Integration of archaeology in architectural design of Milan Metro connection M2–M4 in St. Ambrogio Station

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ABSTRACT: The central section of new metro line M4 in Milan cross an high-density urban area with a lot of issues cause by historical and archaeological building, one of the most complex case is the St. Ambrogio station. The initial solution for the connection between existing metro line M2 and the new one M4 in St. Ambrogio station was to build a 100 m long rectangular open-air tunnel placed above and practically on the same axis with the existing tunnel of M2 built in the 80s with a traditional excavation method, with a gap between the two facilities being quite strait, of about 1.50 m. Such a solution created problems for the further development of the overall project in terms of the traffic/construction site organization, because the connection had to be placed exactly along an important traffic corridor making part of internal ring road of the city of Milan. An alternative engineering and architectural solution has been developed in collaboration with the archeological supervision authorities. The integration and utilization, in the tunnel connecting M2 and M4, of the belowground part of the complex of Pusterla of St. Ambrogio, built in XII century a.C. and under protection of the archeological supervision authorities, helped to avoid a complete surface traffic block, to resolve a number of critical issues from the geotechnical and structural points of view, and to revaluate the archeological site that was incorporated into the connection between the M2 and M4 metro stations.

1 GENERAL INFORMATION OF NEW METRO LINE M4

The construction of Line 4 of the city of Milan has been set up and managed in a Public Private Partnership (PPP); for this purpose an ad hoc company has been set up, two-thirds owned by the Municipality of Milan and a third by the private partners in charge of designing, constructing and managing the new line 4 of the Milan underground (M4 Spa society).

The duration of the concession is approximately 31 years (370 months) from the date of signature of the Convention (December 22, 2014), of which 88 months for the construction of the entire work.

The Private Members, selected through a specific call for tenders, are formed the CMM4 consortium consisting in a temporary grouping of the companies Salini-Impregilo, Astaldi, Ansaldo STS, AnsaldoBreda (later Hitachi Rail), ATM and Sirti. The same is given the burden of design the Executive Project of the work, as well as the realization of the same (EPC contract). Within the above framework, MM company, in addition to drawing up the project in the preliminary phase, has had a controlling role in the executive design developments, the Technical Assistance to the Client, the Safety Coordination and Work Supervisor.

The new metropolitan infrastructure create a fast public connection along the east/south-west route through the historic city center, developing for 15km from San Cristoforo to Linate, with 21 stations, 30 line shafts and 1 depot-workshop.

It is an automatic metro without driver on board (driverless) with automatic dock doors and CBTC signaling system (Communication Based Train Control); the fleet consist of 47 vehicles.



Figure 1. Contract scheme and general planimetry of line M4.

There are two interchanges with the existing metro lines, one with the M1 line, at the San Babila station, and one with the M2 line (green), corresponding to the St. Ambrogio station. A further connection with the yellow line (M3) is being studied at the Porta Romana course.

There be three interchanges with the suburban railway lines at Forlanini FS station, Dateo station and San Cristoforo station, and one with Linate airport.

Most of the underground development of the track is made by mechanized excavation, using two TBM geometries: one with an excavation diameter of 9.15 m, in the central section to accommodate the station platform directly in the gallery; the other with a smaller excavation diameter (D = 6.36/6.70 m), for the realization of the peripheral sections. In total, be used n. 6 TBM EPB for tunnel excavation.

2 ARCHEOLOGY IN M4

2.1 General overview of archeology in M4

The goal of bridging the infrastructure gap between the south-west and east areas of the city (compared to the center), of certain usefulness and ambition, has generated a railway track that has considerably involved a part of the center of Milan, although aware that this would have necessarily involved a series of inconveniences to the city and to the citizens. Among these, of sure importance are the management of vehicular and pedestrian traffic, the management of relationships with the existing and even more commercial realities, but also the interface of the construction sites with a multitude of pre-existences with a strong historical and architectural interest and/or archaeological.

On the other hand, Milan was founded about 2,600 years ago, beginning an ascent that led it to be a cultural, commercial and military center among the most prosperous in Northern Italy since Roman times and, on several occasions, also Capital of the Roman Empire West. A thousand-year history of such importance can not but leave traces of itself and in fact even Milan does not escape this rule of Italian population centers. There are in fact innumerable portions of cities that have returned, over time, more or less important signs of the past epochs. The above map shows the pre-existences known and considered relevant from a historical, archaeological, architectural and monumental point of view. Naturally the greatest denseness of findings regards the city center; to name a few are the amphitheater, the circus, the Erculee thermal baths, the access gates to the fortified city, as well as a series of palaces from different historical periods each, in its own way, an important hallmark of its era. The overlapping of this map with the M4 layout makes clear how inevitable the theme (citing the Archaeological Superintendence of Milan) of the relationship between modern needs and protection of the past would have been inevitable.

The forecasts referred to this paragraph have actually been complied with, not without some surprises. Infact, in the course of the works, with particular reference to the sites located in the most central area of the city, numerous archaeological finds were found, among which Roman and medieval masonry structures, funeral objects, foundation of ancient monument Pusterla of Fabbri, Roman baths, burial grounds.

What has been found has become part of a specific project dedicated to works for Line 4 entitled "Time travel with metro line M4" on show for 3 month (September-December 2018) at the Archaeological Museum of Milan sponsored by the City of Milan, in collaboration with the Contractor, in order to spread the knowledge of Milan that was.



Figure 2. Plan of archaeological risk areas and archaeological finds.

2.2 Archaeological procedures in M4

Since 2004, thanks to the collaboration between the subjects interested in the realization of line 4 and the Italian authority responsible for the protection of cultural heritage (Ministry of Cultural Heritage and Tourism), a series of in situ verifications have been studied and agreed to give a series of design indications with respect to possible interference of the M4 with elements of archaeological importance.

The collaboration of all the Parties has also produced a specific agreement for the discipline of the archaeological theme, in which specific procedures are followed to assist specialized personnel during the construction of the work and any further intervention procedures in case of discovery finds of archaeological interest. In particular, for the central section of the Line, which is developed from the S. Vittore shaft to the S. Damiano shaft (included), there have been other cases.

First, the excavations are subdivided by type between:

- 1. excavations necessary for all the works as a corollary of the mere realization of the profund body, such as for example the sub-services to be modified to free the areas;
- 2. excavation of the bodies of work (stations and artifacts).

In the first case, considering the widespread reorganization that took place in the last decades and concerning the city's infrastructural networks, it was substantially taken into consideration the scarce probability of finding archaeological evidence, at least up to a depth of about 2m from the road level; from there and up to the share of sterile soil, tests were carried out with metal detectors for layers of one meter in order to intercept any suspicious masses.

Within the impression of the bodies of work the above-mentioned intervention logic has remained valid up to 2m depth from the countryside, then use the geo-radar for layers of two meters up to the share of the sterile soil and then authorize the second phase of research of war bombs (the deep one).

During all these phases the presence of specialized personnel is always guaranteed, operating according to two possible approaches:

- Assisted Excavation consisting in the presence of qualified personnel during all excavation work until reaching the sterile layer of soil;
- Archaeological excavation implemented when something significant has been found and which provides for the suspension of work to allow an excavation of an archaeological type with manual means adapted to the type of discovery that emerged.

3 ST. AMBROGIO STATION AND HIS CONNECTION WITH METRO LINE M2

3.1 Archaeological-monumental & Architectural-structural overview

The St. Ambrogio Station (ST09) is definitely a paradigm of the above. It is part of one of the most complex junctions of the city, grafted on two major roads such as Carducci street (north-south road axis) that connects the Cadorna railway station to the first ring road of Milan, and San Vittore street (east-west axis) along which overlook, within 300 meters, the San Giuseppe Hospital, the Basilica of San Vittore, the National Museum of Science and Technology, some historic buildings (including Cova Castle), some pre-existing archaeological sites including the remains of the Maximinianus Mausoleum and the Pusterla (ancient gateway to the medieval city), up to the Basilica of Sant'Ambrogio (one of the most important churches extended, as well as being the symbol of the city itself) and the Catholic University of the Sacred Heart (among the most important universities of Milan). To this is added the presence of the homonymous subway station Line 2 (green one) to which you have to connect, in addition to a multitude of public transport lines and private traffic enjoyment of the aforementioned streets and commercial realities to be preserved.



Figure 3. Plan of St. Ambrogio M4 station and archaeological surrounding area.

With great care and a good dose of ingenuity, it was possible to define a space sufficient for the creation of a typological subway station along the San Vittore street, in the section between Carducci and De Togni streets.

The St. Ambrogio station is one of the so-called deep stations of Line 4, those stations which, due to unfavorable boundary conditions, had to deepen more than the others to avoid hindering existing networks and structures. It is a station that engages between the two gallery (even and odd), connecting to them by a series of connecting tunnels, developed in only 13 meters of width within a road from the overall width (between the buildings) of about 16 meters.



Figure 4. Longitudinal section of St. Ambrogio M4 station and the section of M2 gallery.

3.2 Problems connected to the traffic node

The complexity of the road network S. Vittore - Carducci streets, right from the first phase of the study of the site, appears one of the most critical knots of the entire M4 line, being via Carducci an integral part of the inner ring road of the city and transit center of transport lines local public. The works of the S. Ambrogio station, given the density of the urban fabric in which it is located, can only occupy the surface road surfaces.

Specifically, the works of the station body completely occupy the west axis of S. Vittore street, the corridor connecting the M2 line (rectangular box 7,20x3,6 m) extends south for about 100m, completely occupying Carducci street and the atrium floor with the turnstile access line of the station is located right in the central part of the road crossing.

Moreover, the complex execution of the works of the atrium and corridor connecting M2–M4, which are performed with excavation in open air, without the use of diaphragms or micropiles, being placed above the tunnel of the M2 underground line (frank between the two structures equal to 1.06 m), metro line in operation and built in the 80s with traditional excavation method. To mitigate the impact of the works, the station, according to what is foreseen by the definitive project, is carried out in four phases of construction that provide for the execution of the central body of the station and of the lift tunnels, before moving on to the construction some parts of the tunnel below the intersection between S. Vittore and Carducci street and the stairwell on the south-west side; in the third phase the tunnel along S. Vittore street is developed, in addition to the construction of the station.

In the final design configuration, in addition, the ascent stairs in line were oriented towards Carducci street, with arrival, near the intersection with S. Vittore street, at a mezzanine level useful to realize also a tunnel connecting to the homonymous underground station of Line 2. From the mezzanine floor it was foreseen the possibility of exit on S. Vittore and Carducci streets, both on the south side of the station. Then there was a further access by elevator in the west (near the S. Giuseppe Hospital) that connected directly to the quay floor and, therefore, available to people with motor disabilities.

However, this configuration left unresolved a series of problems, highlighted during the course of the project authorization processes, including:

- The total occupation of the crossing between the Carducci-S. Vittore streets for considerable time, with consequent important effects on citizenship;
- The need to interface with the pre-existing historical-archaeological-architectural relevance, in order to harmonize the project to the needs of protection of cultural heritage, with particular reference to the stairs and exit elevators;
- The occupation of the entire Carducci street for the construction of the connecting corridor towards M2 station;
- Management of unbalanced exit and entry flows towards the intersection of the Carducci-S. Vittore streets, with penalization of the eastern portion and concentration of the entire flow towards a single exit point.



Figure 5. Traffic node S. Vittore-Carducci and tunnel section of M2-M4 connection.

4 Project Solution

4.1 Change to the architectural-functional design of St. Ambrogio station

The in-depth analysis of the aforementioned themes by all the parties involved, has generated a design review capable of resolving the critical issues and optimizing their implementation, both in terms of pure feasibility, and in terms of implementation.

First of all, it was decided to modify the construction sequence of the civil works, anticipating the construction of the roof slab and then working in top-down. The possibility of having already at the first stage of the roofing slab in S. Vittore street will make it possible to improve the pedestrian paths by moving away the building fences from the buildings and shops and reducing the superficial impact of the building site.

The compositional scheme maintains the structure of the station (as a shaft) between the two galleries, while the internal distribution has been completely modified. Further changes were introduced, that reduced the impact on the road network, such as the top down construction of the roof slab and the use of the provisional struts in place of the tie rods, to reduce interference with the surrounding buildings.

The essential feature of design variation is, however, represented by the crossed escalator scheme instead to the continuous drop-down scheme of tender design. Consequently, the longitudinal development of the stairway block is considerably reduced, since the spaces dedicated to the atrium and the platform floor are superimposed. This also implies a substantial difference in the distribution of the station spaces, with a clear separation between the service block and the block open to the public.

The new double-exit architectural and functional configuration has allowed the division into two of the turnstiles lines, decreasing the pedestrian flow volumes pertaining to M4 to be built in the stretch below the intersection Carducci-S. Vittore streets and so the atrium surfaces. In fact, in the definitive project just under Via Carducci the turnstile was located with a greater consequent area affected by the workings and a consequent greater closing time of Carducci street, with a strong impact on the road network.

Minimized the closing time of the Carducci/San Vittore intersection for the construction works of the station body, two design revisions were developed for the connection M2–M4:

- a first coherent with the definitive design tracing, which provided for the construction of the tunnel on the axis of Carducci street, up to the connection with the pre-existing station of metro line 2;
- a second one, which, instead, involves the translation of the connecting corridor towards the east side of via Carducci, realizing the accesses to S. Ambrogio square no longer on via di S. Vittore, but on the hypogeum part of the tower of Pusterla, which is at the same level with the entrance hall to the station.



Figure 6. St. Ambrogio station – architectural plan of the new solution.

It was quite clear that the second solution would have allowed to satisfy more the requests of the various subjects involved, making full use of the design optimizations of the station body, allowing the maintenance of at least one vehicular lane for each direction on Carducci street (as required from the Municipality of Milan to alleviate the road situation), and becoming, at the same time, an opportunity to reuse and enhance the Pusterla complex, one of the monuments symbol of the area.



Figure 7. First (on the left side) and second (on the right side) solution of M2–M4 connection.

4.2 Coordination with Archaeological Superintendeny and design optimization

The desire of the Municipality of Milan to strive for the minimization of the impact of the works on the area, including within the scope of intervention an area (up to that moment in disuse) of the city with considerable historical value. such as Pusterla complex and his

garden, he found the indispensable availability of the Archaeological Superintendency of Milan to evaluate its feasibility.



Figure 8. St. Ambrogio station – overview of the new solution.

Countless specific meetings were held on the topic between Municipality, Superintendency, Concessionaire, Work Supervisor and CMM4 Consortium, to define optimizations of the chosen solution. The Archaeological Superintendency, as far as it is concerned, asked for an in-depth architectural study which, starting from the analysis of the place and the value it represents, led to a project development that respected the place itself.



Figure 9. Planimetry of the new optimized solution.

The CMM4 Consortium, which is responsible for the Executive Design of the work (or its implementation), gave mandate, coordinating its activities, to the CREW Studio (Cremonesi Workshop), to deepen the architectural design development with the objective to combine the infrastructural needs with the stakeholders' one for a satisfactory proposal. The new concept design provides:

- 1. The movement of the lift at the head of the tunnel connecting M2–M4, along the Carducci street, releasing the visual cone East-West in order not to interfere visually with either the Pusterla or the entrance to the Basilica of St. Ambrogio;
- 2. The use of the hypogeum space along its entire length, with entrance through a monumental stairway capable of enhancing the entire architectural space and, at the same time, giving a new and less impacting seat to the pre-existing ventilation grids of the metro line M2;
- 3. Architectural reinterpretation of the access portal to the inter-connecting corridor (useful to reach both the M4 and the M2) of light type, with greater use of glass, material more coherent with the concepts of archaeological philology expressed by the Superintendency in cases of commingling between past and present;
- 4. Intervention of the perimeter walls of the hypogean garden and careful selection of the finishing materials of the area in order to highlight the historical stratifications.



Figure 10. Before work view vs night render of new optimized solution.

4.3 Executive phases and current status of the works

After completing the entire perimeter of the station diaphragms (in several phases) and having modified the entire network of subservices (partially in a definitive way, partially in a provisional way), after having also carried out the first digging in order to realize the consolidation of the bottom part of the station, currently the building site proceeds with the construction of the roof covering of the station, from which will continue to work in top-down mode.

The road network configuration allows, maintaining the continuity of the road system in both directions on Carducci street and the public transport, to start carrying out the preparatory activities for the execution of the tunnel connecting M2–M4.



Figure 11. St. Ambrogio station – construction phase and advancement of work.

5 CONCLUSIONS

The numerous problems linked to the Sant'Ambrogio station have made clear the need for the simultaneous involvement of all the parties involved in the construction of line 4; the mutual collaboration and cooperation allowed to re-modulate the design solution so that, in addition to solving the functional and executive needs typical of an infrastructural work, it took the opportunity to integrate and enhance a symbol of the citizen historical heritage thus contributing to the progress of the city in terms also cultural.

This fully integrated approach to design is once again a winning one and is undoubtedly a way to go with ever greater conviction and effectiveness, as well as with ever greater anticipation compared to the dynamics of project development, in search of the maximum optimization of the entire building process, with particular reference to public works, which, by their nature, anticipate a complex system of procedural management which tends to minimize, if not to exclude, the design review in the phases implementation of the work, contributing in this way to face its realization with greater awareness and serenity, respecting, also times and costs.

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