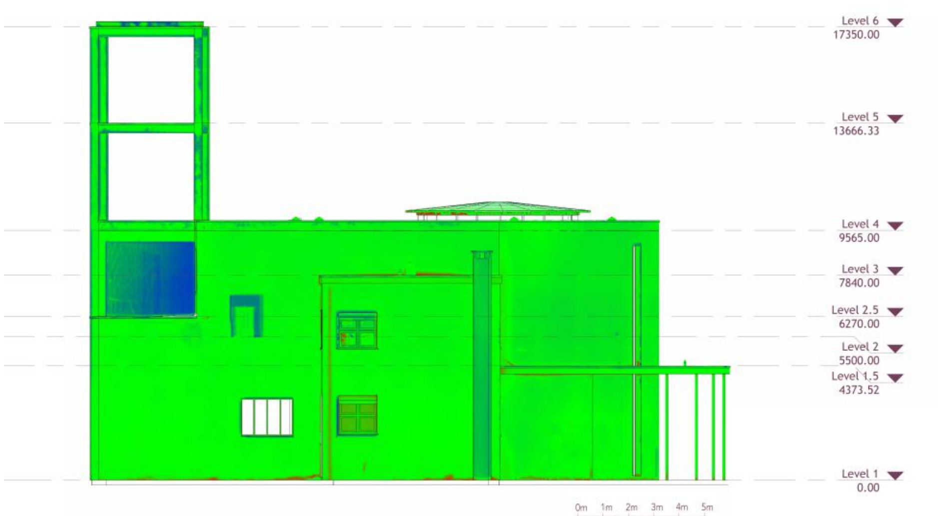


Fig. 60 (above). West Facade LOA
Fig. 61 (below, left). North Facade LOA.

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Part V

Analysis of Degradation and A Project of Restoration

Degradation Analysis of the Existing Structure

1.1 Methodology and Reference Norms

The degradation analysis of the case study follows UNI 11182:2006 norms, the Italian standard for categorizing and assessing material deterioration in built structures. This classification system ensures a scientific and structures approach to diagnosing visible degradation phenomenon, which is crucial for defining appropriate restoration strategies for any building undergoing restoration[1].

UNI 11182 classifies degradation based on observable manifestations rather than causative mechanisms, allowing for a precise evaluation of material decay. The degradation forms identified by these norms are grouped for the purpose of analysis as the following categories:

a. Surface Alterations
This includes effloresce (crystallization of salts on surface), discoloration (fading or staining due to chemical or biological factors), or material deposit (accumulation of atmospheric pollutants, biological growth or dirt etc.) Chemical degradation is also loosely grouped under this category as the only relevant chemical erosion phenomenon to this case study is metallic corrosion (which is the oxidation and deterioration of metal elements due to exposure to moisture, oxygen, and pollutant).

b. Disintegration and Detachment
Including scaling (detachment of thin layers of material), flaking (progressive detachment in smaller fragments, exfoliation (peeling in multiple thin layers) and / or decohesion with the falling of material in form or powder or minute fragments.

c. Deformation and Structural damage.
Under this group, we can include cracking (due to mechanical stress or temperature fluctuations, fissures (deeper fractures or cracks that may compromise structural integrity), swelling

1) UNI 11182: 2006 - Beni Culturali - Materiali lapidei e artificiali - Descrizione della forma di alterazione - Termini e Definizioni.

and bulging (which may be localized deformations caused by moisture, internal stress or expansion of materials)

d. Surface Gaps

This signifies the complete loss of coatings, such as paint or plaster, or the tiles etc.

e. Biological Degradation

This has further types such as biological colonization (growth of moss, algae, lichens, and fungi on the surfaces exposed to moisture retention and low ventilation. Microbial and fungal growth (organic staining and material discoloration due to bacterial and fungal activity, weakening plaster and cement surfaces. And lastly Vegetation growth (root penetration from climbing plants and trees, leading to cracks, mortar displacement, and material detachment.

Methodology Used for Analysis:

The technique used to map degradation of the façade in this case study is that of traditional one using high-resolution two-dimensional Ortho mosaics which were crested using Metashape (see Part III, 3.2). This approach is suitable to identify and color code different materials and types of degradation. It also gives very precise results of mapping the areas in their exact shape, form or texture, thanks to the process of photogrammetry. The only shortcoming of this process is the determination of correct surface areas of the degradation types. As in the historic buildings, the surfaces are not always straight and, in many cases, there are angles, curves or smaller edges which cannot be evaluated in detail. Nonetheless, this remains one of the most used methods in conservation studies.

Proposed HBIM Method:

An approach opposed to the traditional one is the mapping of degradation using HBIM software. This is a method recently being explored by researchers and very few publications are available on the subject. To analyze this case study, a possible strategy proposed is the utilization of Decals in Autodesk Revit. Decal is a tool to place image on the surface of building. Using this tool, Orthomosaics of all the facades can be placed on the surface directly in 3D (divided into part). The beauty of this tool is that it can pe placed on surfaces of any angle, either straight, slanted or cylindrical. After that, the degradation can be modeled on the facades using Generic or other Model In-Place families. This can prove to be a more precise form of mapping degradation areas and BIM can automatically create a schedule of areas, types and levels of degradation. The challenge here is to map it on cylindrical surfaces, such as the wall of the alter space of the church. One of the solutions is to create an extrusion of degradation layer on the cylindrical surface and cut it with voids (following the degradation pattern), which can be only drawn at a planar surface. This method can be time-taking and tedious; however, it may provide reasonable results. Needless to say, the planar surfaces are easier to map, however the cylindrical surfaces are challenging and may provide less accurate mapping results.

1.2 Common Construction Materials and Techniques in Early 20th Century Italian Architecture

The first half of the 20th century in Italy was a period marked by a unique interplay between tradition and innovation in construction techniques. The industrialization of northern Italy contrasted with the more traditional building methods in the South. The evolution of these new construction methods was heavily influenced by the architectural movements discussed in Part I of this thesis, such as Futurism, Novecento, and Rationalism as well as the policies of the Fascist regime, which imposed restrictions on material imports and encouraged the use of locally available materials. This is also the time of heavy production of cement in Italy especially between 1907 to 1935[2]. The following section analyze the most used materials and techniques in Italian architecture of the 1930s.

Reinforced concrete

Reinforced concrete became a crucial material in 20th century Italian architecture, transforming construction through its strength, fire resistance and adaptability. By 1910, its widespread adoption led to government regulations standardizing its use, particularly after the 1908 Messina earthquake which underscored the need for seismic resistance in buildings. In the 1920s and 1930s, its use extended to roofing systems, where hollow brick/clay blocks combined with reinforced concrete proving it to be a lightweight and cost-effective solution that improved thermal insulation while maintaining structural integrity[3]. In 1930's, the S.A.P. slab (solaio auto portante – self-supporting slab), was introduced which was composed of prefabricated beams in reinforced brick with interposed perforated bricks, a solution that significantly reduced construction costs and became synonymous with prefabricated latero-cemento (brick-concrete) floors[4]. These types of slabs have been largely used in the buildings built between 1930s and 40s in Italy with some variations. This hybrid system was preferred for its balance between tradition and modernity, ensuring material efficiency without abandoning local construction expertise.

2) Barozzi, Anna, and Luca Guardigli. 2009. "Italian construction in the first half of the twentieth century between materials restrictions and innovative technology." Proceedings of the Third International Congress on Construction History. Cottbus: BERLIN, NEUNPLUS1. pp. 127 - 134.
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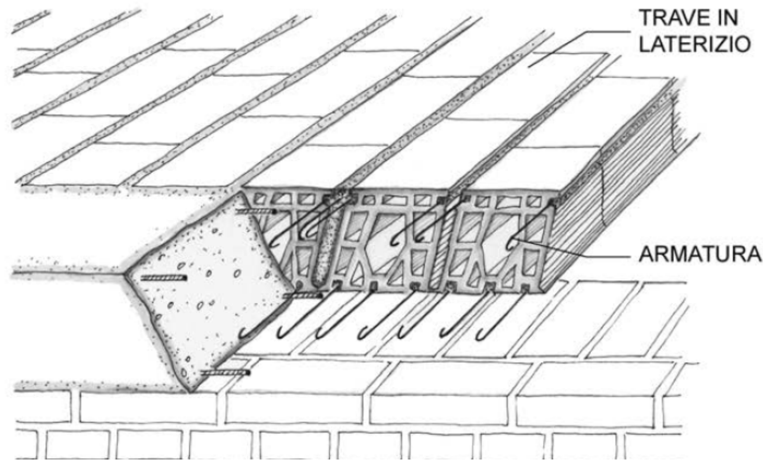
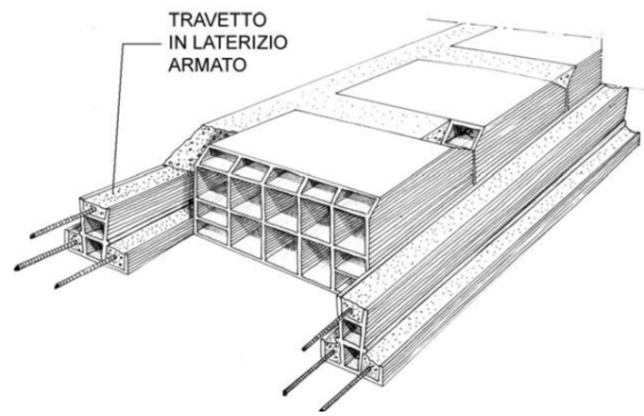
Masonry and Plasters

The use of brick masonry in late 19th and 20th century Italian architecture marked a transition from traditional stone construction to lighter and more uniform materials, especially in public, and residential buildings but their use spread to other building typologies as well. By early 1900, bricks replaced stone in many load-bearing walls due to their structural efficiency and availability. In cities, up to five stories buildings were entirely constructed with load-bearing solid bricks (mattoni pieni). Load bearing structures in this period used thick brick walls, often reinforced with steel or iron tie rods for improved seismic resistance, particularly in Northern Italy[5]. In the late 1930s, hollow bricks also began to be largely used in load bearing walls with reinforcement. They proved to be cost effective and lighter alternative to solid bricks.

Mortars varied based on regional traditions and material availability. In the 1900s – 1930s, lime-based mortars dominated, offering flexibility and breathability. They were often mixed with sand, pigments and animal glue. Marmorino or stucco lucido were used in high quality finishing projects which gave the plaster a look of stone. In the late 30s and 40s, industrial advancements led to the introduction of cement into traditional plasters, mainly to increase durability and resistance to weathering. The other widely used plaster during this time is the Terranova Plaster, originally made with powdered hydrated lime, waxes, oils and mica flakes, which gives it a reflective quality. Lime remained a dominant component for mortar and plasters with a sparing use of cement[6].





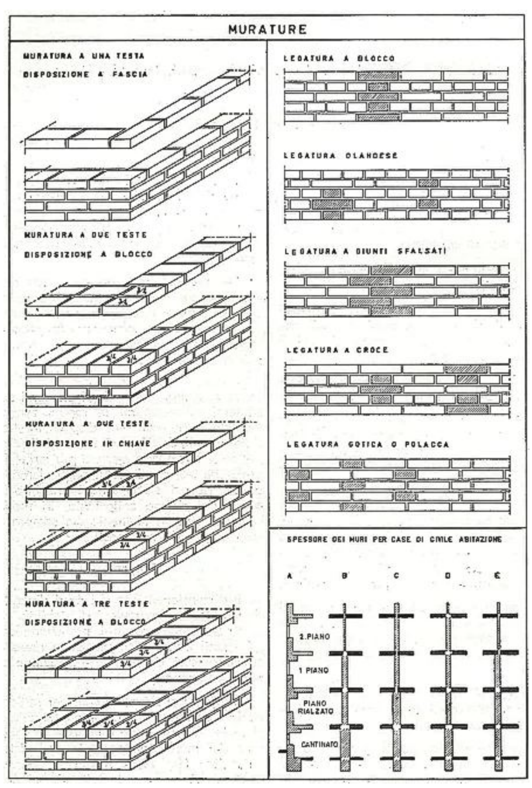


Fig. 1 (above). S.A.P. Slab. Source: http://www.esamedistatoarchitetti.com/1/upload/cap.6_solai_a_struttura_mista_light.pdf (consulted on 10/01/2025)
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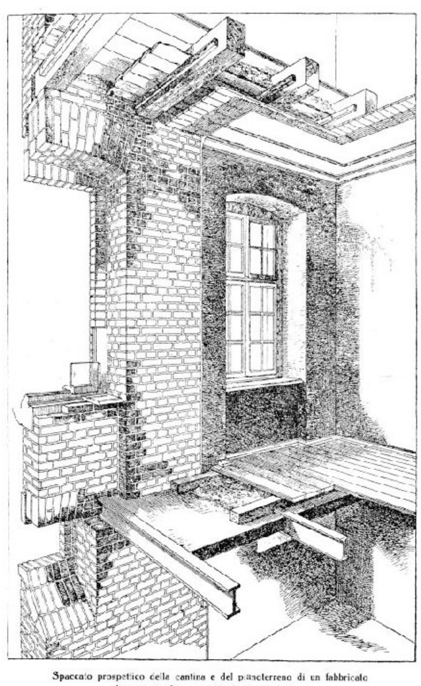
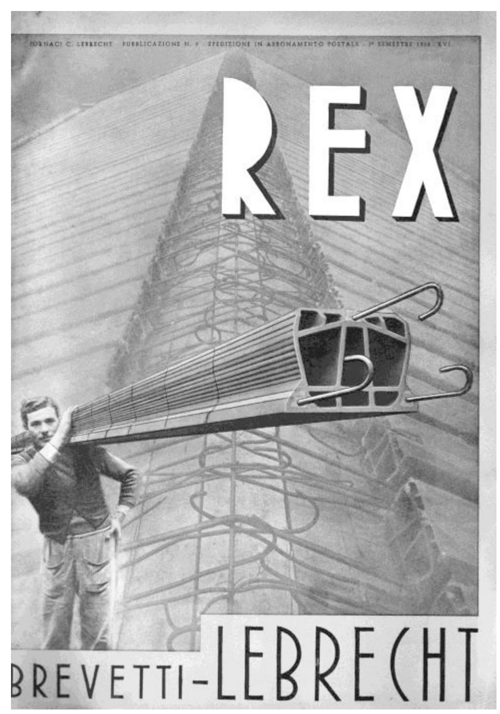
5) De Fino, Carla. 2008. Il Recupero Sostenibile dell'edilizia dei primi decenni del Ventesimo Secolo Mediante Materiali e Techniche Innovative. PhD Thesis, Basilicata: Consiglio Regionale Della Basilicata.
6) Pittaluga, Daniela, and Juan Antonio Quiros Castillo. 2024. "Surfaces of 20th century facades: reflections on their archaeological awareness." TEMA, Technologies Engineering Materials Architecture, 10 (1). doi:10.30682/tema100001.

Steel Framework in Structural Systems

In the early 1900s, iron and steel were primarily used for horizontal structures, particularly in flooring systems, where steel beams supported brick vaults or precast concrete elements, enabling larger spans and thinner floor profiles. Hybrid structural solutions were common, where masonry load-bearing walls combined with steel or reinforced concrete beams, ensuring stability. By the 1930s, steel was increasingly integrated into reinforced concrete structural elements, staircases and roofing systems. The use of steel profiles (I-beams, doble-T beams) became standard in multi-story buildings, where they were embedded into concrete slabs. Steel frameworks, however, remained a secondary choice due to restrictions on material imports under the fascist regime and were mainly used in industrial buildings or bridges. Reinforced concrete replaces steel as a dominant structural system driven by economic and regulatory considerations[7].

Fig. 4 (left). Hollow brick horizontal structures introduced in 1928 but began to be used in late 1930s. Elaboration in Tabarroni's archive[8].
Fig. 5 (right). Elaboration from the Book of Pincherle Muratori showing a perspective section of steel beams used in floor slab above the basement[9].





7) De Fino, Carla. 2008, op. cit., pp. 112-152.
8) Barozzi, Anna, and Luca Guardigli, 2009, *op. cit.*
9) *Ivi.*

Glass and Metal for Facades and Windows

the use of glass and metal in early 20th century Italian architecture signified a transition toward modernist principles, emphasizing, lightness, transparency, and functionality. Advances in industrial glass production and metal fabrication enabled the widespread adoption of large windows and steel or aluminum frames especially in the Rationalist time.

In the early 1900s, wooden frame windows were still common, but as the production of iron and steel improved, metal-framed windows gained popularity for their ability to support larger glazing and to be molded in any shape which is difficult with wooden frames. In Rationalist architecture, continuous glazing bands and large steel-framed openings were a defining feature[10] (as evident in the Sanatorium of Borsalino). By the 1930s, use of aluminum and stainless steel in window frames became more common, offering greater resistance to corrosion compared to traditional iron. However, due to high production cost, the preference was given to steel framed windows, while wooden frames continued to be utilized in smaller projects[11]. Use of metal was not only limited to windows and other elements, but also in roofing, especially large roofing and dome structures, which were then covered with bitumen to protect from rainwater[12].

10) De Fino, Carla. 2008, op. cit., p. 182.
11) *Ibidem*, p. 197.
12) Barozzi, Anna, and Luca Guardigli, 2009, *op. cit.*

1.3 Analysis of Materials in the Church of Gardella

Standing as an important example of early Rationalist architecture and as a first project of Ignazio Gardella, the building design offers many interesting aspects to study. The materials and methods of construction are one of those many aspects. Given the advancements in material technology and industrialization in the 1930s, the church incorporates a combination of traditional elements, such as solid brick masonry, alongside modern materials, including reinforced concrete, steel, and glass. Understanding the composition, function, and technical characteristics of these materials is essential for both historical documentation and restoration planning.

The selection of materials in the church building reflects a balance between durability, cost efficiency, and spatial expression. This section will examine the materials of structure and finishing details used in the church, emphasizing their functional and / or aesthetic roles in the design.

Structural Materials

a. Brick Masonry as Load-bearing Elements.

The main load bearing elements in this church are the Solid Brick Masonry walls. The hypothesis of them being solid brick masonry comes from the study of typical wall dimensions from 1900s to the 1930s. This is also indicative from the thickness of the walls which is up to 60cm in the central nave. The hypothesis has also been double checked by studying the brick bonds exposed in the degraded areas of the façade. Since the areas of Morgue and rectory (north and south wings) were not a part of the survey, their wall dimensions have been hypothesized using the same method as their facades have more than one location of exposed bricks which has helped in creating a conclusion. This conclusion is purely based on observation and the closest similarity with the masonry bonds commonly used.

Fig. 6 (left). Picture of the exterior wall of the Central nave showing exposed "Four headed cross weave".
Fig. 7 (right). Picture of the exterior wall of the Morgue (South wing) showing exposed "Two headed gothic bond".

As per this analysis, there are two types of bonds used in this construction:

1. Four Headed cross weave bond "Tessitura croce a 4 teste" – 50cm (for the central nave area.
2. Two headed Gothic bond "Tessitura gotica a 2 teste" – 25 cm (in both north and south wings.

b. Reinforced Concrete

As a newly explored form of construction material in the 1930s, the use of reinforced concrete in this building is mainly in the horizontal system, that is the floors and the roofs. The only part where it has been used in the vertical system, as per the analysis, is in the structure of the bell tower. It is comprised of columns and connecting beams which are very visible on the outside and make a very prominent element of the front (east) façade of the building.
In the roofs and slabs, as already been discussed, the probable system used can be the slabs in latero-cementizio (brick-concrete) as this was the newly explored and most common system during that time.

c. Wall Finishes

Overall, the exterior finishes of the church are simple plaster and paint, except in some areas where additional materials have been used, probably for waterproofing or other purposes. During a restoration project, it is important to identify with laboratory testing of the materials that which type of plaster is used in the original finishes to propose the best possible solutions for the durability of the structure. This is not a scope of this thesis, however, some of the factors have been highlighted here which may be helpful in further research.

Fig. 8 (left). Perspective views of the Bell Tower, showing a column beam structure. Source: by the authors.

Fig. 9 (right). Perspective views of the Bell Tower, showing a column beam structure. Source: by Team DIRECT.

Fig. 10 (below, left). South Wing Façade – showing clear differentiation of plaster in upper and lower part and the addition of blue ceramic tiles.

Fig. 11 (below, right). North wing Façade – shows a much smoother and less deteriorated finish.

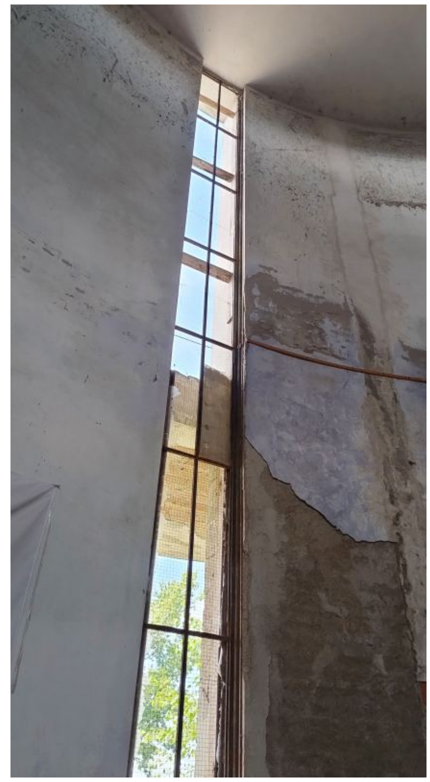
Fig. 12 (left). Type 1 – Wooden frame and Shutter with shutter box outside.
Fig. 13 (center). Type 1 – Module 2 – Wooden frame windows, closed with planks, without Shutter.
Fig. 14 (right). Type 2 – Double casement, wooden frame with shutter.
Fig. 15 (next page, abow, left). Type 3 – Triple casement window – wooden frame and shutter.
Fig. 16 (next page, abow, right). Type 4 - Slit Windows with wooden frame, closed with metal wire mesh with a metallic frame.
Fig. 17 (next page, center, left). Type 5 – Wooden window frame closed with wire mesh and wooden planks attached to the exterior of the original frame.
Fig. 18. (next page, center, right). Type 6 - Triple pane casement window closed with wire mesh and wooden planks attached to the exterior of the frame.
Fig. 19. (next page, below). Circular windows with thin metal frame. These are closed by adding planks to the interiors of the windows.

Sources: all the photos are taken from the survey by Team DIRECT and/or by the authors.

Based on the analysis, it seems that the plasters used for different blocks are a mix of cement and lime-based mixtures. This is evident in the façade analysis of the southern wing (morgue) where a demarcation line has been noticed with the change of plaster. It could have been that the older finishes were replaced with newer mix of cement-based plaster. Apart from this, ceramic tiles have been used in the same southern wing at the base, which also seem to be an attempt of restoration, forming a damp proof course to protect from rising damp but it seems to have not worked so well.

d. Window Finishes

There are a total of 7 typologies of windows as explained in Part IV. Typical materials used in the windows are wood, glass, and metal. Almost all the windows on the ground floor are closed with wooden planks for protection from environmental and physical factors. The typology of these windows are Casement hinge widows as well as Vasistas. Photos of all window types are shown below.


e. Roof and other Finishes

The roofing system is flat horizontal reinforced brick concrete structure as already mentioned along with a dome above the altar space. The exterior surface of the roof has been covered with bitumen sheets, which also include the exterior surface of the dome. The structure of the dome comprises steel and wooden elements, together with radial wooden sheathing as a top surface covered with metal sheets (in zinc or copper) See Part IV, 3.5 for details. Secondly the material of the clerestory windows of the dome has also been realized in some form of metal. Provided the corrosion on the surface of the window frame, it is unlikely that they are of aluminum.

Metal has also been used in the coping of the parapet walls, which seems to be an attempt of restoration. However, this application does not seem to be a successful attempt, considering the degradation of the walls due to dripping water on the surface (coltura) below the coping. Lastly, the semi-circular elements on the roof, assumed as anchor points for restoration works, are considered to be of concrete.

Fig. 20. Present condition of the roof.
Source: Team DIRECT

1.3.1 Material Analysis – West Facade

West façade has been selected for mapping materials for the purpose of analysis as it is the only façade which visibly incorporates all primary materials used in the church's construction. Additionally, its orientation and exposure to weathering factors make it valuable reference for assessing material behavior, construction techniques and aging patterns to properly identify structural and aesthetic characteristics. The analysis at a larger scale is attached to the appendix of this thesis.

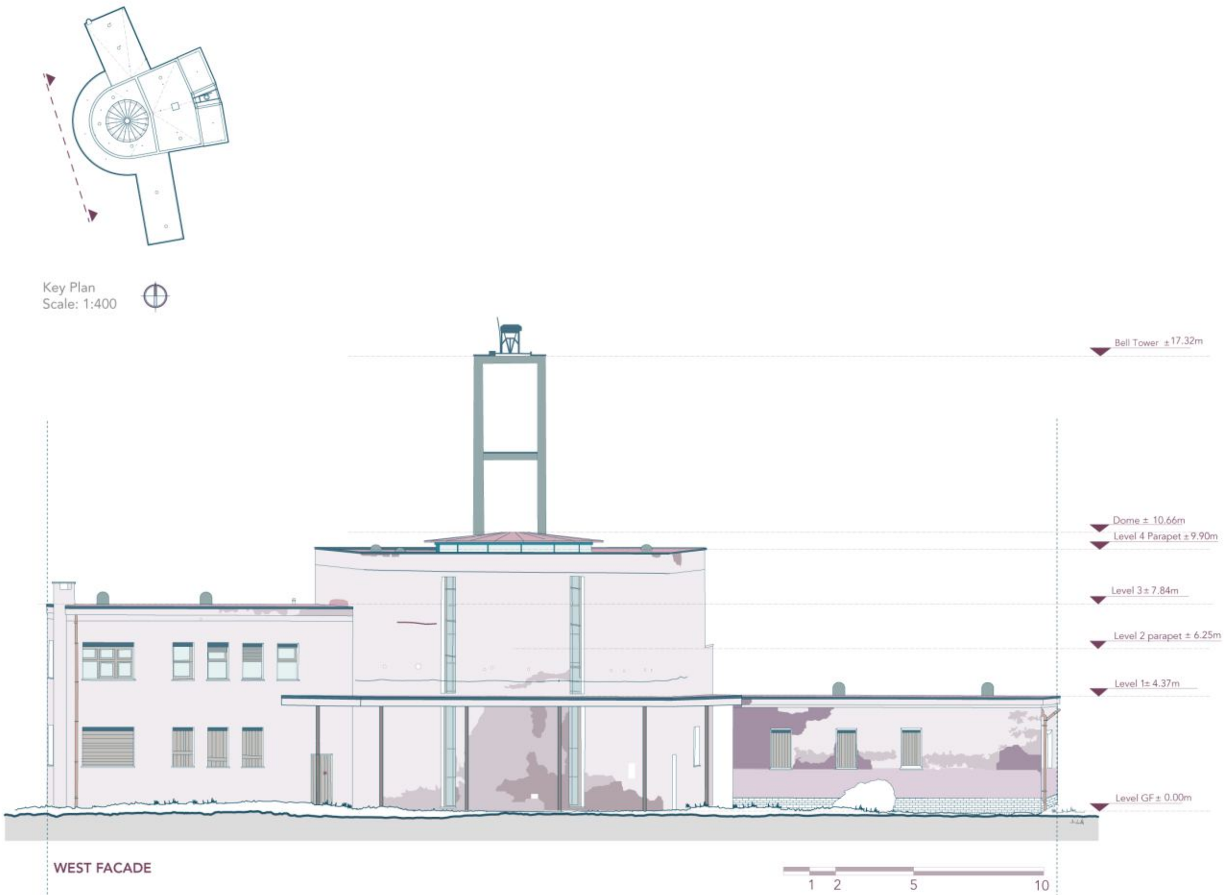


Fig. 21. West Façade Material Mapping in reference to the Orthomosaic. Source: Elaboration by the Authors

Material Legend – Part 1

Load Bearing Elements

Cross weave bond Four headed

This hypothesis is based on the thickness of these walls. The four headed corss weave bond is up to 50cm thick and these walls are from 50cm to 60cm thick. This synthesis proves that these are solid brick walls which support the large open space and ceiling of the alter. The bond however, seems a little irregular at certain places but the overall structure is intact.

Gothic bond Two headed

The interior of this area was not surveyed but the exposed brick bond allowed to determine the thickness of these walls, which in design documentation is set to 30 cm. The Block weave bond gives a brick wall of 25 cm excluding finishes.
Parts of the perimeter walls of this wing has cracks and fissures, indicating structure has been compromised.

Steel & Concrete Elements

Reinforced Concrete Elements

Found in Bell Tower, Chimney, and roof anchor elements

Steel Columns

6 Steel columns of 5 cm radius supporting roof of Ambulatory

Building Services

Drainage Pipes

The drainage pipes on the facade seem to be in plastic, vey similar to PVC. Comparing with old photos of the church, these pipes are seemingly original and have not been replaced.

Wall Finishes

Paint on Plaster Type 1

Typical Paint finish found on the facade. The texture of finish is different from that of Type 2 which is apparent in the photographs of how the paint layer has been detached.
For this reason, a differentiation is highlighted which can be due to different types of plasters used.
This texture suggests use of cement plaster for these surfaces.

Paint on Plaster Type 2

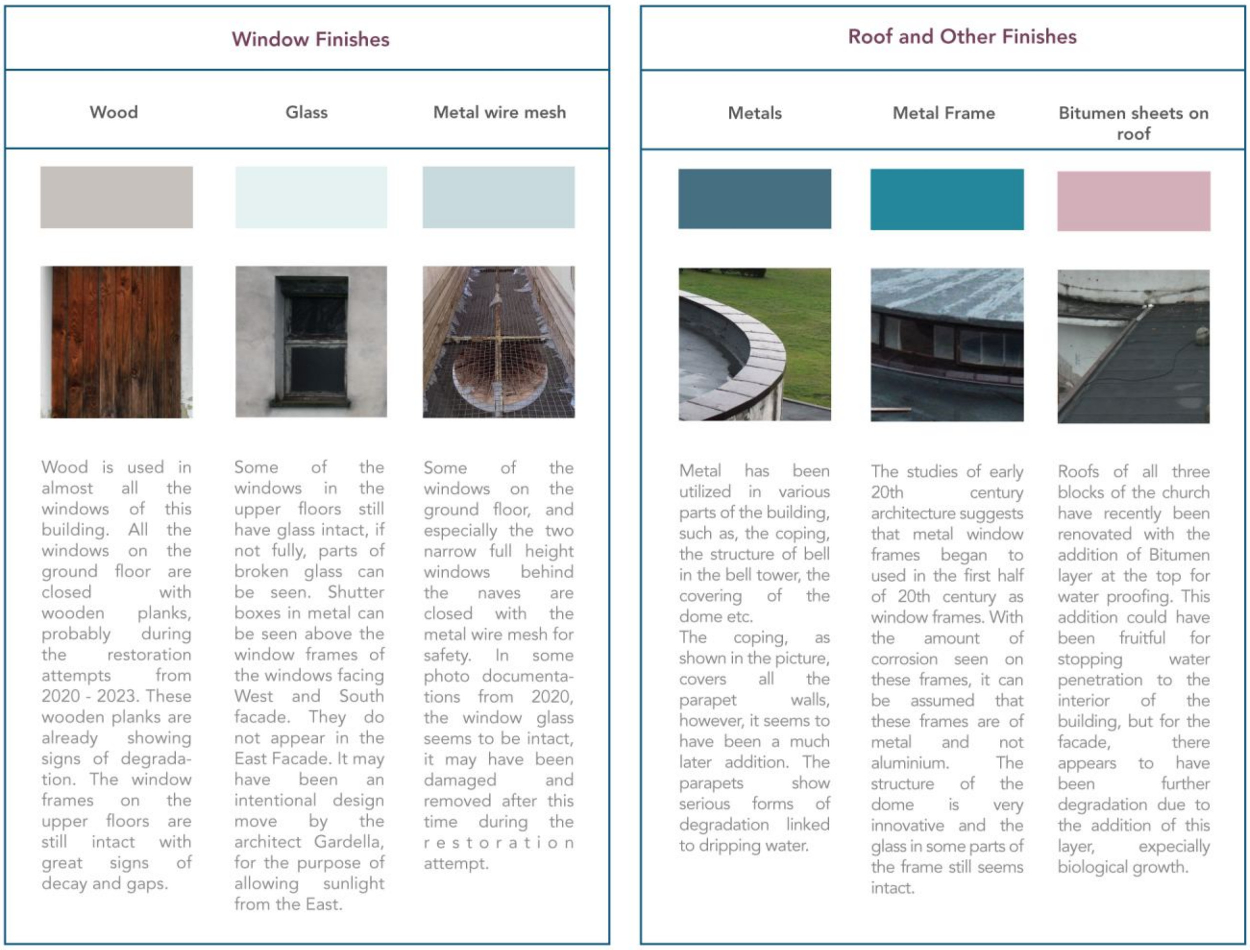
The texture of surface suggests that a different kind of plaster has been used on this surface. The float and scratch coat in the degraded parts suggest a lime based or soft cement based plaster used in this area. The peeling paint layer suggest the issue of rising damp and the structure is in dire need of restoration.

Exposed Plaster Layer

All three layers, that is, the scratch coat, float coat and the finish coat are exposed. Flaking layers of paint can be seen in these area. Overall the condition of finishes are severely deteriorated causing various forms of detachment and disintegration.
From the photographic analysis, the plaster seems to be of Type 1, which is cement based (hypothesis).

Ceramic Tiles

At the base of South wing there are ceremic tiles, which seem to have been an addition to form a damp proof course. This addition does not seem to have a greater impact on the rising damp situation as can be seen from the condition of degradation.
These tiles do not go with the rest of the design language of the building.

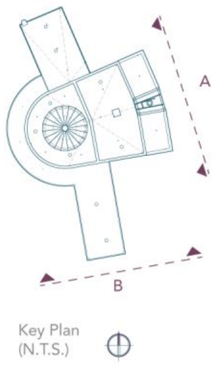


Material Legend – Part 2

1.3.2 Analysis of Degradation and Solutions.

The degradation analysis of all four facades, conducted as a part of this thesis, provides an evaluation of the material decay processes affecting the church building. By documenting and categorizing various forms of deterioration, this study highlights the most prevalent issues found in the buildings of this period. The findings of analysis serve as a foundation for proposing targeted restoration solutions, ensuring that interventions align with the physical and chemical properties of the original materials. Referring to the research and literature on the restoration of 20th century buildings, the proposed solutions aim to preserve structural integrity, mitigate further damage, and maintain the architectural authenticity of the building. The following part shows the mapping of degradation and the categorization of types and causes with their solutions towards the end of this section. The analysis boards at a large scale are attached to the appendix of this thesis at a larger scale.

Fig. 22. Types of degradation on East and South Façade. Source: Elaboration by Authors.



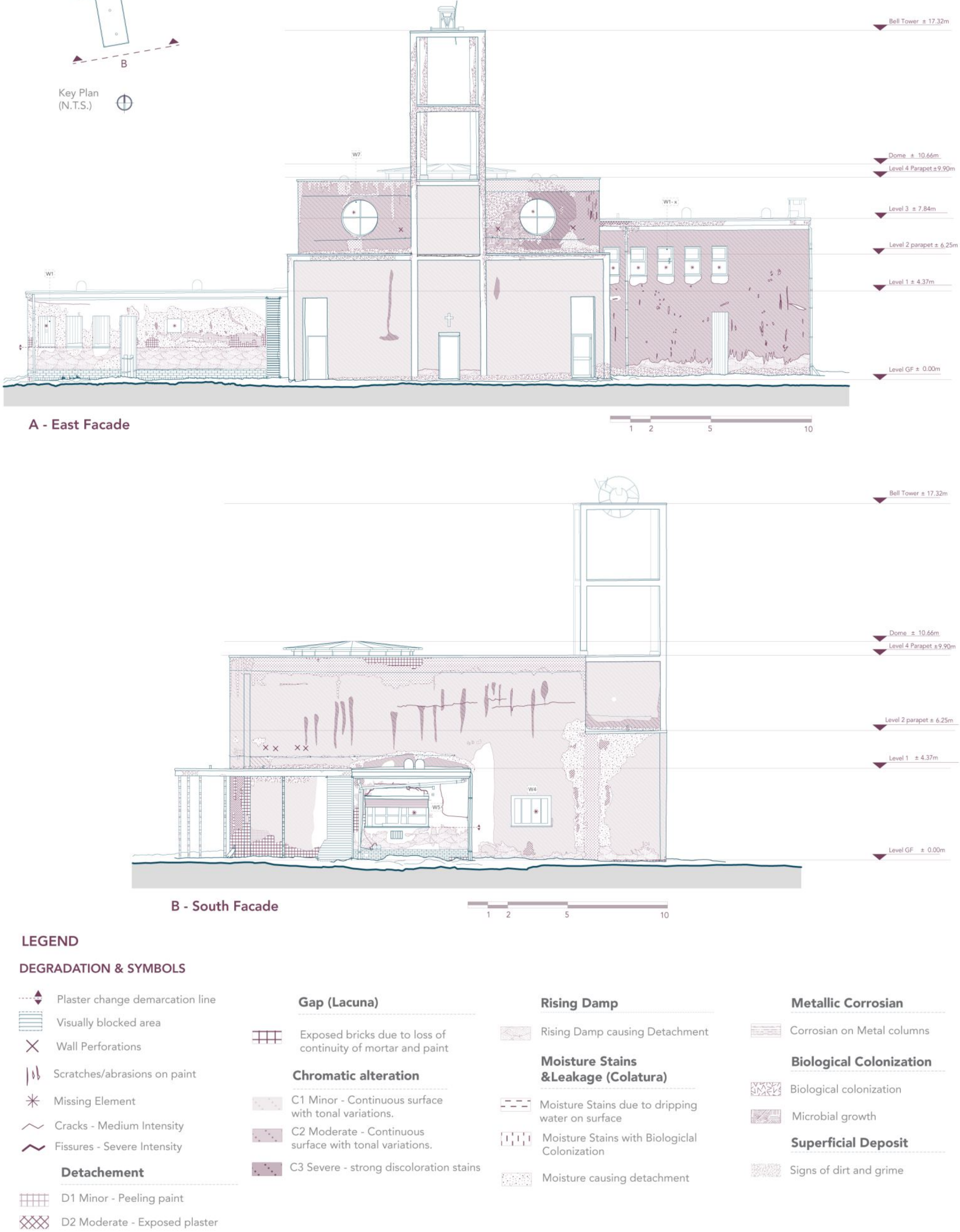
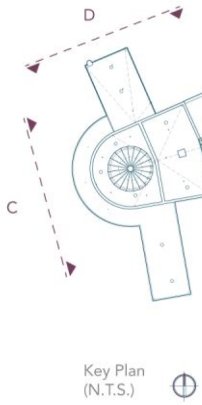


Fig. 23. Types of degradation on West and North Façade. Source: Elaboration by Authors.



C - West Facade

D - North Facade

LEGEND

DEGRADATION & SYMBOLS

- Plaster change demarcation line
- Visually blocked area
- Wall Perforations
- Scratches/abrasions on paint
- Missing Element
- Cracks - Medium Intensity
- Fissures - Severe Intensity

Detachement

- D1 Minor - Peeling paint
- D2 Moderate - Exposed plaster

Gap (Lacuna)

- Exposed bricks due to loss of continuity of mortar and paint

Chromatic alteration

- C1 Minor - Continuous surface with tonal variations.
- C2 Moderate - Continuous surface with tonal variations.
- C3 Severe - strong discoloration stains

Chromatic Sampling

- Testing area for Paint finishes

Rising Damp

- Rising damp causing Detachment

Moisture Stains & Leakage (Colatura)

- Moisture causing detachment
- Moisture Stains due to dripping (leaking) water on surface
- Moisture Stains with Biologiclal Colonization

Metallic Corrosian

- Corrosian on Metal columns

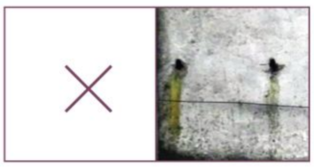
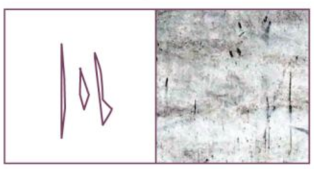
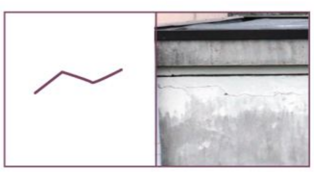
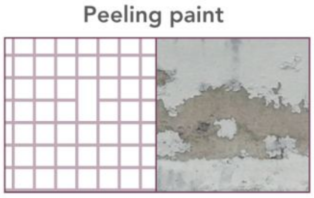
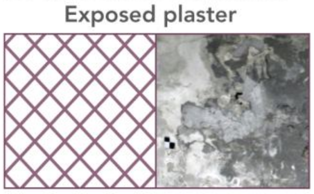
Biological Degradation

- Biological colonization
- Presence of Vegetation
- Microbial Growth

Superficial Deposit

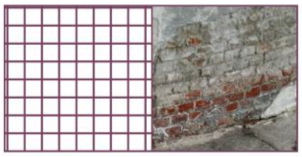
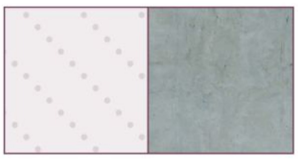
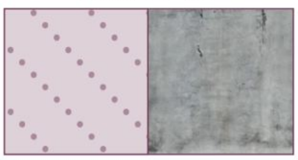
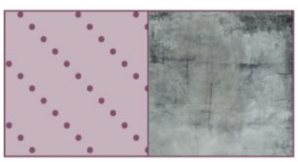
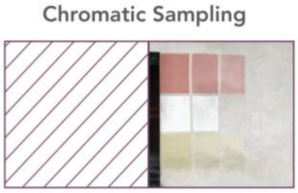
- Signs of dirt and grime

Legend, Description & Causes of Degradation

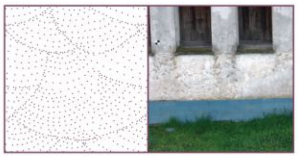
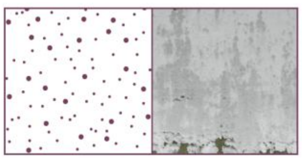
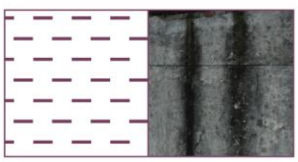
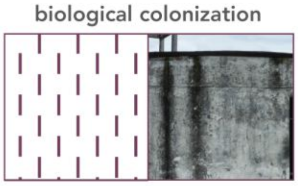
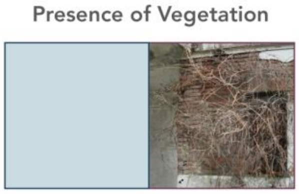
	Type / Symbol	Description	Causes
Material Incompatibility	**Plaster change demarcation line** 	This part of the facade shows ***two types of plaster*** applications. The upper part of the mortar appears smoother and more uniform in texture (likely a cement based mixture). The lower part exhibits more pronounced degradation and moisture related damage (likely a lime-based or weaker cement lime mixture). There is also ***discoloration*** or possible ***erosion*** of plaster in lower part and worse material cohesion.	The two mortars reflect two different times of application, with material quality or composition varying due to factors such as local availability or cost. The lower line of mortar may indicate a repair or restoration phase, where a different, potentially less durable or more porous mortar was used, possibly to address earlier degradation due to rising damp issues.
Structural Degradation	**Wall Perforations** 	The holes appear small and localized, with dark discoloration or staining around them. The staining suggests potential water ingress, or material seepage from within the wall. They are relatively uniform in spacing and alignment, suggesting an intentional or structural purpose. The discoloration below the holes hints at potential water seepage, mold, or biological growth, indicating moisture-related issues	These holes may have been created to anchor structural elements (e.g., scaffolding, signage, or bracing) during construction or previous repair work that began in 2020. Over time, the absence of proper sealing allowed moisture ingress, leading to staining and potential internal degradation.
	Scratches/abrasions on paint 	The black marks are irregular and vertical to slightly diagonal. Some are thin and linear, while others are broader or smudged. They appear scattered across the wall surface, with a higher density in certain areas, suggesting external forces or contact with objects. The wall has an uneven finish, and the scratches are superficial, likely not penetrating deeply into the plaster or render.	The marks could result from physical contact with sharp or abrasive objects, such as scaffolding, ladders, or tools scraping against the wall during construction, maintenance, or repair activities. The irregularity and variety in depth/width of the scratches suggest accidental or unintentional abrasion.
	Crack - Medium Intensity 	The crack appears as a horizontal fissure that extends below the parapet-wall junction but does not exhibit significant displacement or crumbling. The formation of these cracks can be linear or rectilinear and their proper intensity can be tested through a series of structural analysis performed by experts.	Major causes can be Thermal expansion and contraction - Daily and seasonal temperature fluctuations can cause materials to expand and contract at different rates. This cyclic movement creates tensile stresses at rigid connections, such as the parapet-wall junction. Water Ingress and Freeze-Thaw Cycles can be another reason. Since there is an obvious rising damp from the ground, this can be due to Settlement or Structural Movement of the foundations as they cause horizontal cracking.
	Fissures - Severe Intensity 	Diagonal Cracks: Typically caused by differential settlement or structural movement, Horizontal Crack: Likely due to thermal stress or weakened structural elements, especially near load concentrations. The cracks show advanced propagation and connect multiple points, indicating compromised structural integrity. Some areas show detachment of plaster, which exposes the underlying masonry to environmental damage.	Foundation movements leading to differential settlement may have caused tensile stresses in the upper masonry layers, leading to diagonal cracks. The alignment of diagonal cracks suggests stress redistribution due to an unstable load-bearing element. It can also be due to the inadequate structural reinforcement in areas like window lentils or slab-wall junctions leading to shear or tensile failures. Other reasons are same as above aggravated to a worse condition
Disintegration & Detachment	**D1 Minor Detachment - Peeling paint** 	The paint layer exhibits detachment from the plaster surface, with sections curling, flaking, or completely missing. Edges of the detached paint are jagged, and the surface underneath often shows signs of discoloration, dampness, or roughness. The remaining paint appears brittle and uneven, indicating a loss of adhesion to the underlying surface.	Levels of moisture in the wall, due to rising damp, and inadequete waterproofing. The type of paint used may not be compatible with the plaster or previous paint layers (e.g., oil-based paint over a water-based primer or vice versa). These reasons leads to weak bonding and eventual peeling over time.
	D2 Moderate Detachment - Exposed plaster 	The paint layer has completely detached in some areas, exposing the underlying plaster. The exposed plaster shows, rough texture, and potential signs of minor degradation or cracking. The boundary between the detached paint and the intact surface is irregular, with adjacent paint peeling or curling at the edges.	Prolonged exposure to water through rising damp, leaking structures, or condensation can weaken both the paint and plaster. Moisture is penetrating the plaster, causing crumbling, disrupting the paint's adhesion, leading to detachment. Over time, the plaster layer may develop cracks, crumble, or weaken due to natural aging, freeze-thaw cycles, or exposure to moisture.

Legend, Description & Causes of Degradation

Surface Degradation

Type / Symbol	Description	Causes
Lacuna (Gap) 	The plaster layer is entirely missing in certain areas, exposing the underlying brick substrate. The exposed brickwork shows surface weathering, discoloration, and slight mortar degradation between bricks. Adjacent to the lacuna, the plaster exhibits flaking and cracking, suggesting ongoing deterioration.	Exposed brickwork is the advanced stage of degradation. It seems to be due to the rising damp and prolonged exposure to the moisture. Environmental conditions, such as exposure to freeze-thaw cycles, harsh winds, & UV radiation, could have degraded the exposed plaster layer and mortar joints for it to fully detach from the surface exposing bricks.
Chromatic Alteration - C1 Minor 	Subtle discoloration or variation in tone compared to the surrounding facade. appears as slightly darker patches, with no sharp boundaries or significant textural change. These alterations are more evident in areas of the facade likely subjected to slightly different environmental conditions, such as UV light or water retention.	Water absorption due to inadequate waterproofing or retention in porous materials. Deposition of airborne pollutants and dirt, which adhere to damp surfaces. Incomplete drainage from rainwater runoff, leaving behind dirt and moisture residues. It can also be due to UV radiation breaking down the pigments in the paint. It has led to Aesthetic disruption and indication of moisture retention, which can lead to deeper material damage over time.
Chromatic Alteration - C2 Moderate 	The facade shows more pronounced discoloration compared to C1 alterations, characterized by vertical streaks, darker patches, and uneven shading. The streaks can either be water runoff or the superficial scratches. The background surface shows widespread subtle darkening, indicating general weathering or pollutant accumulation.	Same as above. In addition, The scuff-like marks may result from incidental contact with objects (e.g., tools, ladders, or maintenance activities) or superficial dirt streaks from nearby activity.
Chromatic Alteration - C3 Severe discoloration 	This type displays severe discoloration, characterized by dark streaks, diffuse stains, and localized spots of intense discoloration.	Persistent water infiltration and runoff causing saturated materials darken in color, and water runoff causes streaking and staining. Loss of cohesion in the plaster or concrete due to freeze-thaw cycles, chemical reactions, or sustained exposure to environmental stressors.
Superficial Deposit 	In the corners of roof and wall joints, under the ambulatory ceiling, there are visible deposits of dirt, animal excretion, nesting material or pollutants causing dark marks on the finishes. There seem to be the spider webs as well. These deposits are non biological in nature but result from the presence of animals or insects.	Spiders, or other insects using corner for shelter, depositing organic material like webs, egg sacs or droppings. Since the area is protected from direct sunlight, it is an ideal place for animal colonization. In addition, with winds, there is accumulation of dust and grime causing spots on the surface. Lack of regular cleaning has left long term marks on the finishes.
Chromatic Sampling 	This is not considered as a degradation type, instead an intervention method used to test and match the original or intended paint layers for restoration purposes. If executed improperly, they may leave patches unprotected, which can expose the underlaying plaster or masonry to weathering. However, in this case, the sampling is rightfully applied to the least degraded wall.	It often involves removing existing paint layers, leaving the plater or masonry temporarily unprotected. It is done because, as the analysis shows, almost all the building finishes have been degraded and have been exposed to chromatic alteration. However, to promptly address the issue, the final finishes must be decided sooner.
Metallic Corrosion 	Uniform rusting across the surface of the columns. Visible dark orange and brown streaks are characteristics of advanced corrosion. Seems the columns can be structurally compromised due to neglected corrosion and advanced oxidation.	Absence of anti corrosive finish, leaving steel exposed. High humidity and temperature fluctuations, coupled with rain exposure and ground moisture are promoting corrosion. Aging of material can be another reason of deterioration as columns from 1932 have exceeded their protective lifespan. Lastly, poor water drainage / slope of the pavement also leaves the columns in direct contact with water accelerating rusting.

Legend, Description & Causes of Degradation

Category	Type / Symbol	Description	Causes
Moisture Related Degradation	**Rising Damp Causing Detachment** 	The degradation visible includes significant peeling and flaking of the wall's paint layer, exposing the underlying plaster. The deteriorated wall shows multiple types of detachment and growth of moss and algae.	The observed degradation can be attributed to rising damp, which causes moisture to ascend through the wall via capillary action. This phenomenon is often exacerbated by the absence or failure of a damp-proof course DPC, poorly drained soil near the structure, or a high groundwater level. If it is not treated, over time the absorbed moisture dissolves more salts within the wall materials causing further degradation.
Moisture Related Degradation	**Moisture stains Causing Detachment** 	The moisture stain surrounding the central dark streak is lighter in color, with a grayish tone, spreading across a wider area on both sides. The irregular edges and discoloration suggest moisture has seeped into the wall's surface layers , likely saturating the plaster or paint. This area shows signs of surface deterioration, such as minor peeling or roughness.	Caused by the presence of water or moisture in the material, moisture stains are characterized by color changes, usually darker than the original material, and may be accompanied by phenomena such as efflorescence, surface cohesion loss, or biological growth. These stains indicate underlying issues like infiltration, condensation, or rising damp and usually appear irregular, depending on the source and path of the water.
Moisture Related Degradation	**Colatura - Dripping Water** 	Dark moisture stains on the upper portion of the wall, particularly concentrated beneath the metal coping. The discoloration appears as streaks and patches, suggesting water dripping. The stains are darker in some areas, indicating prolonged exposure to water.	The moisture stains are due to water dripping water from the parapet causing stain under the metal coping. This could result from inadequate waterproofing or improper installation of the coping, allowing rainwater to seep beneath or flow over its edges. Repeated exposure to dripping water leads to moisture accumulation and stains on the wall surface, and the absence of proper drainage exacerbates the problem.
Moisture Related Degradation	**Moisture stains with biological colonization** 	Vertical black streaks originating from the parapet area and extending downward, suggesting dripping water (colatura) and organic residue. In this case, moss patches and darkened greenish areas hint at the presence of mold or algae colonies, often caused by continuous damp conditions. In case of North Facade, there is a patch of exposed brickwork, suggesting detachment of plaster.	The lack of effective coping and drainage system in the parapet area has let water to run along the wall for long period of time. Dripping water leaves mineral residues and provides a suitable environment for algae or mold to grow. Moisture has also facilitated the growth of microorganism and black fungi. Lack of hydrophobic or protective coatings has allowed water to infiltrate and detach the plaster.
Biological Degradation	**Biological Colonization** 	Persistent degradation at the wall base with visible dark greenish discoloration, mainly at the grass-line. It shows presence of moss and algae patches indicating moisture exposure. A clear demarcation between the green-stained area and the rest of the wall indicates interaction with soil moisture. Prolonged moisture exposure has led to biological colonization.	There are multiple causes of this, firstly it is rising damp, a capillary action drawing water from the ground into plaster. Secondly, poor water drainage near the wall, or absence of DPC layer. Thirdly, the consequence of above two factors have allowed biological growth, encouraging moss, algae and fungal growth. The last factor is proximity to vegetation and soil, adding organic matter and promoting microbial colonization.
Biological Degradation	**Presence of Vegetation** 	Plant and moss growth are visible, particularly in cracks and deteriorated plaster areas on the East and North facade. Vegetation appears to root within openings in the brick or mortar joints. Moisture and organic matter accumulation are evident, facilitating biological colonization and damage to the structure	Existing cracks and voids in plaster or masonry provide entry points for plant roots to anchor. Poor maintenance of parapet or coping above allows water infiltration, encouraging vegetation. Prolonged dampness, insufficient drainage, insufficient exposure to sunlight and absence of biocidal or hydrophobic coatings are all the factors allowing the growth of vegetation.
Biological Degradation	**Microbial Growth** 	This is only apparent on the north facade. The irregular pattern of dark and light spots are the characteristics of microbial growth. Areas of surface erosion likely caused by reduced sun exposure and poor drainage on the north facade. This type of degradation is linked to chemical damage of the cementitious material such as production of organic acids, sulfuric acid or other compounds which degrade the material.	Damp environment of the surface promoting microbial growth causing chemical damage to the surface. Porous surface of plaster retaining water. Lack of maintenance and accumulated organic matter and environmental pollutants on the surface contributing to soiling and discoloration.

Solutions and Interventions

The solutions to the most common forms of degradation are discussed below.

Compatibility of Plasters

The plastering incompatibility phenomenon is only visible in the southern block of mortuary where the upper and lower plaster degradation shows different material composition of both plasters. Before intervention, it is essential to analyze the chemical and physical composition of both plaster layers. Laboratory tests such as X-ray diffraction (XRD) and thermal analysis should be conducted to determine the chemical composition, binder types, and aggregate characteristics of both plaster layers. The plaster should match the mortar (layers used between the joints of the bricks). As studies suggest, that even though Portland cement was introduced in 1870s, but it was not used in masonry construction until the 1930s[13]. Based on literature available on the restoration of 20th century buildings, it can be assumed that natural cement mortar has been used in binder, such as air lime or hydraulic lime, and their compositions must be tested before conservation for their compressive strength, water absorption by capillary action, water vapor permeability and water vapor diffusion resistance[14]. It is also a possibility that in the rest of the parts, Portland cement has been used as that started to become common in that time.

Studies suggest that air lime mortars and lime-cement mortars used in buildings constructed between 1904-1944 are highly to intermediately prone to capillary absorption and draying[15]. With the amount of capillary action visible in the façade of southern wing, it seems highly likely that lime based mortar has been used in the original construction. For any proposal it is necessary to check which additives will be important to create compatibility with the existing plaster and to control the moisture rise in the walls.

Wall Perforations

Firstly, the stained surface must be cleaned using Biocidal cleaner to remove biological growth and the stains / discoloration around the perforations. Even though salty deposits (efflorescence) have no visible presence in the area, if in case through testing it appears, a neutral pH rust remover or poultice with clay and distilled water can be used to remove any rust or salt content present. Holes must then be filled with suitable lime-cement based mortar, with fine aggregates for larger voids. For smaller perforations, lime putty filler can be used. Finally, the surface must be finished with required aesthetics and materials.

13) Mack, Robert C., FAIA, and John P. Speweik. 1998. Repointing Mortar Joints in Historic Masonry Buildings. 2 Preservation Briefs, Washington D.C. : U.S. Department of the Interior National Park Services Cultural Resources.

14) Andrejkovi ová, Slavka, Hamid Maljaee, Diana Rocha, Fernando Rocha, Maria R. Soares, and Ana Velosa. 2022. "Mortars for Conservation of Late 19th and Early 20th Century Buildings — Combination of Natural Cements with Air Lime." materials 15: 3704. doi: 10.3390/ma15103704.

15) Almeida, Luís, António Santos Silva, Rosário Veiga, and José Mirão. 2023. "20th Century Mortars: Physical and Mechanical Properties from Awarded Buildings in Lisbon (Portugal)—Studies towards Their Conservation and Repair." Building Materials, and Repair & Renovation 13 (10): 2468. doi: 10.3390/buildings13102468.

Surface Cleaning

Degradation types such as Scratches, Superficial deposit, and Chromatic Sampling or Graffiti can be managed by cleaning the surfaces using low pressure water washing and soft natural-bristle brush to remove surface dirt and loose particles without damaging the plaster. For persistent grime and dirt, additional detergents or surfactants can be used such as non-ionic detergents and scrubbing with nonmetallic brushes[16]. A more interesting method is put coatings with self-cleaning properties on the wall surfaces exposed to rain and winds such as hydrophilic surface coating or nanoparticle-based treatments, which facilitate the natural runoff or dirt and pollutants during rainfall[17]. However, any chemical cleaning agents should be carefully selected to avoid surface discoloration or residue buildup. After cleaning, a breathable protective coating applied to reduce future contaminant adhesion, ensuring long lasting restoration results.

Cracks and Fissures

The first step in restoration should involve diagnostic surveys using non-destructive methods, such as thermography and laser scanning, to assess crack depth, movement, and the potential structural impact[18].

For non-structural cracks, the recommended repair method involves repointing with compatible mortar, ensuring that the new material has similar thermal expansion and permeability properties as the original masonry. In case of wider cracks due to structural movement, a crack-stitching technique using stainless steel helical bars embedded in grout can restore wall stability and load distribution. In situations where cracks have caused void or detachment, low pressure grout injection can be applied to bond and consolidate the affected areas[19]. For cracks occurring due to moisture infiltration (which is the case of the church), it is essential to first eliminate the source of moisture entry into the masonry by improving the damp proof course, to ensure long term and durable solution.

Detachment, Disintegration & Gaps - Peeling Paint, Exposed Plaster, Exposed Bricks

Firstly, the flaking or peeling paint needs to be removed with the help of mechanical scraping using soft blade. For stubborn areas, natural paint strippers can be used but it must ensure not affect the underlaying plaster. The underlying plaster layer should then be inspected for cracks, detachment or salt deposits using visual inspection and moisture mapping. If there are weak areas, they must be consolidated with grout injections and reapplication of mortar, which matches the original mortar. The surface should then be cleaned and left to dry before the application of primer and paint finishes. In the parts where plaster has completely detached

16) Grimmer, Anne E. 1988. Keeping it Clean: Removing Exterior Dirt, Paint, Stains and Graffiti from Historic Masonry Buildings . U.S. Department of the Interior National Park Service.

17) Brande, Thijs Van den, Bert Blocken, and Staf Roels. 2013. "Rain water runoff from porous building facades: implementation and application of a first-order runoff model coupled to a HAM model." Environmental Science Engineering 177-186. doi:10.1016/J.BUILDENV.2013.03.014.

18) Lignola, Gian Piero, and Gaetano Manfredi. 2010. "A combination of NDT methods for the restoration of monumental façades: The case study of Monte di Pietà (Naples, Italy)." Journal of Cultural Heritage 11 (3): 360-364. doi:10.1016/j.culher.2009.11.010.

19) Thomaz, Ercio, Hipólito Sousa, Humberto Roman, John Morton, José M. Silva, Márcio Corrêa, Oscar Pfeffermann, Paulo B. Lourenço, Romeu S. Vicente, and Rui Sousa. 2023. Defects in Masonry Walls Guidance on Cracking: Identification, Prevention and Repair. CIB W023, International Council for Research and Innovation in Building Construction.

from the surface, exposing bricks to vulnerable conditions, it is necessary to first analyze the content of moisture penetration in the exposed surface, and if the brick has been weakened, a deeply penetrating consolidant maybe applied to strengthen the masonry substrate. The new plaster finish should align with the original composition of mortar and plaster (such as hydraulic lime based with added natural pozzolanas). Application of Siloxane-based water repellants on the masonry can also help in long term moisture management.

Chromatic Alteration

The first step in the intervention process involves chromatic and material analysis using spectrophotometric and stratigraphic investigations to assess the extent of discoloration and identify the best restoration approach. Noninvasive cleaning techniques such as low-pressure water misting, soft brushing, and non-ionic detergents can effectively remove grime, dirt and pollution related deposits. However, if the alterations are due to material degradation, the restoration process may involve localized pigment reintegration using the composition of paints suitable for the substrate material, as these chromatic alterations can also be due to presence of inorganic pigments in the mortar. The selection of paint should be careful and protective treatments such as breathable hydrophobic coatings can be applied to prevent further discoloration while maintaining permeability of the surface.

Rising Damp

One of the most effective solutions is chemical injection treatments, which involve introducing hydrophobic materials into the masonry pores to create a water/repellent barrier. These treatments can either be solvent-based (siloxane or silicone resins dissolved in organic solvents) or water-based (silane or siloxane emulsions in water), depending on the compatibility with the existing materials. However, studies suggest that the effectiveness of these injections varies based on masonry porosity and / or wall thickness[20]. For long-term moisture control, it is crucial to improve drainage around the foundation, ensuring that water is directed away from the building. Additionally, breathable restoration plasters with high porosity and salt-resistance properties should be applied to affected walls to allow trapped moisture to evaporate without further damage[22]. Another option is a wall base ventilation system, which is typically used in the solutions for rising damp in historic buildings. It facilitates air circulation at the base of the wall, accelerating moisture evaporation, but its feasibility for the site of church needs to be studied with the help of experienced professionals.

20) Sardella, Alessandro, Paola De Nuntiis, Marzia Rizzo, Chiara Giosuè, Francesca Tittarelli, and Alessandra Bonazza. 2018. "In situ performance evaluation of chemical injections against rising damp: A case study in Italy." Measurement pp. 128-136. doi:10.1016/j.measurement.2018.08.011.

21) Lubelli, B., R.P.J. van Hees, and J. Bolhuis. 2018. "Effectiveness of methods against rising damp in buildings: Results from the EMERISDA project." Journal of Cultural Heritage 31 (Supplement): pp. S15-S22. doi:10.1016/j.culher.2018.03.025.

22) Palla, Franco, Giovanna Barresi, Ambra Giordano, Slavatore Schiavone, Maria Rosa Tarapani, Valentina Rotolo, Maria Giobanna Parisi, and Matteo Cammarata. 2016. "Cold-Active Molecules for a Sustainable Preservation and Restoration of Historic-Artistic Manufacts." International journal of Conservation Science 7 (Special Issue I): pp. 239-246.

23) Marin, Emanuela, Carmela Vaccaro, and Marilena Leis. 2016. "Biotechnology applied to Historic Stoneworks conservation: Testing the potential Harmfulness of two biological biocides." International Journal of Conservation Science 7 (Special Issue I): pp. 227-238.

Colatura (Dripping Water and Dripping water on surface with Biological Growth)

Firstly, it is important to do the diagnostic assessment of the surface using UV fluorescence imaging and microbial analysis to determine the extent and type of biological growth present. Cleaning should be done with a low-pressure water misting or soft brushing technique to remove loose deposits, followed by non-ionic detergent or ammonium-based solutions to break down mineral deposits and pollutants while preserving the original plaster or render. Where necessary, localized micro-abrasive cleaning can be applied to stubborn deposits. To prevent recurrence, a hydrophobic, self-cleaning coating can be applied to affected areas, ensuring that water droplets bead and run off the surface without depositing residues.

For the areas with biological growth, after the mechanical removal of biofilms, biocidal treatments should be applied to prevent recolonization. To ensure long term treatment, it is recommended to address the main causes of the formation of colature in the first place, such as fixing the slopes on the roofs for proper drainage or improving the design of the coping with drip edges to prevent water from flowing along the façade.

Biological Colonization

It involves mechanical removal of biological growth using soft brushes and controlled water misting, avoiding aggressive methods that could damage the original surface. Following this, biocidal treatments should be applied selectively, with low toxicity aqueous-based biocides to avoid chemical damage to the substrate. Quaternary ammonium compounds are commonly used biocides, but their use is harmful to the environment. In recent years, more sustainable alternatives have been studied for replacing chemical treatments. Biological biocides derived from naturally occurring microbial inhibitors provide an alternative to conventional chemical solutions. In a study, cold active biomolecules extracted from marine organisms are evaluated for their ability to control microbial colonization while remaining non-toxic to both conservators and to the environment[22]. In addition, biological biocides have been explored in studies, such as Natria for the removal of biological patinas, and they have proven to be useful in early 20th century buildings and least harmful to the environment[23].

Microbial Growth

It can be specifically seen on the Northern façade. For treatment, as already mentioned, recent studies propose the use of bio-based cleaning agents such as enzymatic or bacterial treatments. Research on the use of marine organisms as sources of bioactive molecules for microbial control presents an innovative and sustainable method for heritage conservation, reducing reliance on traditional chemical biocides[24]. Another advanced solution is the application of Photocatalytic TiO2 (titanium di-oxide)– based coatings for mortars on the façade. These coatings have self-cleaning ability, depollution effect and antimicrobial properties. However, the overall life cycle sustainability of using this compound needs to be studied taking into the toxicity of nanoparticles release and the end of life of this solution[25].

1.4 Conclusions of Analysis and Proposed Solutions.

The restoration of this 20th century modernist/ rationalist church by Gardella required a precise and well-researched approach, respecting the original materials and construction techniques while integrating sustainable and scientifically backed solutions. The primary issues observed include plaster degradation, cracks, chromatic alterations, and biological colonization, all of which require targeted interventions.

For surface cleaning, biological and microbial growth, non-ionic detergents, and bio-based solutions offer sustainable alternatives while minimizing damage to the plaster and brick structure of the building. Cracks and fissures must be addressed using injection grouts and compatible mortars, ensuring structural stability without compromising historical authenticity. Rising damp mitigation requires the introduction of breathable renders and hydrophobic treatments, prioritizing solvent-free and vapor-permeable solutions. The removal of stains of dripping water and related biological colonization involves water-based biocides and self-cleaning coatings to provide a long-term solution.

The proposed restoration strategies are based on the understanding of the authors with the backing of scientific literature available. For a restoration project, it needs to be further studied based on the techniques identified in this section to ensure that the interventions align with contemporary research on 20th century building restoration and using advanced and sustainable solutions while maintaining the authenticity and structural integrity of the building.

24) Barresi, iovanna, Enza Di Carlo, Maria Rosa Trapani, MariaGiovannaParisi, Chiara Chille, MariaFrancescaMule, Matteo Cammarata, and Franco Palla. 2015. "Marine organisms as source of bioactive molecules applied in restoration projects." Heritage Science 3 (17). doi:10.1186/s40494-015-0046-1.

25) Bersch, Jéssica D., Inês Flores-Colen, Angela B. Masuero, and Denise C. C. Dal Molin. 2023. "Photocatalytic TiO2-Based Coatings for Mortars on Facades: A Review of Efficiency, Durability, and Sustainability." The Effects of Climate Change on the Durability of Built Assets 13 (1): 186. doi:10.3390/buildings13010186.

Urban and Regulatory Framework for Restoration Project

2.1 Integration with the General Regulatory Plan (PRGC 1990) City of Alessandria

Urban planning in Alessandria is governed by the Piano Regolatore Generale Comunale PRGC 1990 act and the last version available on the website was updated in November 2022. This regulatory plan defines zoning classifications, land use regulations, and construction constraints. The Sanatorium of Borsalino, located in Borgo Cittadella, falls withing a historically and environmentally regulated area, requiring that any restoration or adaptive reuse project align with urban, cultural, and geological constraints.

The following analysis of the regulatory plan synthesizes the urban regulations, construction restrictions, and geological-hydrogeological constraints affecting intervention possibilities at the Sanatorium of Borsalino, ensuring compliance with regional and municipal planning policies.

2.1.1. Regulations of the Zone: Borgo Cittadella and the Sanatorium of Borsalino

The district Borgo Cittadella, where the Sanatorium of Borsalino is located, is designated under Article 49 of the PRGC as an area of architectural, environmental, and documentary value. This classification imposes strict preservation regulations to safeguard the historical integrity of the area while allowing for controlled interventions. Additionally, the Sanatorium of Borsalino is listed under "Aree ed edifice individuate ex articolo 24 Legge Regionale n. 56/77", a category reserved for historically and culturally significant buildings. This designation means that the building is protected under regional heritage laws, requiting special approval for any modifications, restorations, or adaptive reuse proposals.

The PRGC permits the following interventions under this article:

- Ordinary and extraordinary maintenance, allowing for structural repairs and material replacements that do not alter the building's original appearance.
- Restoration and conservation rehabilitation, ensuring the preservation of architectural elements and structural integrity.
- Building renovation, provided that the volumetric and typological characteristics remain unchanged.

However, any significant alteration, expansion, or demolition is prohibited, and adaptive reuse projects must comply with regional heritage conservation policies. This means that repurposing the Sanatorium into a community center must follow guidelines for historical preservation, respecting the original materials, structure, and spatial configuration.

2.1.2. Construction Restrictions

Due to its classification under Article 49 and Article 24 of L.R. 56/77, any construction activity within the Sanatorium of Borsalino must comply with strict regulations on material use, façade preservation, and historical integrity. The following construction restrictions apply:

- Prohibition of alterations to the historic façade, including the removal, modification, or replacement of architectural elements.
- Preservation of traditional materials, ensuring that all restoration work uses historically compatible materials.
- Limitations on modern additions, meaning that any functional adaptation for contemporary use must be non-invasive and reversible.
- Restrictions on vertical and volumetric expansions, prohibiting changes to the building's height, footprint, or massing.
- Adaptations for disables access, provided they do not compromise historical elements.
- Infrastructure improvements, ensuring the site remains accessible within the urban network.

2.1.3.Geological Risk considerations

The Site of Sanatorium is located in the Planar area Geological Class III b a (See Figure 25), which classifies the area as moderately to significantly geologically sensitive. This designation imposes restrictions on structural modifications to mitigate risks related to subsidence, soil instability, and hydrogeological threats.

The following are the considerations:

- New constructions are prohibited unless risk mitigation measures are applied.
- Structural reinforcement is required for existing buildings, including periodic monitoring for settlement and foundation integrity.
- Excavations and modification to underground elements require prior geological assessments.

2.1.4. Hydrological Risk and Flood Management

The Piano Stralcio per l'Assetto Idrogeologico (PAI) and Piano di Gestione del Rischio Alluvioni (PGRA) provide a detailed flood risk classification. According to the most recent updates in the PAI 2022, the Sanatorium is located in a zone classified under the Fascia C (Moderate Risk), meaning that it is subject to potential flooding in the event of extreme weather conditions. Specific constraints for this class include:

- Mandatory risk mitigation measures for any new construction or major restoration project.
- Prohibition of basement construction below a designated safety threshold.
- Drainage and flood-proofing measures for ground-level structures.
- Preservation of existing landscape conditions to avoid disruptions to natural water flow.

These regulations serve as guidelines for developing a project of restoration for the Church inside the Sanatorium of Borsalino.

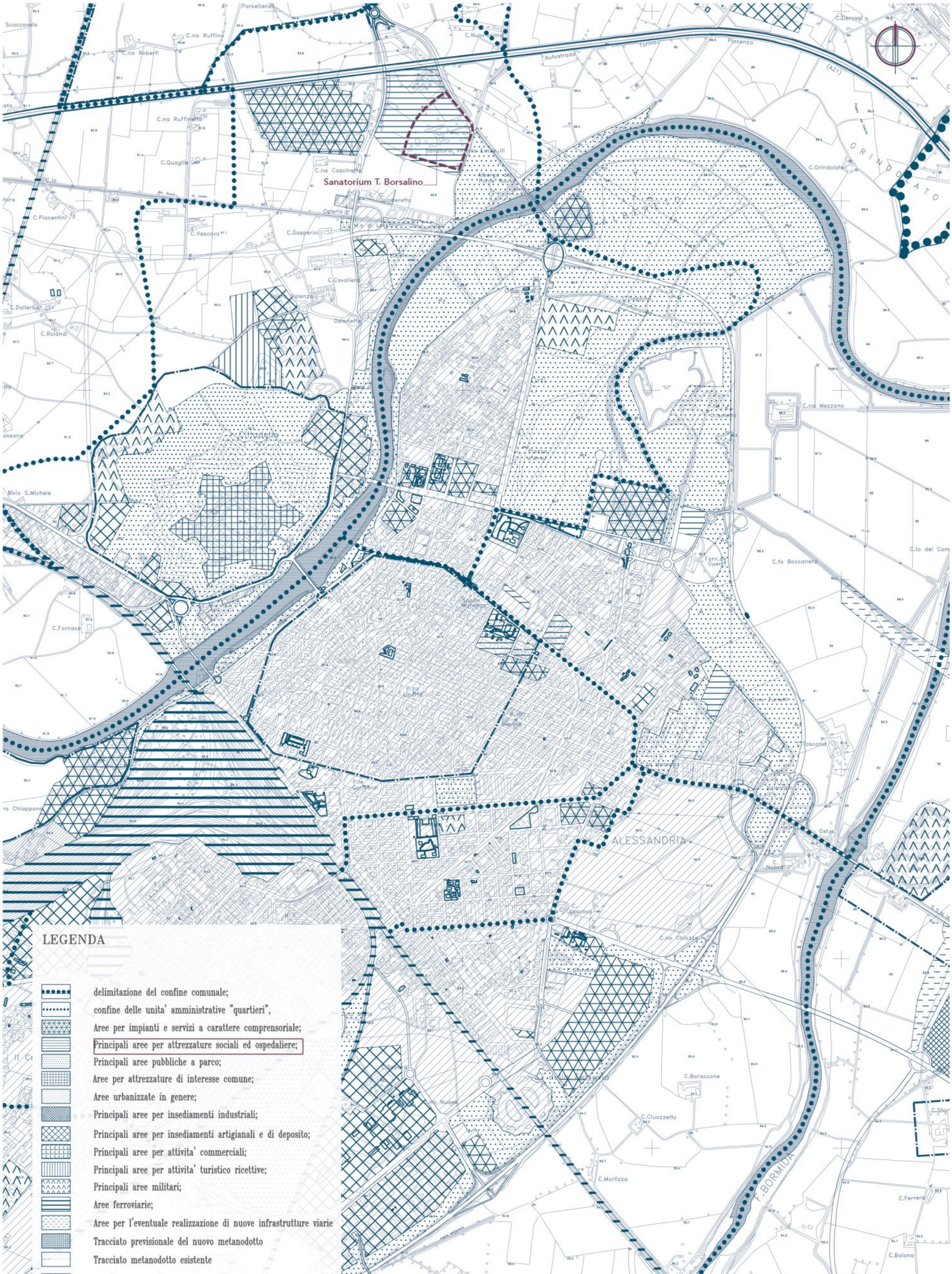


Fig. 24: Piano Regolatore Generale 1:20000 – Land use map (March 2014). Source: comune.alessandria.it

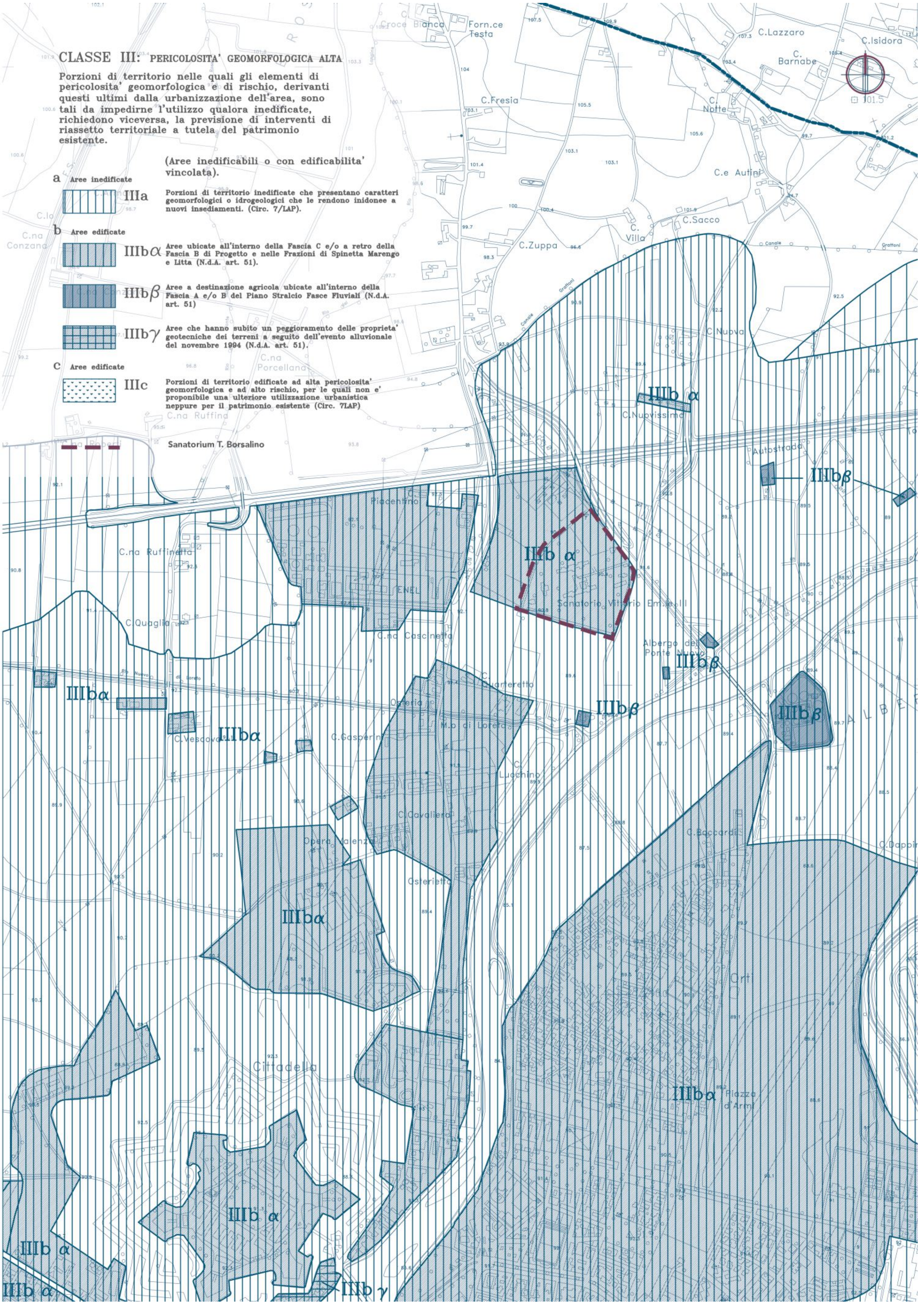


Figure 25: Geomorphological hazard classes. Source: comune.alessandria.it.

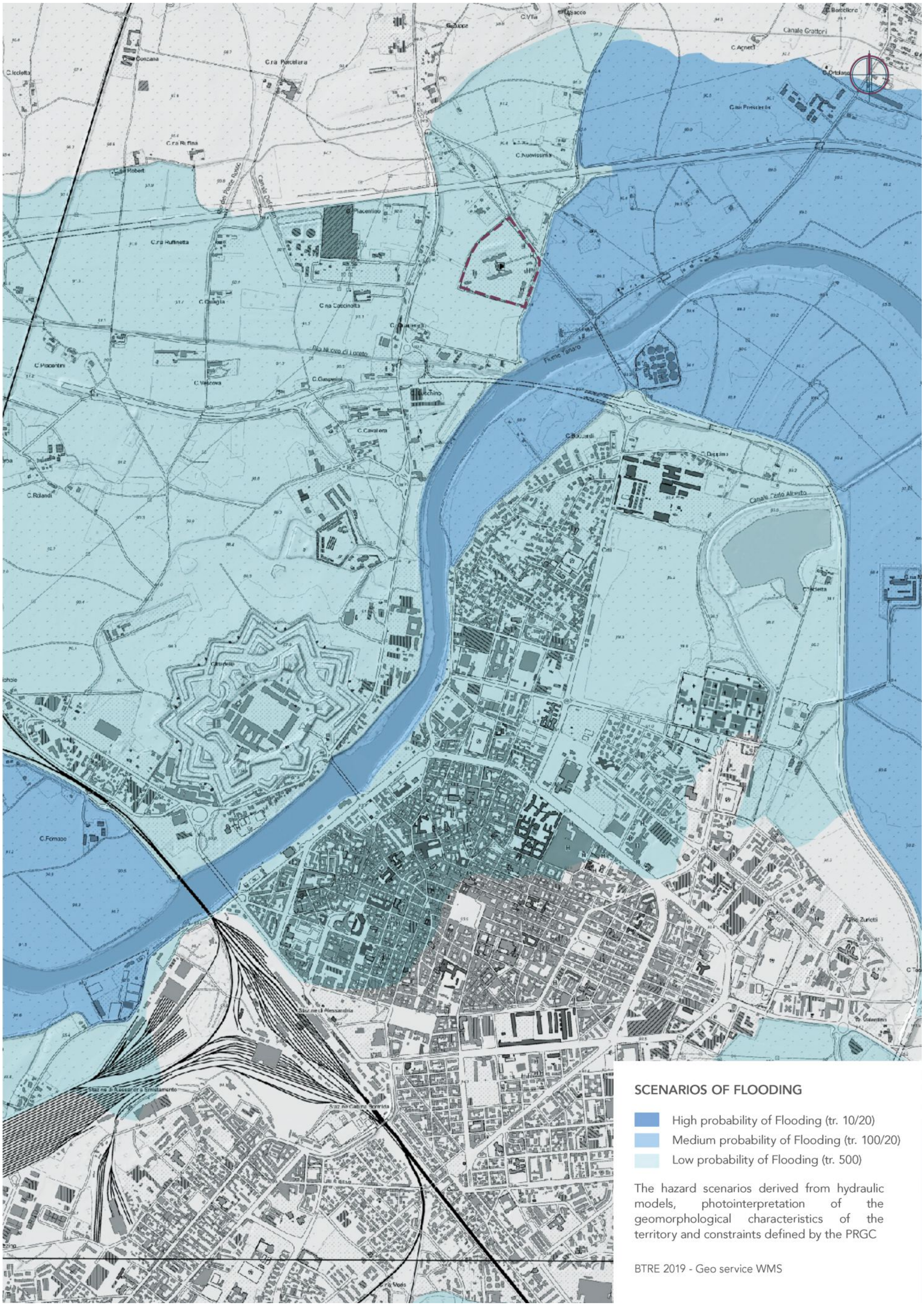


Fig. 25: Flood Risk map. Source: Cartografia Direttiva Alluvione – servizi.piemonte.it.

S.W.O.T. (Strengths, Weaknesses, Opportunities, Threats) Analysis

This thesis intends to propose a new purpose for the church of Gardella which celebrates the historical, architectural, and urban significance of the city. To do that, it is essential to evaluate its strengths, weaknesses, opportunities, and threats (S.W.O.T) to strategically propose an intervention that respects the integrity of space while ensuring functional adaptation. .

Strengths

- Architectural and historical significance as part of the Sanatorium of Borsalino, reflecting early 20th century modernist and rationalist design principles.
- Association with Ignazio Gardella as his first ever architectural project, enhancing its cultural and academic value.
- Well-preserved structural integrity, with load-bearing masonry walls, concrete brick roofing and reinforced concrete columns, making it suitable for restoration without heavy reconstruction.
- Balanced proportions and open spatial composition, allowing adaptability for new functions while maintaining historical authenticity.
- Strategic location within Borgo Cittadella, an area already undergoing through landscape and architectural upgradations and its vicinity to the city center.

Weaknesses

- Visible material degradation, including chromatic alterations, cracking, biological colonization etc., requiring targeted restoration and overall upgradation of the façade.
- Corrosion of metal frames and weathering of wooden window frames require careful intervention strategies to restore the material for longer durability.
- Limited thermal insulation in the opaque structure and damaged transparent elements requiring a strategic framework for energy efficient design.

- Original layout of the church, divided into two naves, may limit functional adaptability for a multi-use community space.
- Regulatory constraints under Article 49 PRGC and Article 24. L.R. 56/77, imposing strict conservation rules limiting design flexibility.

Opportunities

- Potential for an adaptive reuse project for conversion into a community or a cultural center, enhancing public engagement while preserving architectural identity.
- The research and realization on the project can serve as a model for conserving early 20th century buildings in North Italy, aligning with heritage conservation and sustainable development goals.
- Enhancement of accessibility and urban integration, allowing the site to be repurposed without compromising its historical significance.
- Potential integration of contemporary building technologies, improving functionality while respecting historical conservation principles.

Threats

- Ongoing material and structural degradation, if not addressed promptly can further damage the structure.
- Seismic vulnerability, due to possible lacking construction techniques utilized at the time of construction.
- Location in Flood risk zone Fascia C (PAI) and Geological Class III b a, requiring flood proofing and hydrogeological risk mitigation strategies.
- Strict cultural heritage prevention laws limiting modifications, requiring bureaucratic approvals thar may delay intervention timelines.
- Potential funding challenges, since the site is not listed as a national or world heritage site, it may be difficult to arrange funds for a restoration project.

This S.W.O.T analysis provides a strategic understanding of the architectural, urban, and environmental factors influencing the restoration and repurpose of the Church in the Rehabilitation center, Ex-Sanatorium of Borsalino.

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Part VI

Project Proposal

Preserving architectural heritage is crucial for maintaining cultural identity, historical continuity, and promoting sustainable urban development. Historic buildings serve as tangible records of past civilizations, reflecting artistic movements, construction techniques, and social transformations. The Church of Ignazio Gardella, built in the 30s in the Sanatorium of Anti-Tuberculosis Vittorio Emanuele III complex, now known as Teresio Borsalino Multipurpose Rehabilitation Center, is a remarkable example of Italian Rationalism, where its minimalist yet expressive design showcases Gardella's mastery of spatial composition, combining functionality with deep symbolism, evoking and adapting the ancient spaces of a Catholic church to a more modern era with a specific user in mind: the tuberculosis patients. However, like many heritage sites, it faces deterioration due to material aging, environmental conditions, and a state of neglect caused by a lack of use. Advanced conservation tools such as LiDAR scanning, photogrammetry, and Historic Building Information Modeling (HBIM) enable highly accurate documentation and restoration planning, ensuring that interventions respect the original design while addressing structural vulnerabilities.

1. Master plan

The Church of Ignazio Gardella was conceived as a spiritual space within a medical treatment center, adapted to the needs of tuberculosis patients. Over time, the sanatorium has changed its function, evolving from a specialized hospital to a rehabilitation center, reflecting a new dynamic in the use of the complex. The Presidio Riabilitativo "Teresio Borsalino" has established itself as the only mono-specialist rehabilitation hospital in Piedmont, offering neurological, orthopedic, and cardiorespiratory rehabilitation services. Every intervention must consider the current reality, in this case, the first element to assess is the lot where the church is located, as it has been undergoing diverse transformations across the years; various works have been carried out, such as the integration of a zen garden or a basketball court.

The Presidio Riabilitativo "Teresio Borsalino" is located in a natural oasis that provides its users—whether staff, patients, or visitors—with recreational and therapeutic spaces designed to promote well-being and offer a break from hospital routines. Currently, the complex features a running track, a basketball court, a zen garden, and a greenhouse which is located next to the church. As part of a strategy to improve the environment of the rehabilitation center, the proposal includes expanding the zen garden, creating a new recreational area in the northern section of the lot, and revitalizing the Church of Ignazio Gardella and its surroundings.

The objective is to ensure that users continue to experience a strong connection with nature. For this reason, the proposed interventions will be designed with a minimal-impact approach to preserve the existing landscape. Additionally, these spaces will be interconnected through a proposed pathway that will run through the complex's green areas, thereby avoiding the existing routes primarily intended for vehicular traffic.

The proposed unifying path will be designed with a semi-permeable surface, maintaining an uninterrupted water cycle, reducing surface runoff, and promoting the recharge of underground aquifers. Furthermore, given that this complex is located in a flood-risk area, ensuring adequate infiltration spaces is a crucial element for effective water management and the mitigation of potential environmental impacts.

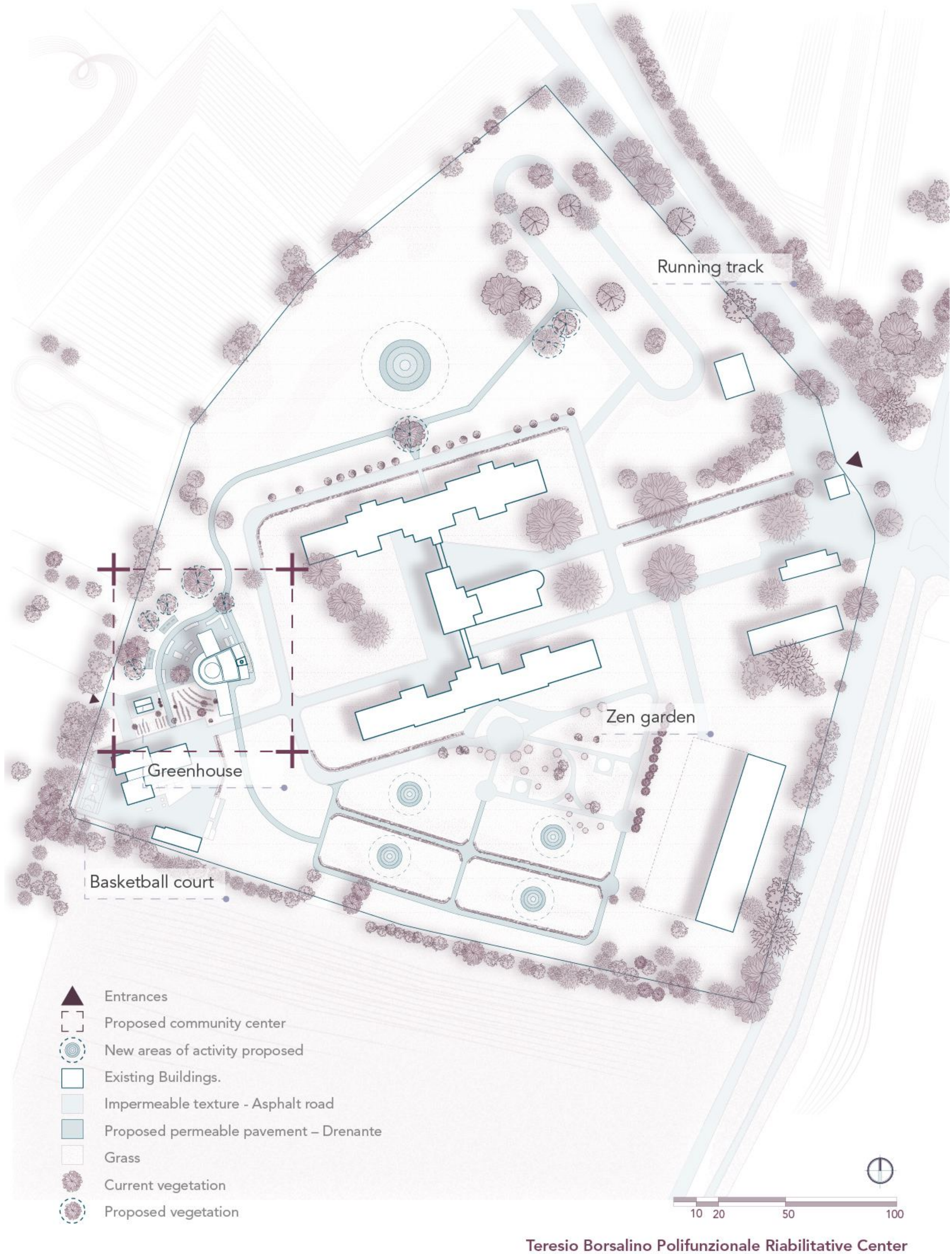
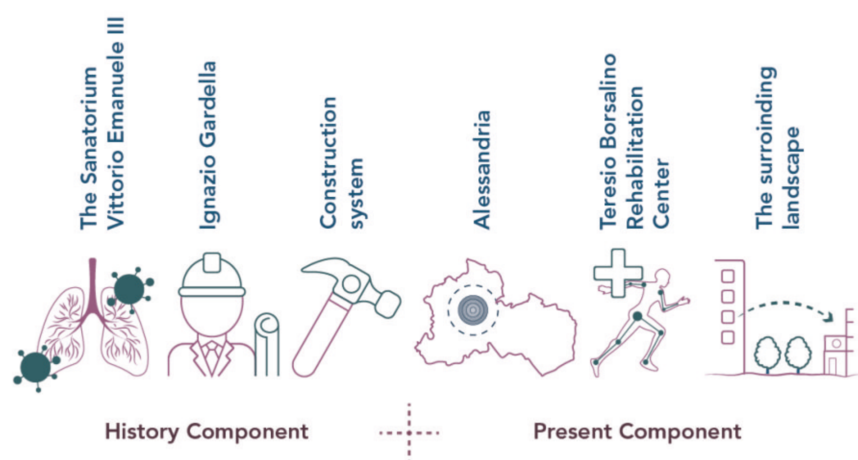


Figure 1: Proposal Master plan of Teresio Borsalino rehabilitation center.

1.1 Understanding its past and evolution

Providing a new use for the church that meets contemporary needs will create a renewed dynamic within the site. This re-signification process is based on a critical approach that considers both the past and the future of the church. It is essential to understand its historical and architectural significance within the context in which it was conceived while also envisioning how it can adapt to the healthcare complex and its broader impact beyond it. Under this framework, the following aspects have been identified:

Figure 2: Components of analysis.



Historical Component

The Sanatorium and Its context: The church must be understood as an integral part of the Sanatorium of Anti-Tuberculosis Vittorio Emanuele III, one of the public works carried out in Alessandria that demonstrate the commitment of Teresio Borsalino and the city to combating tuberculosis. Within this framework, the church served not only as a spiritual space but also complied with the regulations of the time, which mandated the strict segregation of spaces based on the gender of the patients. Furthermore, not all areas within the church had a religious function. What would traditionally be classified as a transept in a conventional church was instead repurposed in this project to house spaces such as the morgue and the priest's residence. In this way, the church fulfilled not only a liturgical purpose but also played a practical role in addressing various operational needs of the healthcare complex.

Ignazio Gardella and his legacy: This church stands as one of the earliest works of Ignazio Gardella, a master of Italian Rationalism. Its architectural value is further enhanced by its connection to the Gardella family legacy, as the project was initially assigned to his father, Arnaldo Gardella, who was unable to complete it due to his sudden passing. Consequently, Ignazio took over the project before even graduating as an architect or engineer, marking this building as a significant milestone in his early career.

Construction innovations: The church is a testament to the technological advancements of its time, incorporating two distinct construction methods. The bell tower, located at the main façade, asserts its hierarchical importance not only through its height but also through its structural innovation, utilizing a column and beam system. Meanwhile, the rest of the complex is supported by load-bearing walls covered in plaster and white paint, creating continuous surfaces that reinforce rationalist language by highlighting the purity of geometry.

1.2 Present and evolution of the environment component

Alessandria: The city has become an open-air museum showcasing the architectural contributions of the Gardella family, whose work has significantly shaped the city's identity. From Jacopo Gardella (1845-1923) to Arnaldo Gardella (1873-1928), Ignazio Gardella (1905-1999), and his son Jacopo Gardella (1935-2021), the family has played a crucial role in the evolution of Italian Rationalism, adapting architecture to the social needs of different eras. Some projects, such as the Borsalino Employee Housing, have retained their original function, while others have been repurposed—like the Borsalino Factory, now an Esselunga supermarket, and the Anti-Tuberculosis Dispensary, converted into a polyclinic. However, certain structures, including the Hair Cutting Plant and Gardella's church, have been neglected and fallen into disrepair.

The church stands not only as a testament to Ignazio Gardella's architectural legacy but also as a symbol of Alessandria itself, a city that has continually redefined its built heritage to align with modern needs. Restoring the church would reintegrate it into the urban fabric, reinforcing the narrative of the Gardella family's lasting influence on Alessandria's architectural and social landscape.

The Teresio Borsalino Rehabilitation Center: With the decline of tuberculosis as a public health concern, the former Sanatorium Vittorio Emanuele III was left abandoned. However, over time, the complex was restored and repurposed into a multidisciplinary rehabilitation center, aligning with contemporary healthcare needs. This facility, named in honor of Teresio Borsalino, a key figure in Alessandria's public works development, offers specialized and comprehensive therapeutic care, using advanced techniques to restore patients' physical, cognitive, and emotional functions. Its primary goal is to facilitate patient reintegration into daily life, establishing itself as a space for healing and progress.

Within this context, Ignazio Gardella's church should be understood as part of this new dynamic within the complex—not just as an architectural relic but as a space for reflection and recreation for the facility's users.

Surrounding Garden and Environmental Integration: The complex currently features a running track, a zen garden, a basketball court, and a greenhouse, all designed as open-air spaces that seamlessly blend with the natural landscape. These areas promote outdoor interaction, fostering an environment of well-being and connection with nature. In contrast, the Church of Ignazio Gardella serves as an enclosed, introspective space with a distinct role compared to the other areas, which provide complementary activities to the rehabilitation center.

Given this context, the church should be recognized as a new activity hub that, despite its enclosed nature, must not be disconnected from its surroundings. Its re-signification involves not only its architectural restoration but also its integration with the surrounding landscape, fostering a dialogue between the interior and exterior. This approach requires planning not only for its interior space but also for its immediate environment, ensuring a harmonious connection between architecture and nature, reinforcing its role within the complex and expanding its impact on the site.

A new Purpose: The Legacy Center

The previous analysis has led to the development of a proposal for the re-signification of the Church of Ignazio Gardella, preserving its historical values while integrating them with present-day needs to ensure the continuity of its use. The proposal envisions the transformation of the church into a publicly accessible community center, ensuring that the legacy of Ignazio Gardella, a key figure in Italian architecture and the urban development of Alessandria, is not confined to a select few but remains open to all who wish to explore the origins of this influential architect.

This space has been named "The Legacy Center", a reference to the architectural and cultural impact of the Gardella family in Alessandria. The choice of name underscores the importance of preserving and promoting the history of a family that has shaped the city's urban landscape for generations. Beyond its historical significance, the Legacy Center aspires to become a hub for cultural, educational, and reflective activities.

2.1 Program distribution

The proposed activities have been designed to serve both the rehabilitation center's users and the citizens of Alessandria, ensuring a continuous connection with the surrounding environment. At a macro scale, the program is divided into two main areas: one dedicated to education and another focused on recreation and social engagement, both interconnected to create a flexible and dynamic space.

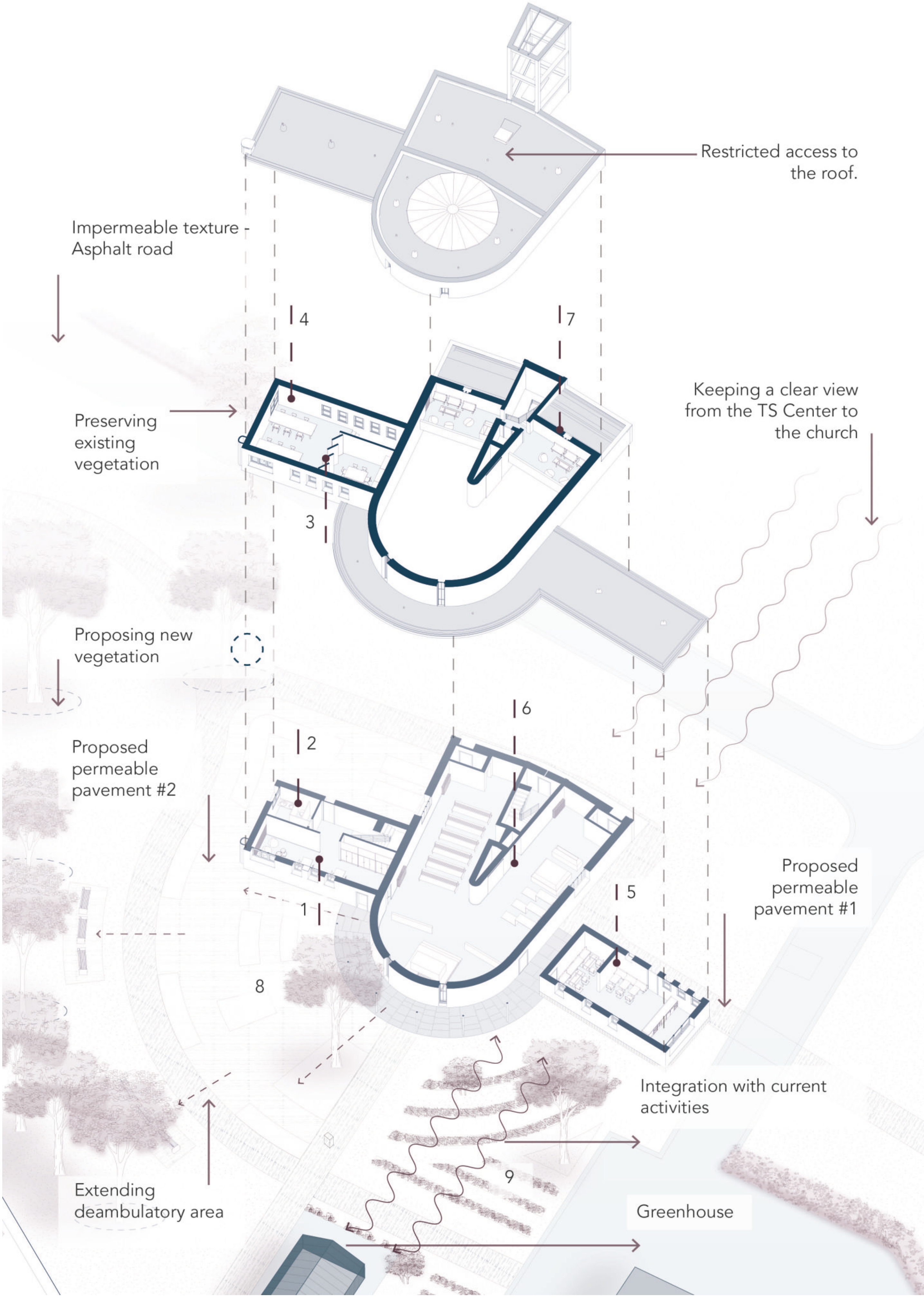


Figure 3: Proposal - Axonometric.

Former Priest's House – North Wing:

This section of the complex will house the educational function, distributed across two levels to encourage different types of interaction: collaborative and individual work. The spatial layout has been reconfigured to create uninterrupted areas, replacing the previous compartmentalized design to enhance visual connectivity with its surroundings and provide the feeling of a more expansive space. On the upper floor, open sightlines have been maximized, while on the ground floor, a clear distinction is established between study areas and service spaces.

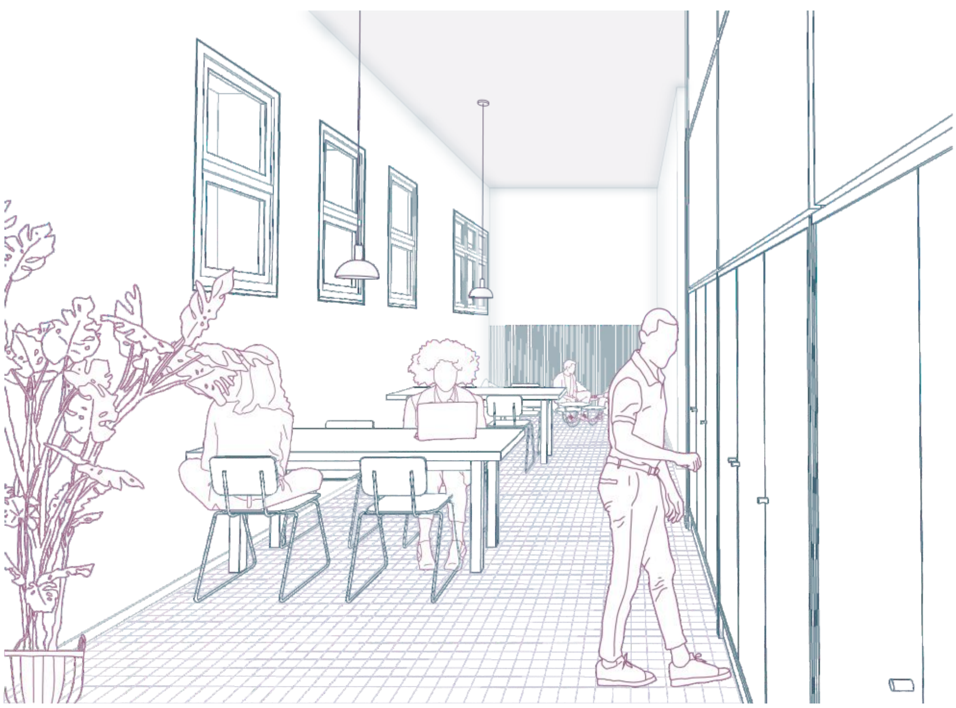
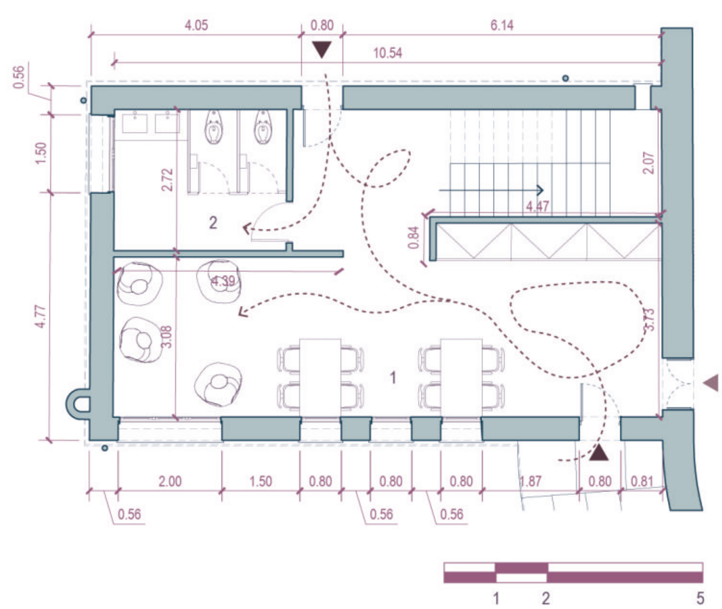


Fig. 4 (left). Collaborative workspace on the ground floor.
Fig. A (below). Flow diagram of Ground floor - North wing.

Ground Floor:

Collaborative workspace (1): Designed as a meeting point where user interaction is encouraged, fostering teamwork and the exchange of ideas.

Service area (2): Incorporates a bathroom facility, with separate sections for each gender, including sanitary installations and sinks, ensuring user comfort.



First Floor:

Flexible collaborative workspace (3): A versatile area that can adapt to user needs. It can function as an individual study space or be transformed into a private meeting room through the use of pivoting doors, allowing for a modular configuration that adjusts to different requirements.

Individual study area (4): A dedicated space that promotes independent work, optimized through the strategic arrangement of furniture to support focused tasks.

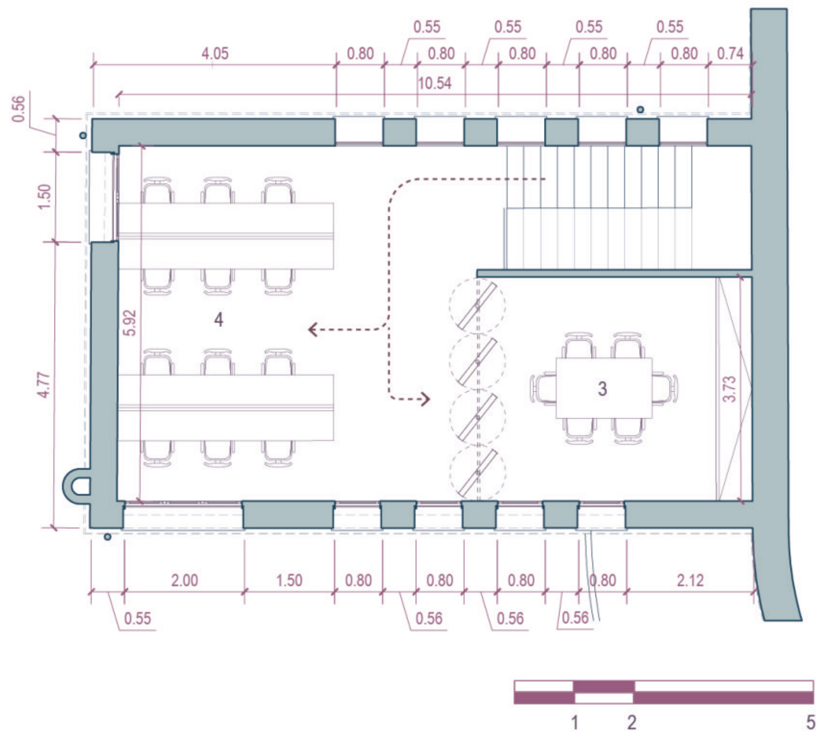
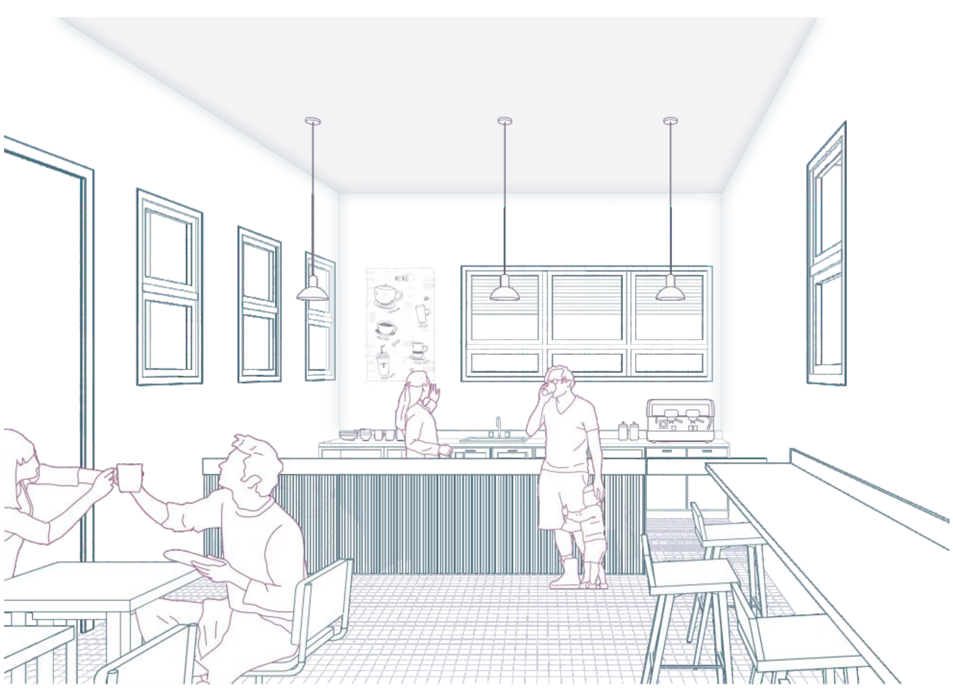


Fig. B (right). Flow diagram of first floor - north wing.
Fig. 5 (below). Coffee lounge on the ground floor.

Former morgue – south wing:
A greenhouse and an area for cultivation is in front of this wing, therefore there is a unique opportunity to integrate the church with the fresh produce cultivated in the garden.



Ground floor:
Cold Kitchen – Coffee Lounge (5): A space where visitors can relax, eat and interact. It is essential to emphasize that this will be a cold kitchen space, meaning no cooking will take place on-site. This decision is crucial to preserving the structural integrity of the historic building, as there is a risk of fire and the excessive heat, smoke, and grease accumulation could accelerate its deterioration. Instead, the coffee lounge will serve pre-prepared food, along with hot and cold beverages, ensuring a safe and enjoyable culinary experience within the complex.

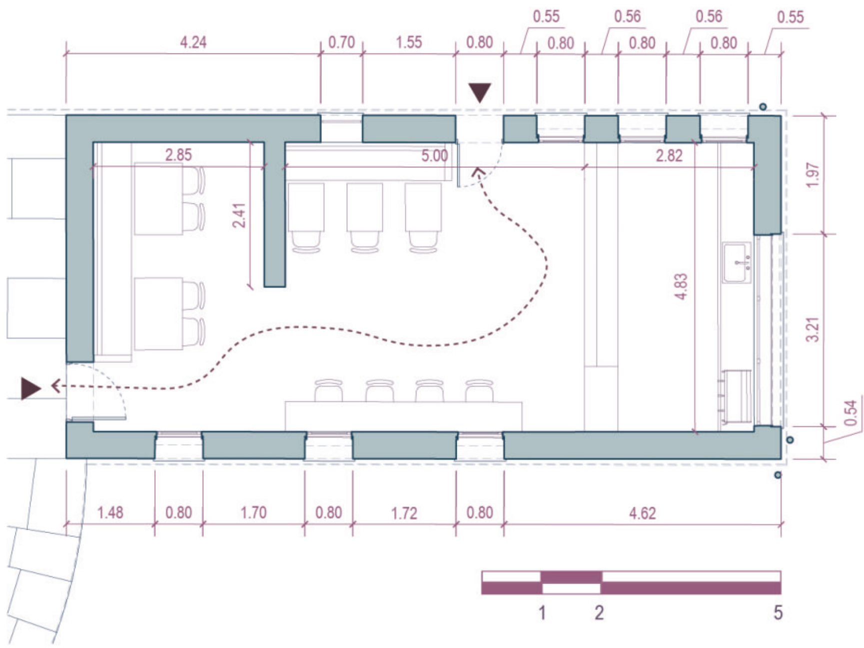
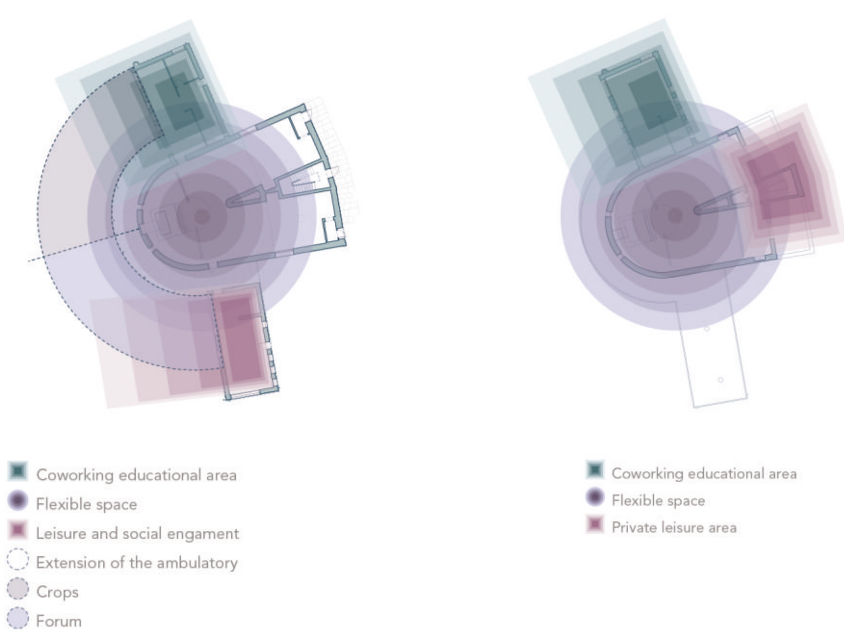


Fig. C (left). Flow diagram ground floor - south wing.
Fig. 6 (below). Concept diagram of spaces on the ground floor.

Former Religious Center – Central Nave:
Originally, the central nave was the heart of the church, where the altar and congregation gathered for religious services. Today, this space will be redefined as the link between the two functional wings, the educational and social engagement areas.

Ground floor:
Flexible space (6): Designed as a dynamic area adaptable to various activities based on the needs of the facility. Its versatility will allow it to host rehabilitation center conferences, recreational activities such as yoga classes, and cultural events. As part of the proposal, the Gardella Hall will be introduced, featuring a removable exhibition dedicated to the legacy of Ignazio Gardella. This display can be adjusted or dismantled as needed, ensuring that the central nave remains a multifunctional environment. In this way, the former religious center will not only preserve its historical significance but also integrate seamlessly into the contemporary functions of the complex.



First floor:

Break area (7): This space has been designed as a quiet retreat, separate from social interaction, providing a peaceful environment for hospital users who seek a moment of solitude or time with their families outside the confines of the medical facility. Given its function as a relaxation area, its use will be restricted when the flexible space is hosting dynamic activities to ensure a tranquil atmosphere.

2.2 Public Space Strategies

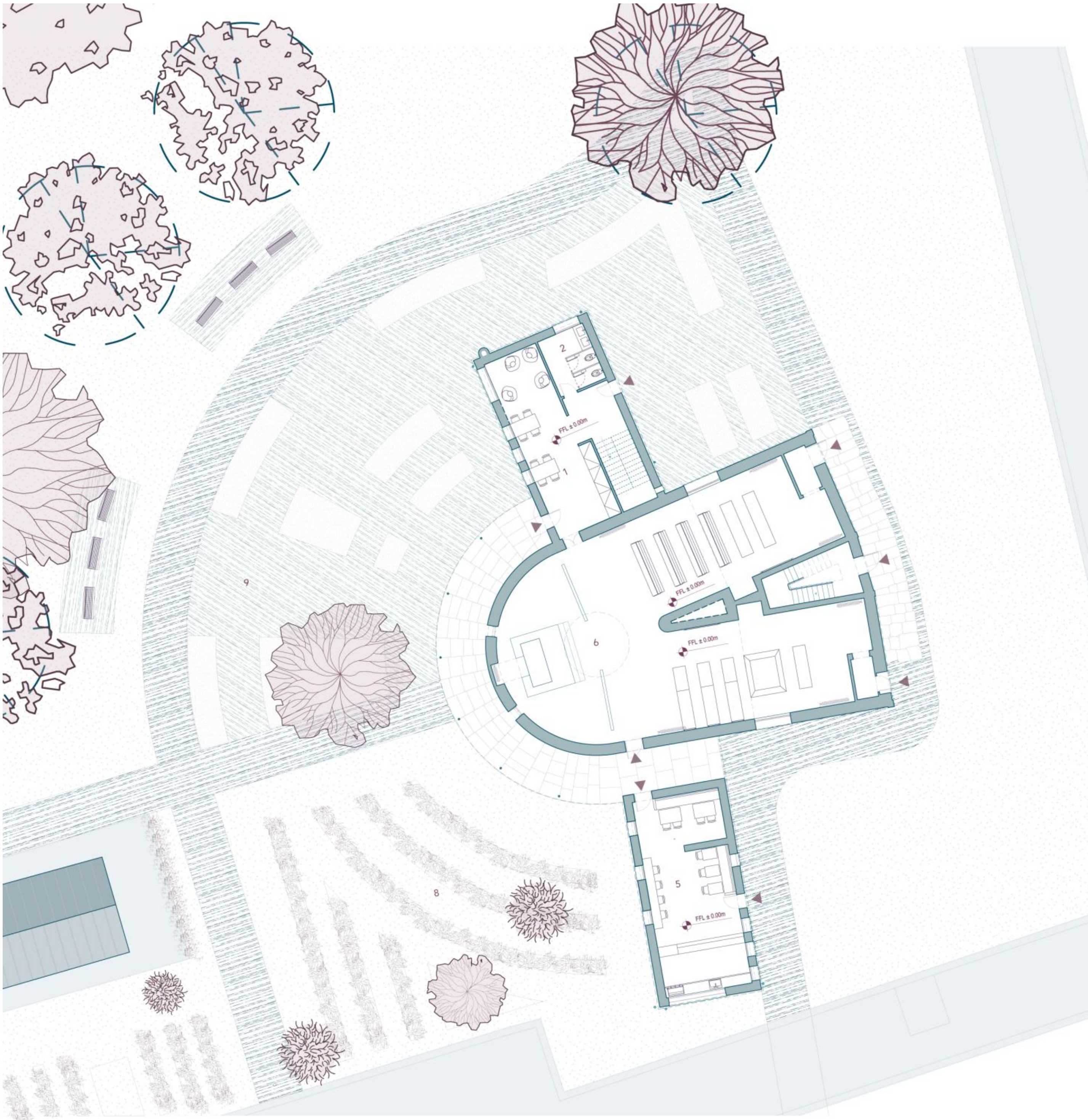
As previously mentioned, this building must maintain a seamless connection with its surroundings, ensuring that indoor and outdoor activities complement each other. The Legacy Center is envisioned as a dynamic space, where movement between the interior and exterior becomes an integral part of its identity.

The ambulatory, which originally served as a protective space for the altar and a connector between the transept wings, will retain its structural function in the new center. However, its role will evolve into a bridge between the building and external activities. While it previously linked the church to an inactive exterior, it will now strengthen the relationship between the structure and its surrounding activities, fostering a more integrated experience. The interventions are as follows:

East Façade – Integration and Connectivity: As the main façade of the building, it is crucial to preserve its architectural prominence, ensuring it remains a visual landmark from the Presidio Teresio Borsalino. To achieve this, no invasive interventions will be made in front of the façade. Instead, an open space free of trees will be maintained to preserve unobstructed visibility, while a connecting pathway will be introduced to link the church with the rest of the complex's activities, improving accessibility and reinforcing its presence within the site.

North Wing – Study and Gathering Spaces: Since this wing is dedicated to work and study-related functions, it is essential to consider the need for users to step outside for breaks. To accommodate this, the proposal includes the creation of a piazza with a permeable surface, designed as an outdoor discussion and relaxation area. This space will serve as a natural extension of indoor activities while also incorporating seating areas, allowing users to unwind and engage in conversations in an open-air setting.

South Wing – Connection to the Greenhouse: Wing that hosts the cold kitchen-coffee lounge, draws inspiration from one of the elements within the complex: the greenhouse. Given this conceptual and functional relationship, these two spaces will be interconnected through a cultivation area, which will be accessible from within the café's perimeter. This integration not only enhances the sustainability of the space but also offers visitors an enriched sensory experience, allowing them to interact with food production processes while enjoying a natural and immersive environment within the facility.

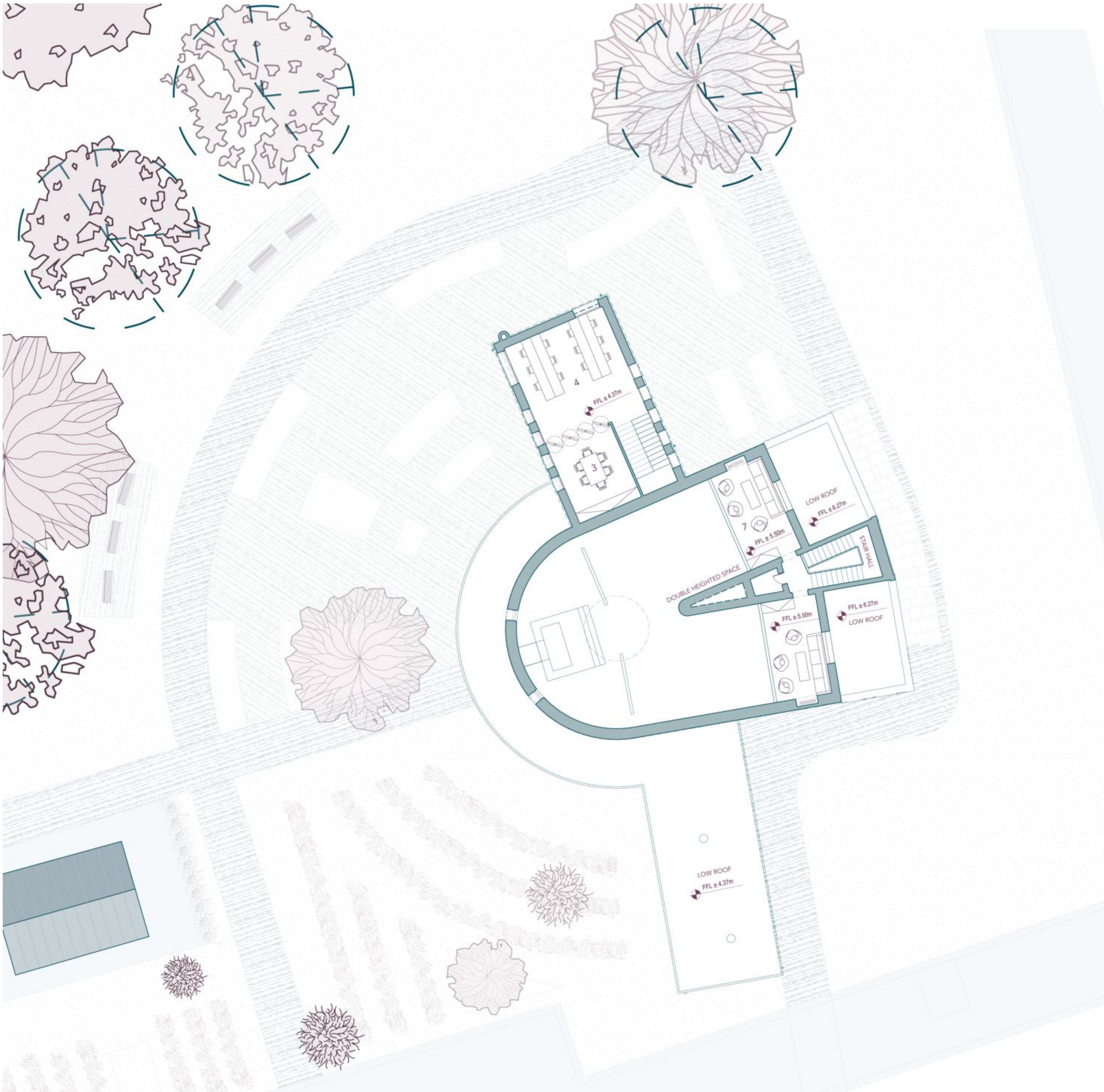


LEGEND OF SPACES AND TEXTURES

- ▲ Entrances
- 1 Collaborative workspace
- 2 Service area
- 5 Cold Kitchen – Coffee Lounge
- 6 Flexible Space
- 8 Crops
- 9 Forum - Piazza
- Stone
- Impermeable texture – Asphalt road
- Green
- Proposed permeable pavement #1
- Proposed permeable pavement #2
- Green house
- Previous vegetation
- Proposed vegetation

1 2 5 10

Fig. 8. Ground Floor.



LEGEND OF SPACES AND TEXTURES

4 Collaborative workspace

3 Service area - Restrooms

7 Break area

Greenhouse

Previous vegetation

Proposed vegetation

1 2 5 10

Fig. 9. First floor.

Gardella Hall: A Space of Memory and Transformation

As previously mentioned, the former central nave, which was once divided by gender, is now integrated into the Legacy Center as a flexible space within the complex. As a symbolic tribute, it is proposed that the first activity within this new facility be a removable art exhibition dedicated to Ignazio Gardella. This exhibition will explore his architectural impact on different scales: his role in the construction of the church, his influence on the urban transformation of Alessandria, and his broader architectural legacy beyond the city.

The proposal divides the central nave into three thematic sections, as follows:

North Nave: Designed to recreate the original atmosphere of the church, allowing visitors to experience how the space felt in the 1930s. Through an immersive architectural reconstruction, this section will transport visitors to the past, providing educational areas detailing the history of the Sanatorium Vittorio Emanuele III, the contributions of Teresio Borsalino in Alessandria, and the architectural significance of the church within this historical framework.

South Nave: Focused on Ignazio Gardella's career, this section will showcase the evolution of his architectural style over time. By displaying his most significant works, visitors will gain insight into how his design language developed, solidifying his status as a key figure in Italian Rationalism.

Altar: Preserving its original design, the altar area will serve as the main stage for speeches and presentations within the exhibition. This space will host lectures, discussions, and cultural events, enriching the visitor experience.

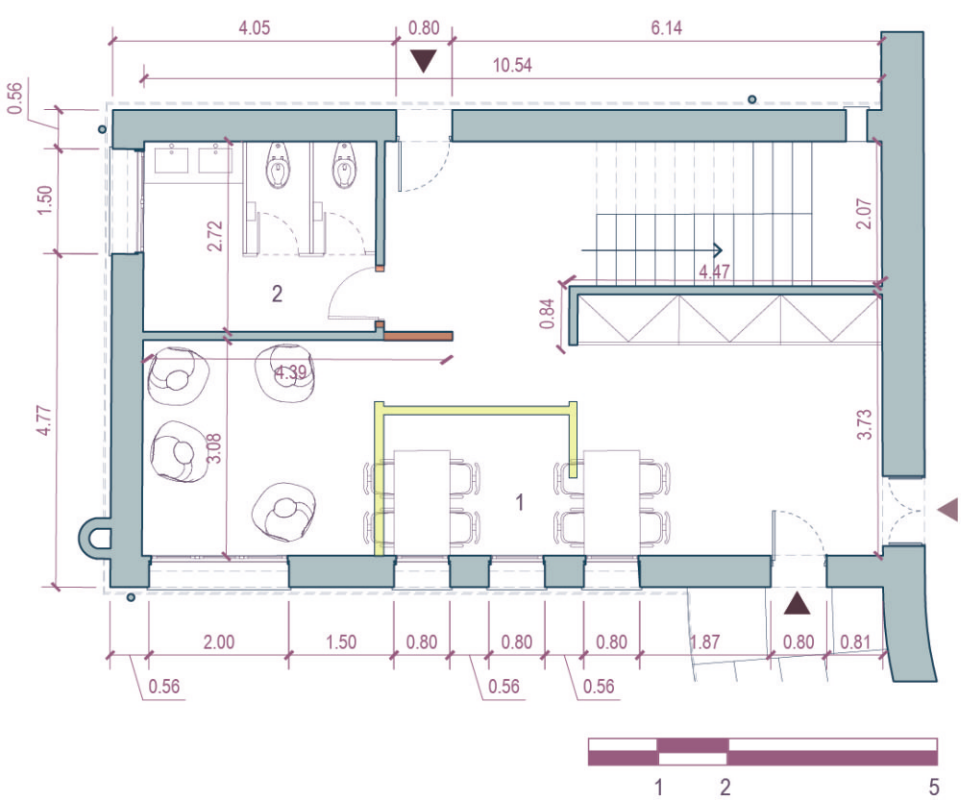
This inaugural exhibition at Gardella Hall will not only serve as a way to honor the space's history but also act as a foundation for future cultural and educational activities within the Legacy Center.

Demolition and construction

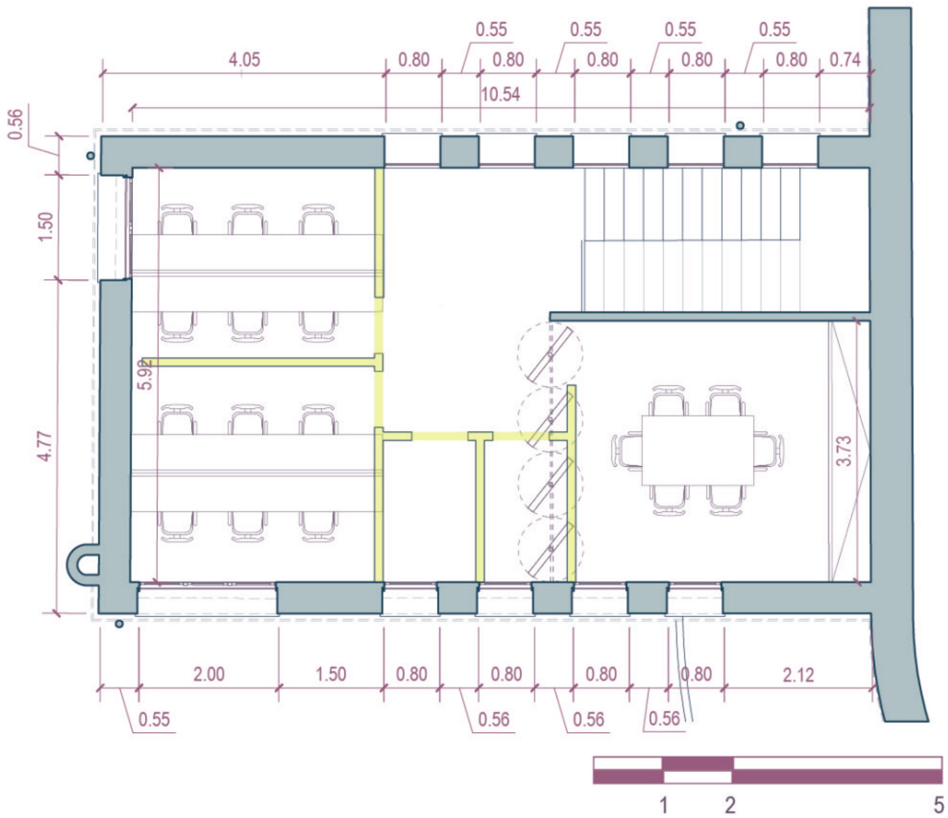
No invasive interventions will be carried out on the façade, ensuring that the building retains its original geometry and architectural purity. Similarly, the central nave will remain unaltered, preserving its existing structure without modifications.

The north and south naves, however, present a particular challenge. Since these areas were restricted during the architectural survey, their exact layout remains uncertain. As a result, the current plans cannot be considered entirely accurate. However, from an academic perspective, a proposal has been developed based on a structural wall hypothesis, drawing from spatial analyses obtained from other informational sources, including studies and publications on the work of Ignazio Gardella.

Fig. 10: Demolition and construction plan from ground floor – North wing.



Since these two wings are not part of the church's primary liturgical space and will be repurposed within the Legacy Center, the following modifications represent in red for construction and yellow for demolition have been implemented to adapt them to their new functions:



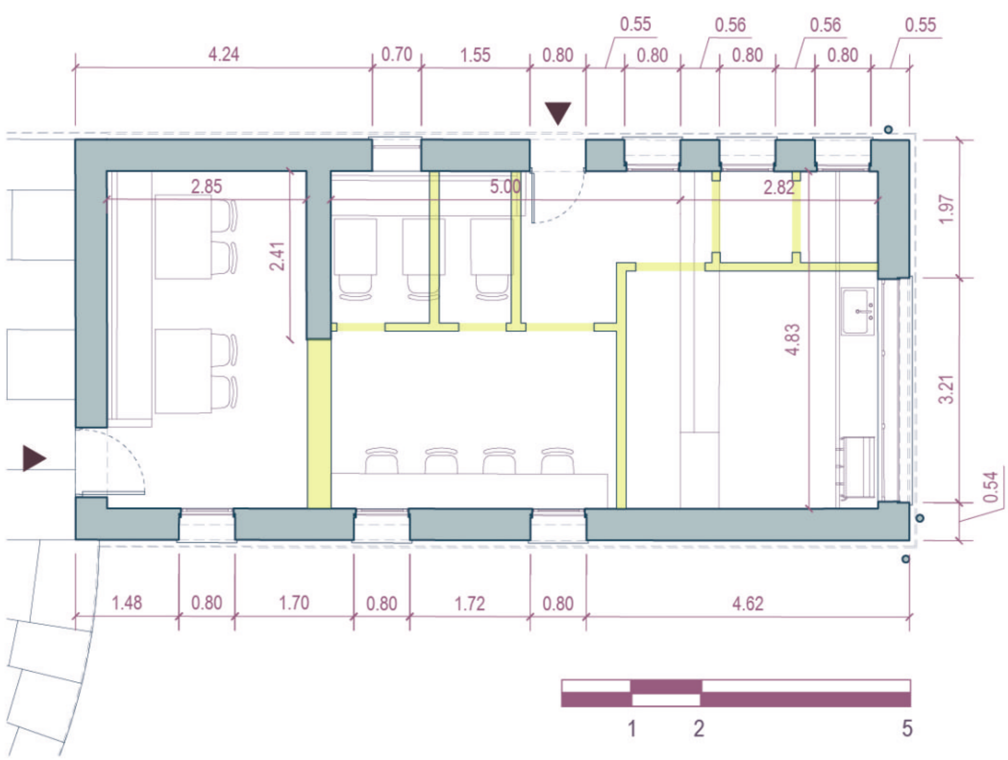


Fig. 11: Demolition and construction plan from first floor – North wing.
Fig. 12: Demolition and construction plan from first floor – south wing.

Conclusion

This thesis provides a multidisciplinary investigation into the Church of Ignazio Gardella within the former Sanatorium of Borsalino, integrating historical analysis, digital surveying, material degradation assessment, and restoration strategies. The research highlights the role of geomatic tools in documenting and conserving this early 20th-century monument while addressing the complexities of regulatory frameworks and urban reintegration.

The historical research establishes the church's significance within the Rationalist movement, emphasizing its role as Gardella's first independent architectural project following his father's death. Rationalist architecture in Italy aims to balance modernity with historical continuity, favoring clarity, functionality, and structural integrity. The church reflects these principles through its simple volumetric composition and material efficiency, aligning with broader developments in early 20th-century architecture. The study also illustrates how Alessandria's urban expansion and evolving architectural trends shaped the church's integration into the broader built environment, further justifying the need for its conservation.

The 3D survey, forming the core of this research, employs LiDAR scanning, UAV photogrammetry for generating point cloud data which is employed in 2D documentation, and a structured Scan-to-BIM approach to generate precise 3D representations. This study determines that while LiDAR provides high accuracy for structural mapping, photogrammetry is more effective for capturing surface textures and material conditions. The HBIM model facilitates the integration of multiple information related to the case study, improving the efficiency of conservation planning. However, the creation of digital libraries for architectural details and elements presents certain limitations, as the scans do not capture millimeter-level details. To produce highly accurate representations of intricate architectural components, traditional survey methods must supplement the digital process. Manual refinement in historical modeling workflows remains necessary to ensure the highest degree of accuracy in the HBIM model.

The material degradation assessment identifies rising damp, detachment, chromatic alteration, biological colonization, and microbial growth as the most significant deterioration factors affecting the church. Rising damp leads to paint and plaster detachment along with complete disintegration of finishing materials exposing the masonry to further environmental degradation, particularly in lower sections of the masonry. Surface detachment and chromatic alterations are linked to moisture penetration and environmental exposure, accelerating material decay. Biological colonization and microbial growth, particularly on shaded and poorly ventilated surfaces, contribute further to degradation. Restoration strategies emphasize sustainable and bio-based solutions, promoting the use of environmentally friendly cleaning agents, biocidal treatments, and reversible conservation techniques. The findings underscore the necessity of balancing material preservation with ecological responsibility, ensuring that restoration interventions are both effective and minimally invasive.

The study of regulatory constraints and urban planning serves as a foundation for defining what is and is not possible when proposing a new function for the church. The analysis of the General Regulatory Plan (PRG) clarifies intervention limitations, particularly concerning flood risk and heritage preservation law. While not the central focus of this research, understanding these constraints plays a crucial role in shaping the project proposal, ensuring that any intervention strategy aligns with both legal requirements and practical feasibility. The research demonstrates how urban policies act as guiding parameters, ensuring that any design intervention is not only historically sensitive but also realistically implementable within the existing framework.

The final phase of the thesis has provided a new function for the church. The design proposal transforms the church into a Legacy Center, honoring the architectural contributions of the Gardella family while creating a cultural and social hub. The intervention preserves the architectural integrity of the building while enhancing its functionality. The nave is repurposed into a versatile exhibition and event space, with modular setups to accommodate different uses. A lightweight, reversible installation introduces a small library and reading zone, offering an intimate setting within the vast central space. The outdoor landscape has been transformed into a socializing space for the users and new pathways are introduced to have better connectivity with the overall complex. While the North wing is converted into a reading, working, socializing space, whereas the South wing is dedicated to a small cold kitchen area which will serve snacks and refreshments that do not require cooking. These modifications can enable the building to function as a dynamic venue for cultural exchange, research, and public engagement, reinforcing its role as both a heritage landmark and an active community space.

Finally, this research reinforces the critical role of advanced surveying techniques in restoration projects. The case study of Gardella's church exemplifies how historical scholarship and technological innovation can work together to safeguard architectural legacies while ensuring their continued relevance within modern urban contexts. Future implementations of this methodology could focus on developing the HBIM model at a higher Level of Development (LOD), reaching LOD E or F, by incorporating more detailed physical and semantic information. Conducting direct material and degradation surveys within the BIM environment could enhance precision, providing a more comprehensive record of the building's current state. Additionally, continuously updating the As-Is conditions through BIM would establish a digital twin of the church, offering a dynamic tool for monitoring changes over time and supporting long-term conservation planning.