3-D SURVEY APPLIED TO INDUSTRIAL ARCHAEOLOGY BY TLS METHODOLOGY

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ABSTRACT

This work describes the three-dimensional survey of "Ex Stazione Frigorifera Specializzata": initially used for agricultural storage, during the years it was allocated to different uses until the complete neglect. The historical relevance and the architectural heritage that this building represents has brought the start of a recent renovation project and functional restoration.
In this regard it was necessary a global 3-D survey that was based on the application and integration of different geomatic methodologies (mainly terrestrial laser scanner, classical topography, and GNSS).
The acquisitions of point clouds was performed using different laser scanners: with time of flight (TOF) and phase shift technologies for the distance measurements. The topographic reference network, needed for scans alignment in the same system, was measured with a total station. For the complete survey of the building, 122 scans were acquired and 346 targets were measured from 79 vertices of the reference network. Moreover, 3 vertices were measured with GNSS methodology in order to georeference the network. For the detail survey of machine room were executed 14 scans with 23 targets.
The 3-D global model of the building have less than one centimeter of error in the alignment (for the machine room the error in alignment is not greater than 6 mm) and was used to extract products such as longitudinal and transversal sections, plans, architectural perspectives, virtual scans
A complete spatial knowledge of the building is obtained from the processed data, providing basic information for restoration project, structural analysis, industrial and architectural heritage valorization.

1. INTRODUCTION

The building of "Stazione Frigorifera Specializzata" is a part of the big old complex of Magazzini Generali, in Verona. This area was built in the 20's of the twentieth century as storage structures and market, mainly for agricultural products but even for other different kind of merchandise. Storage of grain and of foreign and domestic merchandise and the availability of a refrigeration system suitable for storing meat, fruit and vegetables have made Magazzini Generali one of the most important commercial node of the north-east of Italy.
The increase in activities throughout the years has required the expansion of the space and the creation of new structures to satisfy the market request. In this context from 1929 to 1930 was built the Stazione Frigorifera Specializzata (Figure 1) designed by engineer Pio Beccherle.

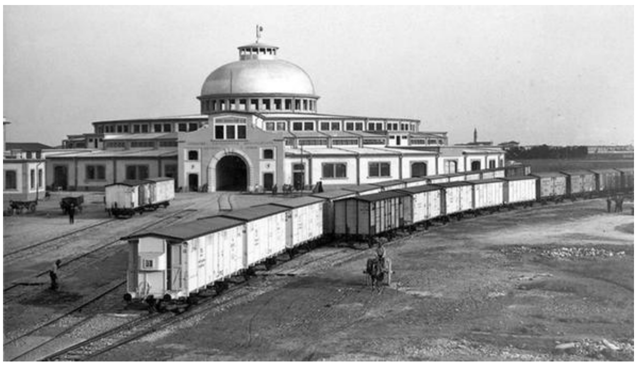

Figure 1. View of the Ex Stazione Frigorifera in the 30's.

Between the 50's and 60's, because of the beginning of other activities and the competition from private companies, the Stazione Frigorifera was increasingly less necessary, and that area of Magazzini Generali was used, from 70's, mainly for storage of motor vehicles, with a marginal use related to other activities (reception center and cultural space).
The recent years were characterized by a complete neglect and degradation of the building and surrounding area: now the revaluation project of the area will allow a structural and functional recovery of the Stazione Frigorifera.
The architecture presents at the same time a monumental style and formal solutions which fully meet the functional logistic requirements.
The building had a central plan distribution, pivoted on a turning platform for internal handling of railway wagons: they were used for the transport of foodstuffs coming from the nearby station of Porta Nuova and were directed to the refrigeration cells. In the external band were located the rooms used for discharging and workmanship of products.
The entire building has a circular plan of 107 m of diameter and covers a surface of about 10000 m^2: it is developed on two floors and is topped by a ribbed dome in reinforced concrete, with a diameter of 24 m, that covers the central hall of the structure where was installed the turning platform.
Nowaday the platform and the railways have been dismantled, as well as the isolation layer on the wall of the cold storage.

2. SURVEY METHODOLOGIES

This work makes use of some of the main geomatic methodologies for 3-D survey, from classical topography and GNSS for the reference network to terrestrial laser scanning for the entire survey of the building.
The measurments of the spatial coordinates of the points in classical topographic methodologies is performed by measuring distances and angles from a reference point by means of total stations and/or levels for more precise elevation data. The distance is measured using electromagnetic waves generated by

the instruments: the signal is shoot towards the object; after striking of the surface, a part is back reflected and is received by a device in the total station. The distance is calculated by measuring the running period of the signal (outgoing and returning wave). Moreover, the measurment of azimuthal and zenithal angles allows the spatial positioning of the points using the polar coordinate system. Subsequently, the firmware of the instrument transforms these coordinates into the local Cartesian reference frame.

This method is used for the measurements of topographic networks, connecting inter-visible points with a triangulation approach: these points are chosen in stable area incorporating the object of 3-D survey and represent the reference for each other measurements.

In order to georeference the network and, consequently, the entire survey, it's necessary to obtain the geographic coordinates of an adequate number of vertices.

Global Navigation Satellite System (GNSS) allows the measurements of 3-D coordinates of each point on the Earth's surface based on US Global Positioning System (GPS), Russian Global Navigation Satellite System (GLONASS), Chinese BeiDou Navigation Satellite System (BDS), Indian Regional Navigational Satellite System (IRNSS) and the under development European Galileo.

Using data from satellites, the 3-D coordinates of the point on the ground are measured with precision until less than 1 centimeter. This accuracy is obtained using at least two instruments: the first one (Master Station) is located on a known point, while the second one (Rover Station) on the point object of the survey and the two instruments acquired data at the same time.

Sometimes, due to the availability of many permanent GNSS stations (Master) that acquired data continuously, only one instrument is necessary for the survey (Rover). For georeferencing topographic networks into global reference systems two or more points of the network have to be measured with GNSS receivers with static, rapid-static or RTK (Real Time Kinematic) methods, obtaining the coordinates in national or international reference systems.

The different approaches for GNSS surveys depends on the final precision needed.

The main methodology in this work, in terms of amount of collected data, is the terrestrial laser scanning (TLS). It provides spatial data about the surveyed object or scene in a short time and with high accuracy, generally in the order of millimeter.

The instrument works through the automated measurement of distances and angles, in order to obtain the 3-D coordinates for each measured point of the object. Laser scanners can works through different technologies for the measurements of distance: time-of-flight (TOF) or phase shift measurements. In the first one the measure is performed through a laser beam, generated from the center of the instrument, that hit the surface of the object and come back to the scanner: measuring the time needed for the double path, the distance between the center of the instrument and the object can be calculated. Moreover, knowing the two angles in the space, the 3-D coordinates of the point can be obtained in the laser scanner reference system. Turning between 0° and 360° the scanner can acquire the entire scene around it and represent the scanned objects in a "point cloud". Depending on the resolution and level of detail required, the final survey can include several millions of 3-D points.

On the other hand, with the phase shift method, the instrument compare the phase that come back from the object with the phase produced by the laser scanner: using the phase difference, the distance instrument-object is calculated and, with the measurements of the two angles in the space, a point cloud can be structured.

In terrestrial applications only the visible surfaces can be surveyed, and the acquisitions from different points of view are useful to reduce the shadows zones.

The alignment of different scans is performed with algorithms of software that uses overlap areas between contiguous point clouds, or by means of integration with topographic classical methodologies; in this case specific targets are placed on the surface to be surveyed and are measured both with laser scanning and topographic techniques in the same common reference system (planning and measuring of the local or global topographic network is necessary) (Fabris et al., 2010). The later approach, the one using classic topography instruments, is suggested for the alignment between scans without overlapping regions, for example in the co-registration of point clouds concerning the external and internal portions of the building (Fabris et al. 2007).

Accuracy of the terrestrial laser scanner mainly depends on: the device; the measured range, that is the time-of-flight measure, or the distance calculated by the phase comparison between outgoing and reflected signals; the resolution, that is the combination between the smallest possible increment of the angle between two successive points and the size of the laser spot itself on the object; the edge effects of the object, in fact, a variety of wrong points can be produced near the edges; the reflectance of the surfaces: normally, white surfaces will yield strong reflections whereas reflection is weak from black surfaces; the effects of colored surfaces combined with the spectral characteristics of laser (green, red, near infrared), so shiny surfaces usually are not easy to acquire; the environmental conditions: temperature, atmosphere, interfering radiation, presence of covering vegetation, dust in the air, fog.

Together with the points, the instrument can acquire also images using the internal camera coaxial to the laser scanner, and so providing data in the same reference system of the scan: in this case, each point of the scan can be colored with the colors derived from the image, providing a photo-realistic vision of the scene through the creation of texturized models.

Figura 2. Aerial 3-D view of Stazione Frigorifera (circular building) and some other sectors of Magazzini Generali, during the works that since some years are carried out in the area (source: Google Earth).

3. TOPOGRAPHIC GEOREFERENCED NETWORK

The topographic network was projected and materialized providing external and internal points (on the ground floor, on the middle floors and on the roof) of the building, connected with redundant measures (distance and angles). The 3-D survey of the Ex Stazione Frigorifera was performed starting from the definition of a suitable number of this reference points and their measurment.
The survey of the network, in a local reference system, was performed using a total station characterized by a precision of 1.5^{CC} in the measure of angles and 2 mm + 2 ppm (parts per million) for the distance measurements. The topographic reference network, composed by 79 points, 40 inside and 39 outside the building (17 on the roofs), is necessary for an high precision alignment and the georeferencing of the point clouds acquired with laser scanners without overlap by means of appropriate targets measured both with laser scanners and the total station.
The processing of the network was performed using all the measurements with a scheme of free-network employing implicit minimal constraints: the coordinates of the points were extracted with a precision in the order of 3 mm with maximum of 5 mm.
Three vertices of the reference topographic network were measured using a GNSS receiver for georeferencing the network in the Italian national cartographic system. This was conducted through RTK measurements, that use the corrections in real time from the ItalPoS (Italian Positioning Service) permanent GNSS network and provides coordinates of points with rapid acquisition.
Data processing allowed to obtain the 3-D coordinates of the three reference vertices with a precision in the order of 8 mm.

4. 3-D LASER SCANNING ACQUISITIONS

The complex geometry of the building has made necessary an accurate preliminary planning of the laser scanning acquisitions, in terms of time, coverage and number of the scans, and model of scanner.
For the internal and external portions of the building a time of flight laser scanner was used while the survey of the machine room has been executed with a phase shift model of scanner that is lighter, more compact and is better suited to the reduced space of the room and allows to move and position more easily.
The first device operates in a range between 0.4 and 120 m and at maximum resolution the scan speed is up to 1 million points/second; the precision for a single measurement, in the 3-D positioning, is 3 mm at 50 m with vertical and horizontal angular accuracy of 8”.
The second laser scanner performs the measurements in a range between 0.6 and 120 m; the maximum speed of scanning is 976000 points/second with precision in the distance, for a single measurement, of ± 2 mm at 50 m and with vertical and horizontal angular accuracy of 32”.
Moreover, due to the morphological complexity of the refrigeration system inside to the machine room were necessary less invasive external references (spheres and targets on the walls instead of circular target on tripod).
The main acquisition concerning the internal and external portions of the structure was executed from the points of the topographic network: for each station, the orientation of the laser scanner was set using the coordinates of the reference points defining, in the same time, other temporary points useful for the subsequent acquisitions.
The portions of the roofs, not visible from the ground, were acquired using mobile platforms from different point of view around the building, up to an elevation from the ground greater than 40 m.
A total of 136 scans were acquired together with 369 targets (Monego et al. 2015).

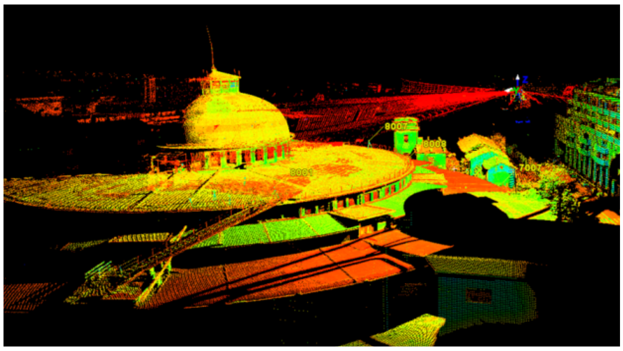

Figura 3. View of a single point cloud acquired from an aerial mobile platform at about 40 m from the ground.

5. 3-D GLOBAL MODEL

All of the the point clouds acquired in the survey were processed, aligned and georeferenced in the reference system of the topographic network. This was possible thanks to the targets positioned on the vertices and measured by laser scanner and total station.
In the end of the procedure a 3-D final model of the building (Figure 4, Figure 5) was extracted with maximum error in the alignment in the order of 1 cm (Fabris et al. 2009; Fabris et al. 2010).

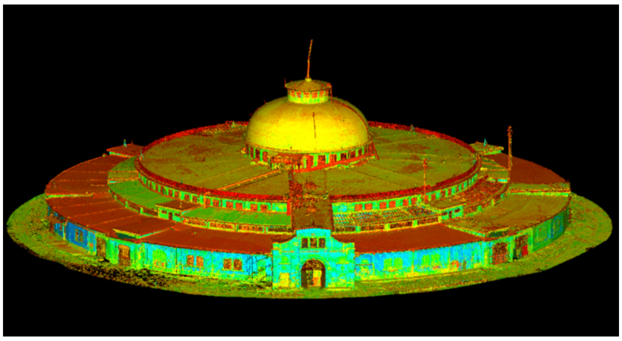

Figura 4. View, with scale of color based on value of reflectance, of the global 3-D model of Stazione Frigorifera.

Both internal and external parts of the model were divided into different layers (that correspond to the different architectonical elements: groundfloor, first floor and dome) in order to have a more manageable spatial dataset and the possibility to work separately with each part of the building.
Subsequently, using a specific software, the 3-D global model was used to extract plans of the structure at different elevations (Figure 6, Figure 8) and vertical sections (Figure 9), radially symmetric and shifted with respect to the center of the dome to obtain specific data about particular sectors of the building.
The generated sections were improved with manual restitution removing the incorrect polylines and optimizing the structural geometries.

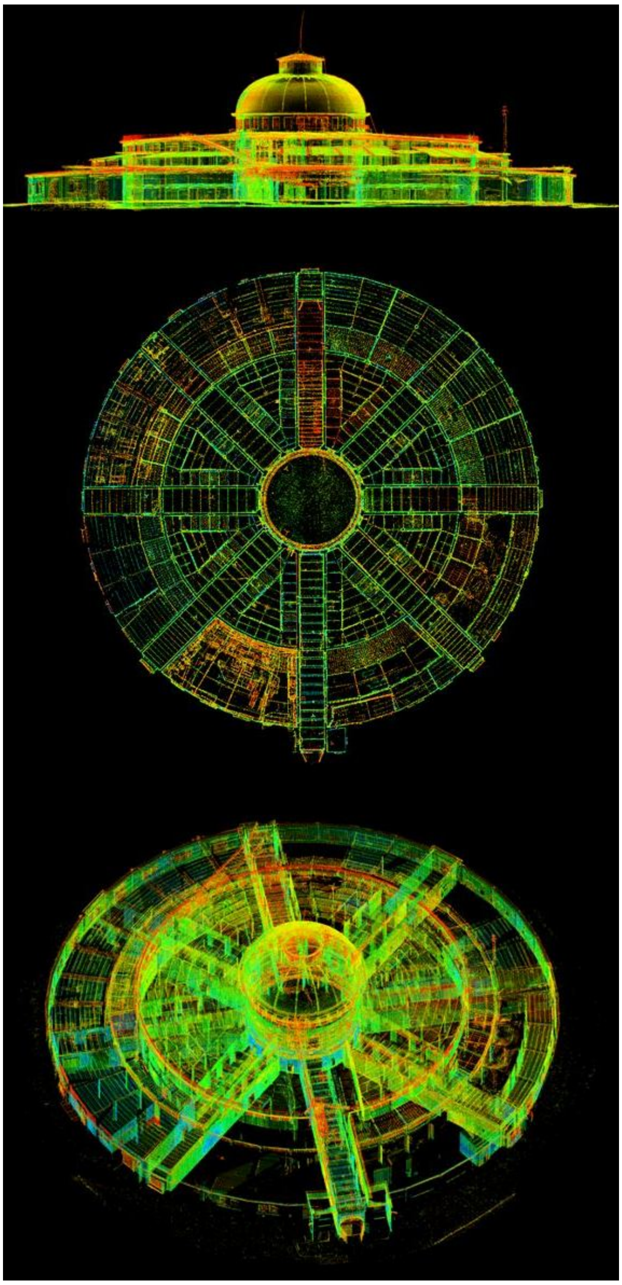

Figure 5. Perspectives of the model with the view of the internal spaces (lateral view, view from above and inclined view).

In order to help the work of graphic restitution virtual scans of the point clouds of some areas were extracted: 3-D points contained in a defined volume of the model were orthogonally projected on a specified plane and an orthophoto is produced (Figure 7). This ortho-rectified images of the areas of interest allow the interpretation of the geometries for a correct restitution of structures and objects and a more easily reading of the geometries that are so not only identified through a simple polyline (Figure 8).
The 3-D global model was processed obtaining a complete set of spatial data, functional to the design phase, by means of a methodology that allowed an adequate investigation, including the structurally compromises spaces and with not optimal environmental conditions and poor lighting of internal portions.

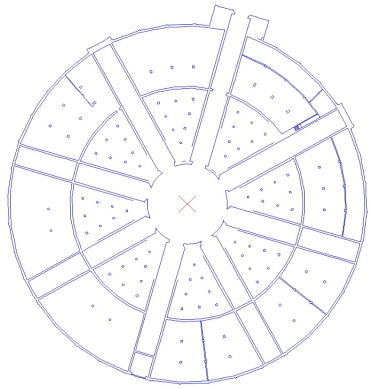

Figure 6. Plan of the ground floor at an elevation of 4,80 m.

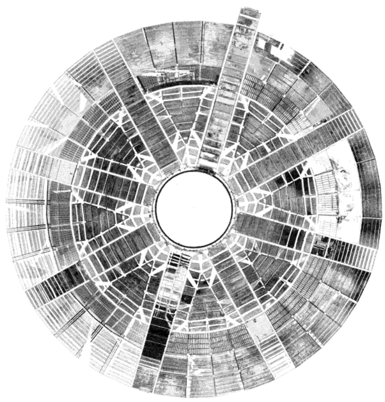

Figure 7. Ortho-image generated from the virtual scan.

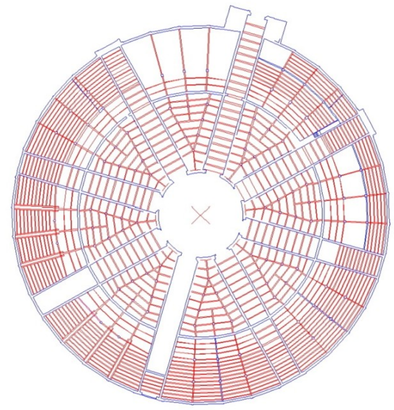

Figure 8. Restitution of detailed geometry of the structures of the ground floor produced by the integration of plan and information from the virtual scan.

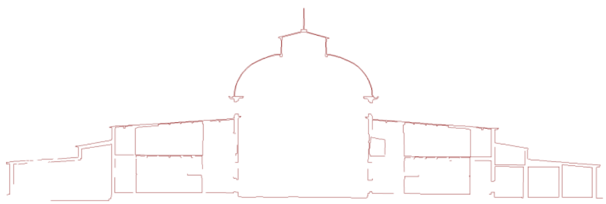

Figure 9. Vertical section passing through the center of the dome extracted from the model.

6. DETAIL SURVEY OF THE MACHINE ROOM

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The machine room of the Ex Stazione Frigorifera has required a more detailed survey campaign due to the importance of the industrial and technological heritage, consisting of the system of refrigeration, that had served the station. The final purpose is to realize a specific recovery project, to create a museum in this portion of the structure.

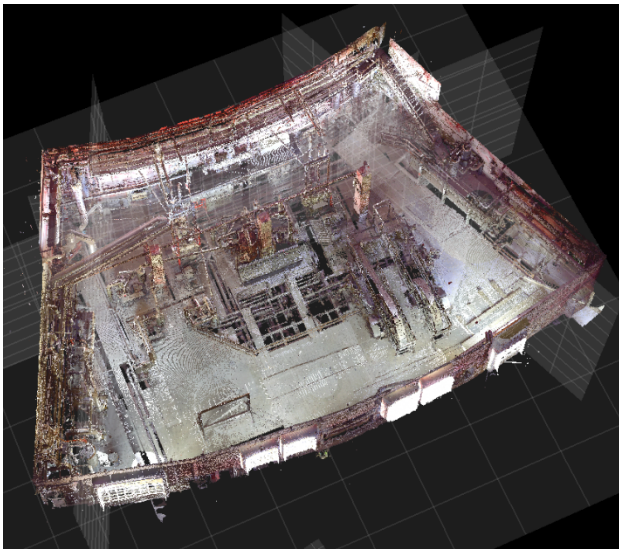

Figure 10. Global 3-D model of the machine room with texture mapping derived from images acquired by scanner.

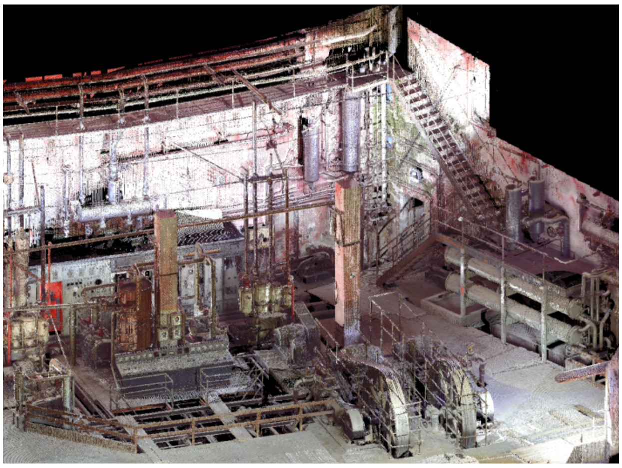

Figure 11. 3-D view of point clouds of a part of the machine room.

The 3-D survey was performed by a phase shift laser scanner with 14 scans; 23 targets were measured with the same total station previously described, from 3 points of the general topographic network: thus, the new survey is carried out in the same reference system.
In this case were used two type of targets due to the morphological complexity of the machine room: reference spheres, located on the floor, and checkerboard target on the walls; in fact, using different type of targets, located in different places, it is possible to improve the final co-registration of the scans.

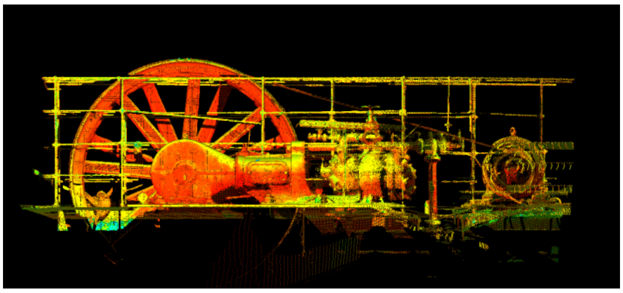

Figure 12. Lateral view (in reflectance colors) of a machinery of the refrigeration system.

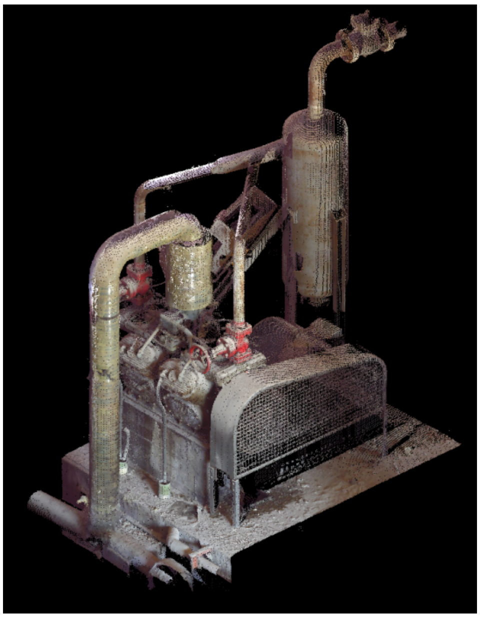

Figure 13. 3-D view of a single element of the machine room.

Figure 14. View of an extract of a control panel from global model.

The editing and alignment of the acquired points clouds were performed with maximum errors, checked on the targets, of 6 mm and generally less than 4 mm (Figure 10, Figure 11).
The images, acquired through the camera (70 megapixel resolution) integrated to the laser scanner and co-axial to the laser beam, allow the texturization of the model, giving it a photo-realistic characterization that fits to the the aim of the survey connected to the realization of a virtual museum and virtual visualization of the area from different point of view.
The high precision and high resolution data of the machine room virtual model can be used for cataloging, recovery and

conservation of machines, thanks to the possibility to be metrically represented and realistically displayed in 3-D (Figure 12, Figure 13, Figure 14).

Also for the machine room a set of virtual scans was produced in order to help the work of positioning and cataloging of piping and machinery (Figure 15, Figure 16). In the phases of dismounting and mounting of the installations this in an important documentation of the initial state of the room with high metric reliability.

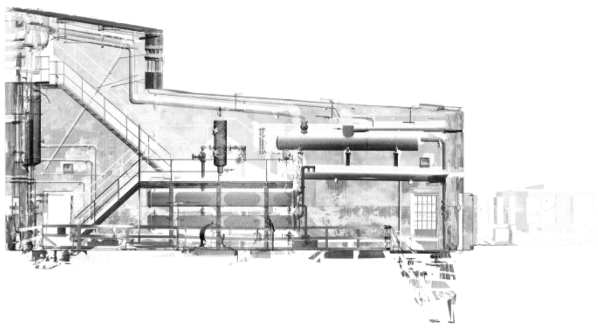

Figure 15. Virtual scan of the west wall of the machine room with piping, machinery and structures that could be mapped.

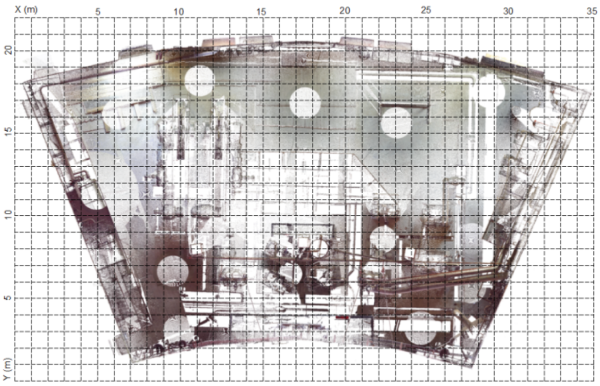

Figure 16. Virtual scan that represents the plan of machine room with a grid as scale reference.

7. CONCLUSIONS

The survey of the Ex Stazione Frigorifera Specializzata, located in the area of Magazzini Generali of Verona, was performed through the integration of geomatic methodologies that provide high precision and high resolution data and allowed the creation of a global 3-D model of the entire building. The complexity of the structure made necessary a large number of scans, often in difficult environmental conditions, especially in the survey of the machine room.

The acquired scans were aligned and co-registered with a maximum co-registration error in the order of 1 cm. The global model was inserted in the same reference system by means of a topographic network measured with a total station and georeferenced in the Italian cartographic reference system using GNSS measurements.

The machine room has required a more detailed survey, due to the historical importance of the machineries of the refrigeration system that are located here. The 3-D model was generated with a maximum error of 6 mm.

Eventually the two aligned models were used to extract products such as longitudinal and transversal sections, plans, architectural perspectives, virtual scans.

In this way, a complete dataset of spatial data was obtained, including detailed metric informations of the damaged or structurally compromised areas, where usually the direct access is not possible.

This work has provided not only an important base of spatial data for engineering application, but also informations useful in characterization and management of the indutrial and architectonical heritage represented by the Ex Stazione Frigorifera.

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