FROM AN INTEGRATED SURVEY WITH MMS TO A SCAN-TO-BIM PROCESS FOR EDUCATIONAL PURPOSES

FROM AN INTEGRATED SURVEY WITH MMS TO A SCAN-TO-BIM PROCESS FOR EDUCATIONAL PURPOSES

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KEY WORDS: 3D integrated metric survey, MMS, scan-to-BIM, Building engineering, 3D models, built heritage.

ABSTRACT:

The mobile mapping systems (MMSs) are increasingly used in the Architecture, Engineering and Construction sector (AEC). Their involvement in the digital transition of our cities and built heritage could be a valuable solution in speeding up the scan-to-BIM processes. In this framework, the course “Knowledge of the built heritage in the era of climate change” of Politecnico di Torino offers an innovative approach for MSc degree students in Building Engineering. In fact, it deals with the whole workflow from the surveying activities (data acquisition and processing), to the BIM modelling up to the final digital twin integrated with e.g. sensors data and management information. This contribution describes the case studies of the multidisciplinary course as an application for this methodology, where not only terrestrial laser scanning or UAVs (Unmanned Aerial Vehicles) have been used, but also MMSs have been tested to understand if they could be a suitable option. This paper aims to show the course experience derived from the collaboration of the geomatics and drawing domains along with students’ results and feedback. Moreover, the research underlines the pros and cons of this procedure.

1. INTRODUCTION

1.1 Knowledge of the built heritage in the era of climate change, the MS course in Building Engineering

The interdisciplinary course "Knowledge of the built heritage in the era of Climate Change" is part of the Building Engineering and Green Building MS degree, designed in 2020/2021, of Politecnico di Torino. In this multidisciplinary course, the different disciplines cooperate for the critical interpretation of heterogeneous data functional to the design of buildings, starting from a 3D metric survey and the related digital model (a Digital Twin). The theoretical concepts are applied to a real case study. Geomatics provides the instruments to understand a 3D integrated metric survey and to post-process the data (from photogrammetric and Lidar acquisition). Digital modeling offers tools to analyze historical data and model the built heritage from 3D point clouds by applying advanced Scan-to-BIM (Building Information Modelling) processes, with a consequent integration in GIS (Geographic Information System/Science) environment. The other two course disciplines, not the focus of this contribution, are ICT (Information and Communications Technology) and Building Physics, which aim to integrate simulated sensors' data and energy models. The objective of this paper is to show the course experience derived from the collaboration of the geomatics and drawing domains. The research focuses on the scan-to-BIM process, especially from the spatial data acquired by MMSs. Section 1.2 describes the two case studies, the first one object of the course of the Academic year 2021-2022 and the second one of the A.y. 2022-2022. Section 2 reports the 3D metric survey workflow and the data processing phases needed to obtain the MMS point cloud used for the Scan-to-BIM procedure. Section 3 underlines the methods used to model the industrial buildings with some criticalities highlighted. Finally, discussions and conclusions have been drawn.

1.2 The case studies

The case studies presented consist of two ex-industrial buildings (Figure 1) needing renovation and re-functionalization actions. They are both located in Turin, Piedmont (Italy) and they were chosen because of different construction techniques (steel and masonry) and epochs. Moreover, they have been selected for the course as examples of possible urban and city projects of re-evaluation of the suburban parts of the city.

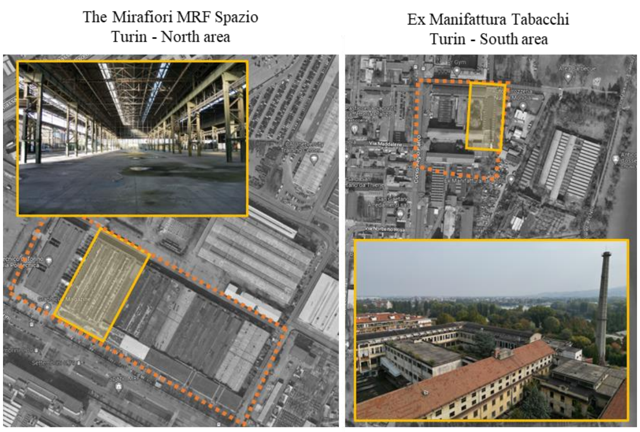

Figure 1. The two case study areas and the modeled portions.

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1.2.1 The Mirafiori MRF Spazio – Turin, Piedmont

The Mirafiori MRF Space (https://spaziomrf.it/) is an industrial building, part of the complex of the industrial area of FIAT in Turin, Piedmont (Italy). In 1939, the inauguration of the FIAT Mirafiori area was celebrated, and the case study played the crucial role of a warehouse for logistics until 2005.
Subsequently, in April 2015, The Torino Nuova Economia S.p.A. (TNE) launched a new project for the renovation of this industrial space made up of a steel structure with truss beams. Architectonically, the warehouse has a rectangular plan. The building has a load-bearing structure of pillars in iron-steel alloy, generally made of metal carpentry, braced using L-shaped sections. The roof is characterized both by pitched and shed typology (Figure 2). The supporting structure of the roof is also in metal carpentry formed by trusses with reticular beams. The external infill walls of the building consist of brick walls spaced out at mid-height and at the top by a double-glazed band that runs along the entire perimeter of the side elevations (Figure 2).

Figure 2. Image from Terrestrial Laser Scanner (TLS) camera.

1.2.2 The ex Manifattura Tabacchi – Turin, Piedmont

Positioned in the northeastern area of the city of Turin, the complex of the Manifattura Tabacchi is characterized by a multidimensional significance for the local area (historical, industrial, social, economic, environmental, architectural, etc.).
In 1740, during the Savoyard Government, tobacco processing was concentrated in the city's suburban area. The Royal factory, completed in 1789, was more than one of the oldest factories in the city but represented one of the largest industrial complexes in Turin. The first part of the complex has a masonry structure with vaulted ceilings and aulic spaces. After being considerably destroyed during the Second World War, it was restored and newly equipped. In 1960, only the part of the plant intended for processing cigarettes was active, with every other department being shut down. The ex Manifattura Tabacchi is today a rich part of the local heritage in terms of materials, design choices, and current state. The first buildings were characterized by long corridors and a modular scansion of the openings with exposed bricks. There is also a notable presence of large internal courtyards, enclosed by the buildings, used to sort the tobacco.
After a closure of almost 27 years, in 2020, a renovation project was proposed. The objective of this project is the requalification, redevelopment, and refurbishment of the complex. The functionalities envisioned are residential, including social housing and university, commercial and executive. For all these reasons, the 3D metric survey and modeling have been carried out (Figure 3).

Figure 3. Part of the ex Manifattura Tabacchi. In the yellow rectangle, the building object of study.

2. MATERIAL AND METHODS

2.1 Scan-to-BIM approaches based on MMS survey

In the last decade, different methodologies and research have adopted scan-to-BIM approaches and workflow based on MMS and Lidar 3D metric surveys. This trend was due to the spread of MMS instruments and techniques and the development of software and algorithms able to manage and easily model built heritage from acquired point clouds. Bassier et al. (2015) started describing several data acquisition techniques and workflows in the domain of Architectural, Engineering and Construction (AEC) industry buildings, concluding that terrestrial laser scanning still has the edge in accuracy and consistency but also stating the great potential of MMSs for mapping purposes. A similar study was carried out by Rashdi et. al (2022), who presented a work reviewing all the different recent researches on scanning technologies for BIM, including MMS. Subsequently, Previtali et al. (2020a) tested and compared the use of MMSs to create informative content models for structural health monitoring. The authors proved the feasibility of MMSs to achieve interesting results in terms of metric accuracy outperforming TLS for acquisition time. Moreover, Previtali et al. (2020b) also presented a methodology for optimal MMS path design in order to obtain a point cloud to be effectively used for BIM modeling. However, it has been validated in an outdoor environment. Sammartano et al. (2021) focused on H-BIM (Historic) modeling procedures based on SLAM (Simultaneous Localization and Mapping) technologies, analyzing the geometries and investigating the GOG (grade of generation) from the point of view of time-cost balance.
In all the just-mentioned cases, the surveying activities have been planned in advance, and the acquisition phases have been carried out in the best possible way; however, in this case, the learning-by-doing approach took precedence over the compliance and best execution of the data acquisitions, thus the results have to be considered from an educational perspective.

2.2 The data acquisition

For both case studies, an integrated 3D metric survey was carried out with traditional topographic techniques (total station and GNSS receivers) and other consolidated approaches, such as terrestrial and UAV photogrammetry, as well as handheld and terrestrial laser scanning techniques. A particular focus has been devoted to the integration of indoor and outdoor environments thanks to the Mobile Mapping Systems (Sammartano et al., 2018; Tucci et al., 2018). The survey was carried out with the students, applying the so-called learning-by-doing approach.
The survey steps followed for the two case studies are the same: firstly a topographic network was created by measuring the different vertex with GPS receivers (Geomax Zenith60), then some markers (GCPs, Ground Control Points) were placed on the facades and on the ground in order to be used to georeference both the photogrammetric and the Lidar (Light Detection And Ranging) data. The markers (checkerboards) on the facades were measured by the total station (Leica TS06) and the ground ones via GNSS technique. Then, photogrammetric UAV (Unmanned Aerial Vehicle) acquisitions were carried out

with a DJI Mavic Air and a Parrot Anafi. A relevant part of the surveying phases, for the 3D modeling purpose, has been the MMS acquisition. Different instruments with different ranges were adopted according to the two courses and the case studies.
For the Mirafiori case study, the indoor spaces were acquired with the Stencil Kaarta (Table 1) in a series of acquisitions lately manually co-registered and georeferenced on the basis of the UAV and TLS integrated point cloud. Four single scans with a closed-loop trajectory were acquired jointly with the students (Figure 4). All the acquisitions were initialized from the same starting point, outside the building, whose coordinates were also acquired.

Device	Features	
 Stencil Kaarta	Operative range	1-100 m
	Ranging error	+- 30 mm
	Vertical/horizontal FOV	30° (v)/360° (h)
	Acquisition speed	300.000 pt/s
 Feature tracker camera	Sensor size	1/3" CMOS
	Pixel	1,3 MP
	Focal length	3,4 mm
	Image size [pixels]	1280x1024

Table 1. Kaarta Stencil specifications.

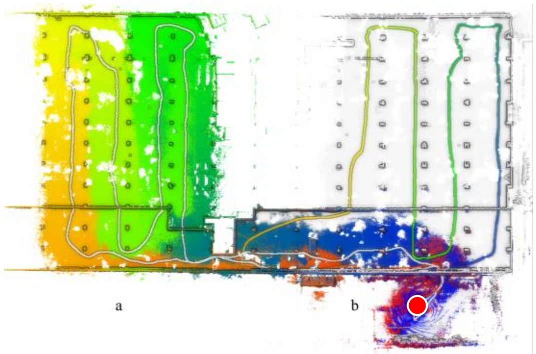


Figure 4. Example of two not adjacent scans with corresponding trajectories and starting acquisition point (red). Horizontal section.

As regards the ex Manifattura Tabacchi case study, the MMSs involved were the ZEB Horizon by GeoSLAM and the BLK2GO by Leica (Table 2). Also in this case, the point clouds were co-registered afterward, the trajectory path followed a closed loop and began from a unique point in the courtyard. Unfortunately, the latter was quite narrow, and with a high vegetation coverage, consequently, it was not possible to acquire the coordinates of the starting point through GNSS. This element could have helped the subsequent georeferencing.

Device	Features	
 ZEB Horizon	Operative range	100 m
	Ranging error	Up to 6 mm
	Vertical/horizontal FOV	270° (v)/ 360° (h)
	Acquisition speed	300.000 pt/s
 Leica BLK2GO	Operative range	25 m
	Ranging error	+/-10 mm (indoor)
	Vertical/horizontal FOV	270° (v)/ 360° (h)
	Acquisition speed	420.000 pt/s

Table 2. ZEB Horizon and Leica BLK2GO specifications.

Given the possibility of testing two devices, all the indoor accessible spaces were acquired with both. A union of the point clouds obtained from both devices was then used as a basis for the BIM modeling.

2.3 The processing phase

After the acquisition, the topographic network and the GPCs coordinates were calculated. The photogrammetry products such as points cloud, DEM (Digital Elevation Model) and orthophoto were generated and the point cloud from Lidar scans extracted.
The data post-processing phases changed according to the MMS used. The Stencil Kaarta required a manual registration of the single scans through ICP (Iterative Closest Point); the ZEB Horizon was processed directly in the GeoSLAM Connect, the first processing restituted a scan not correctly aligned (Figure 3) and revised afterward. For the BLK2GO, a single scan was obtained and integrated with those of the ZEB Horizon.

2.3.1 The Mirafiori MRF Space

The Kaarta scans were post-processed using the values adapted for large indoor environments, namely: voxelSize 0.2 and cornerVoxelSize: 0.2.
For those scans where the pattern was quite regular and similar, the *Adaptive Data Replay Tool* was used with values for laser odometry of:

- maximumIterations: 50
- matchingRotationThreshold: 0.05
- matchingTranslationThreshold: 0.05
- matchingDurationThreshold: 0.5

After that, the four single scans were manually aligned since the common parts were not sufficient to perform an ICP. The resulting point cloud was finally registered with the georeferenced UAV and airborne point clouds (Figure 5).

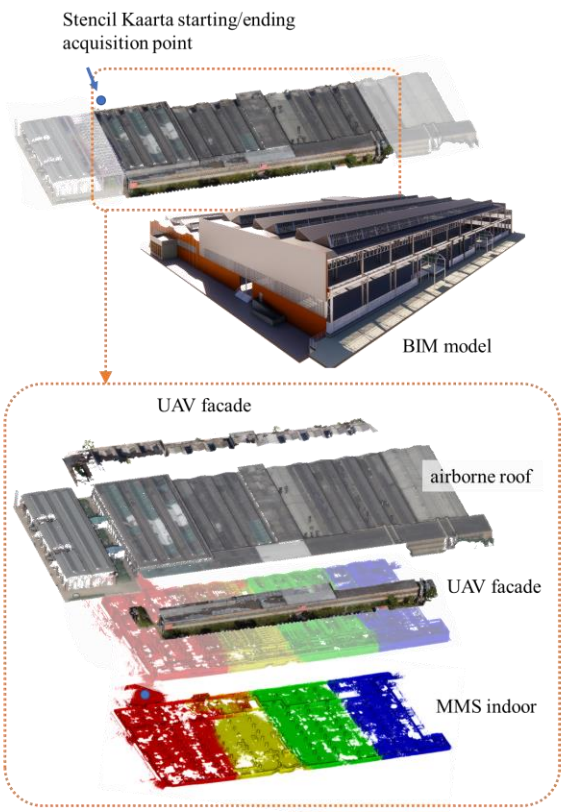


Figure 5. Data integration and final BIM model. The different colors of the MMS point cloud show the four scans registered.

Lastly, to assess the correctness of the georeferencing operation, a *CloudToCloud* analysis (Cloud Compare) was carried out, highlighting a drift issue down the end spans, due to the length of the building (about 300 m) (Figure 6). This criticality was then taken into account during the modeling phases.

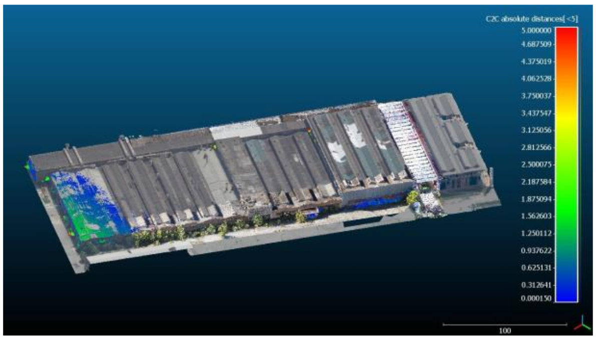


Figure 6. *CloudToCloud* within a range of 20 cm, emphasizing the drift error in the last part of the MMS point cloud.

2.3.2 Ex Manifattura Tabacchi

Zeb Horizon scans initially showed some alignment issues between the outward and return signal, resulting in a misaligned point cloud (Figure 7). However, after some post-processing operations in Geoslam Connect, the problem was solved, and the union of the two acquisitions of the upper floor resulted congruent. As for the lower floor, a single scan acquired with the BLK2GO was kept (Figure 8). In this way, it was also possible to investigate if there were any differences in terms of modeling between the two options.

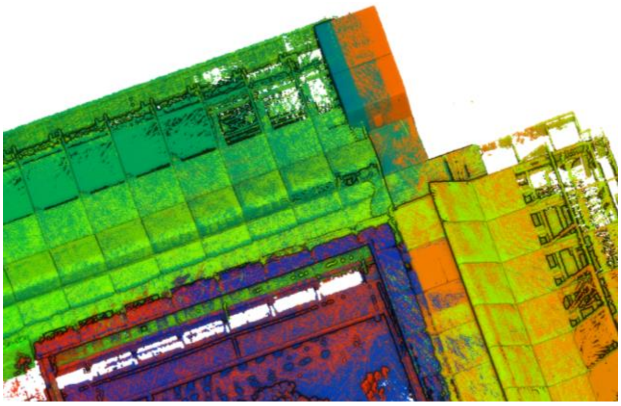


Figure 7. Case study 2. Misalignment in the acquired point cloud (colored with the GPS time scalar field). It is clearly visible in the top part, where the lift shaft appears doubled (green/orange).

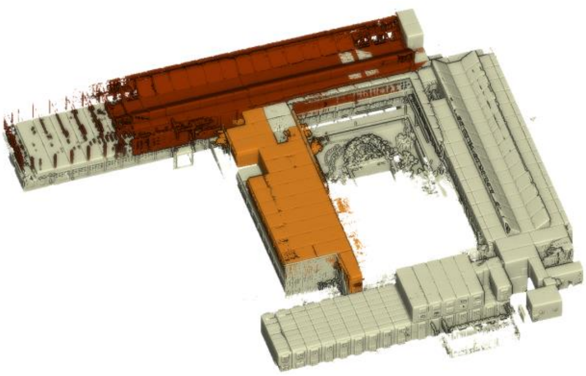


Figure 8. ZEB Horizon scans (red and orange) and BLK2GO single scan (grey).

For the co-registration, the students performed an ICP of the MMS point clouds on the UAV and TLS ones. The different point clouds had a good percentage of overlap, so there have been no critical issues in identifying the initial homologous points, especially if we consider the overlap of the point cloud obtained from the drone and that of the interiors. In fact, the acquisitions always began from the internal courtyard of the factory, thus having as common points those of the facades and the flooring.

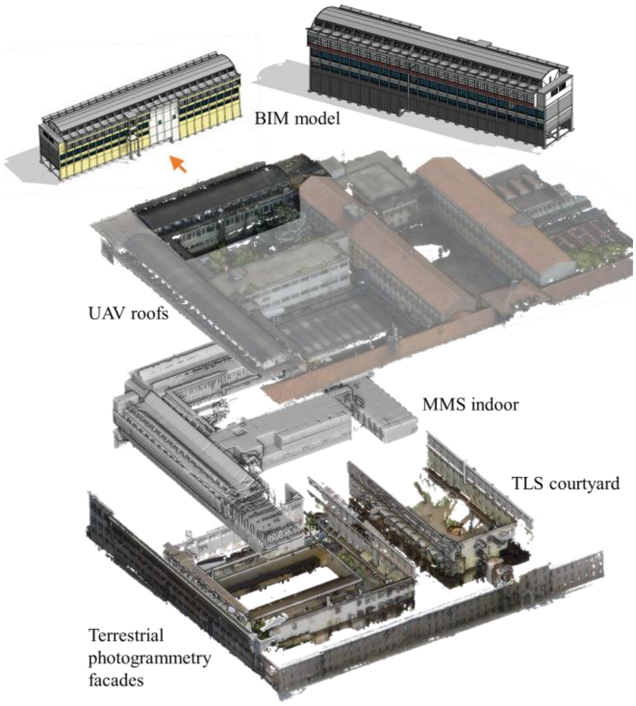


Figure 9. Data fusion with outdoor (UAV and TLS) and indoor (MMSs) point clouds.

Finally, feedback on the quality of the operations carried out was obtained through the *CloudToCloud* comparison. The photogrammetric and LiDAR point clouds were then merged, and the distance between this point cloud and the MMS one was evaluated in the range of 1 m.

From what was obtained, it was verified that in the areas of effective overlap the datum ranges between 1 and 4 cm (making the results suitable for a representation scale of 1:100/1:200). Figure 10 shows how it was checked not only the part of the internal courtyard (yellow rectangle), but also all the windows of the other sleeves (white rectangles), in such a way as to guarantee a correct internal-external alignment of the whole cloud and not only in the vicinity of the initial acquisition point.

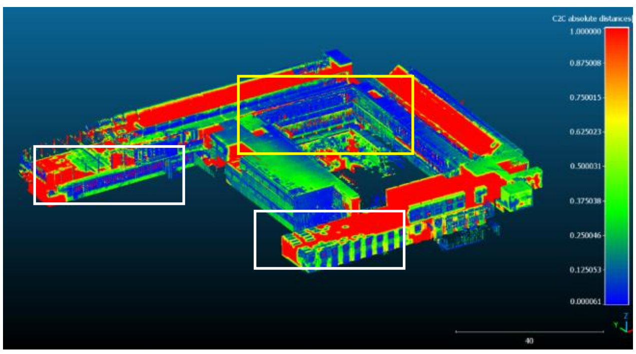


Figure 10. *CloudToCloud* results.

3. RESULTS

3.1 ScanToBIM approach

The knowledge restoration objectives underlying the digitalization of existing complexes, such as those selected as case studies, involve different scales of investigation, ranging from the general to the particular, from the urban to the building level. The purpose of the modeling phase was, in fact, to achieve a reliable model of both the external surface of the building envelope and the distribution of interior spaces. Autodesk Revit has been chosen as educational software, and the FARO *AsBuilt* plugin has been selected for the model accuracy evaluation. According to the specific interdisciplinary integration goals promoted by the course, three different subject models are to be derived. Urban, architectural, and structural models are defined and managed separately, afterward integrated together through a coordination model. The georeferencing of the point cloud allows the coordinates of the Revit project to be set rigorously. In this way, the location of the virtual model is matched to that of the real site, having a global reference system. Consequently, the coordinates of the points in the cloud were used to set a shared coordinate system useful for the correct methodological organization of a coordination file, considering the relative breakdown of the models that constitute it. Altogether, the students needed to use an intermediate program such as Cloud Compare or Autodesk ReCap to enable the point clouds to be used within the modeling environment. In fact, the processed points were redundant and make the task unmanageable. Additionally, a severe limitation is the impossibility of importing the point cloud within Revit's family creation editor. In this context of existing buildings, it has often been necessary to create ad-hoc component families. However, more than the high reliability of shapes and dimensions acquired by the field survey is needed for digitalizing the heritage. In fact, the information only refers to the elements visible during the inspection. It returns just the overall geometry, shape and boundary of the outer shell of the envelope, the structure and the partitions. Therefore, in both case studies, the metric information has been integrated with other documentary sources, such as project archive drawings, calculations, structural or authorization documents, and specialist investigations to achieve a knowledge model and the level of information needed to perform maintenance and management activities. CAD files worked as a double-check for detecting possible processing errors in restituting from the point clouds or inconsistencies between the current status and the project one. In connection with this critical synthesis, required to correctly interpret the different sources, the Level of Reliability (LOR) parameter was assigned to the different components of the model (section 3.1.2).

The Scan-to-BIM results achievable with the existing tools can be very different depending on the type of components characterizing the asset.

Overall, FARO's *As-built* plugin was tested for the automatic generation of building and structural components. This functionality was not available for urban context modeling because the tool does not provide for point conversion through the *Masses* category, which is used for representing building volumes. Walls were correctly recognized in most cases, although in historic buildings it is possible to encounter tapering that is not recognized. Concrete structural elements, if visible, are easily converted, as in the case of ex Manifatura Tabacchi. In contrast, steel elements (Mirafiori case study) achieved poor results. *As-built* was also used to control the deviation of the realized model from the acquired point cloud.

A significant advantage of using an integrated point cloud has undoubtedly been the possibility of verifying, for example, the size of masonry, the position of fixtures and pillars, and roof pitches by sectioning with horizontal planes. The large empty open spaces found in both case studies were well-represented by the point clouds. In the same way, it has been possible to have an elevated number of transverse and longitudinal sections from which to determine the heights of the different rooms, the scheme of the trusses, and the roof layout. In the following sections, specific feedback from the students' modeling experience is reported.

3.1.1 The Mirafiori MRF Space

In the case study of the Mirafiori MRF Space industrial building, a lack of data in the MMS point cloud was encountered concerning the high complexity of the steel frame constituting the skeleton of the building. In fact, the Stencil Kaarta point cloud was not dense enough to precisely identify the profiles of the structure's metal framework. In particular, criticality was found for the structural pillars, beams, and roof elements. For the latter, the point cloud did not allow the correct recognition and definition of the reference points, probably due to the vertical height, of approximately 13 meters, the material, and the geometric shape complexity (Figure 11).

Therefore, for the structural model, CAD files were used as a reference; the UAV and TLS point clouds were mainly used for the architectural model, while the MMS point clouds served for the general sizing and position of elements. In addition, from the MMS point cloud, the sections of beams and pillars were also verified.

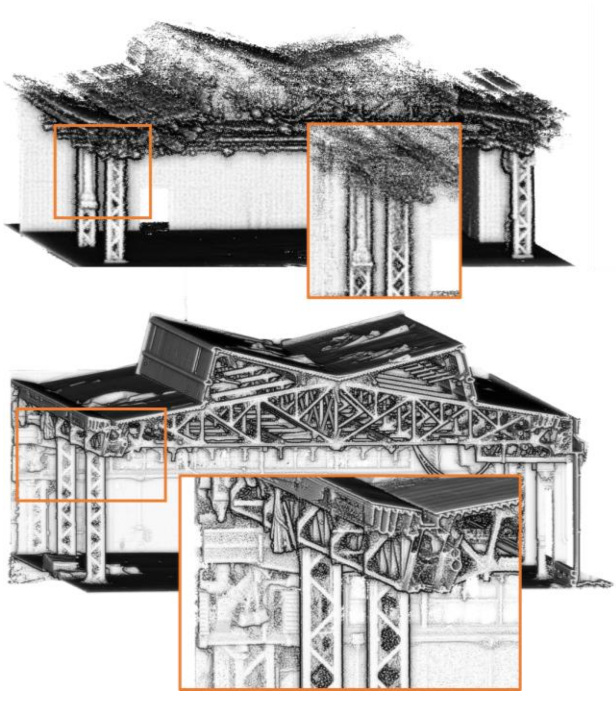


Figure 11. Comparison between the Stencil Kaarta point cloud and the TLS one.

Furthermore, internal crosswinds of the shed roof, which are very small and inclined, were detailed and modeled from the CAD file, since it was not possible to properly recognize them from the point cloud (Figure 12). Then, a script through Dynamo plugin, to optimize the modeling and automatically generate the structure by replicating the type frame along the two main axes was set up (Figure 13).

Figure 12. Cross-section of a span.

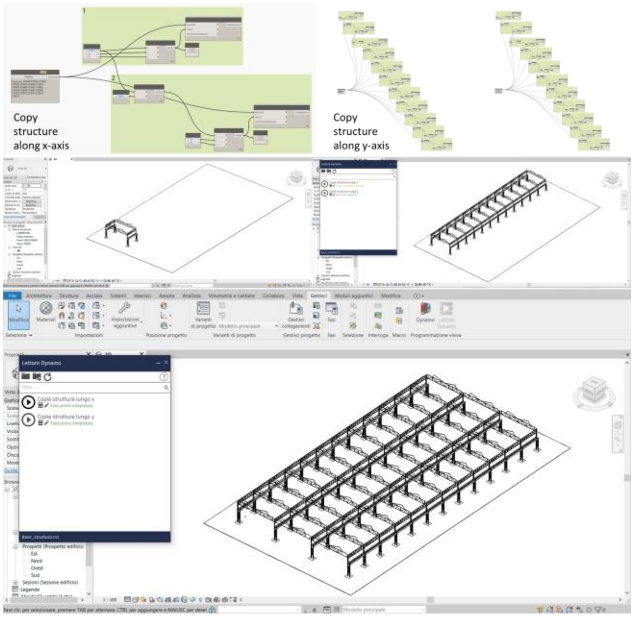


Figure 13. Dynamo script for automatic structural frame generation.

However, once the modeling was completed, an inconsistency was found between the structural model (modeled from the CAD files) and the architectural model. For this reason, the point cloud MMS was also useful as a reference for the manual alignment of the models.

Finally, the deviations between the model and the point cloud were checked via *As-built*, confirming deviations compatible with a representation scale of 1:100/1:200 (Figure 14).

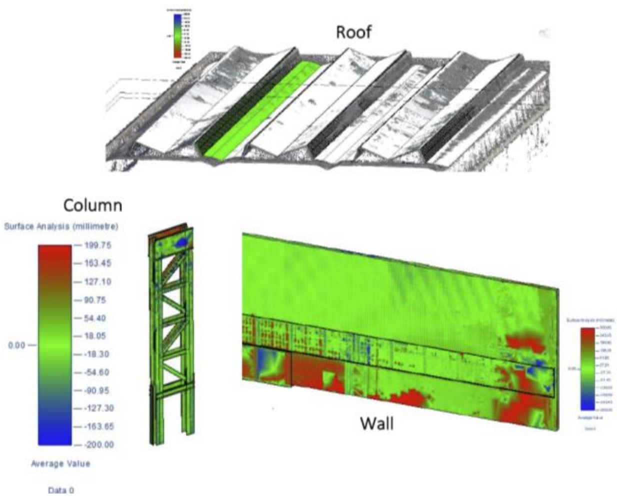


Figure 14. Surface deviation. Greenish parts represent values close to 0, while reddish and bluish have positive and negative values respectively, according to the analysis range set.

3.1.2 Ex Manifattura Tabacchi

In this case, unfortunately, one of the major criticalities highlighted by the students was the weight of the files and their management within the object-oriented modeling software. In fact, at first, *As-built* was selected for the modeling of pillars and walls starting directly from the point cloud, but, by requesting the direct loading of the point cloud within the Revit project, the modeling phases became excessively slowed down to due to program overload. The cleaning of the point cloud and its subsampling constituted an attempt that did not lead to the expected results.

For this reason, in some cases, the structural and architectural elements were modeled starting from the dimensional information obtained from archival plans; while the point clouds (linked to the project) were used for the positioning of the grids (scan of the pillars), of the levels (scan of the floors of the building) and as a check on the effective presence and dimensions of the modeled components. While in other cases, the students managed to take advantage of the *As-built* features for the correct reconstruction of the structural elements constituting the enclosure (Figure 15).

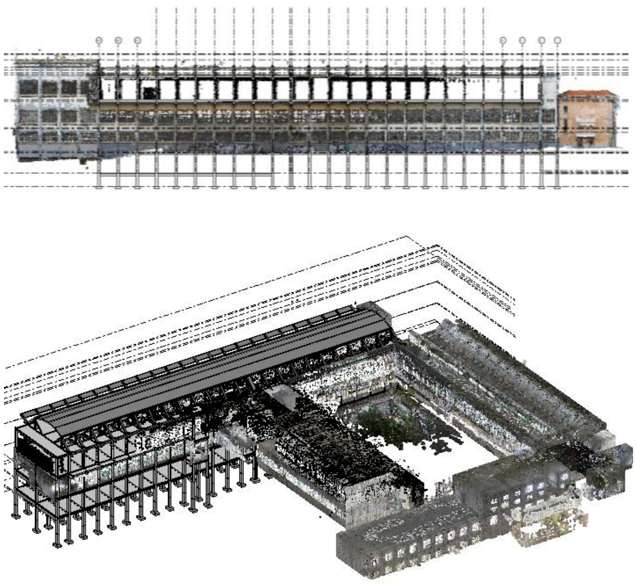
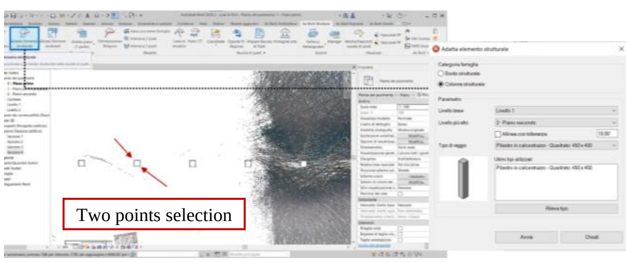
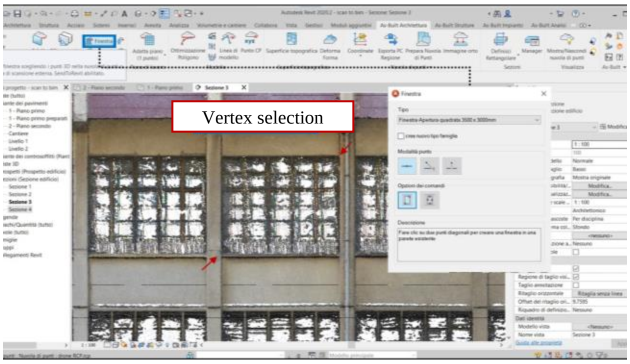


Figure 15. The structural model with the reference point cloud.

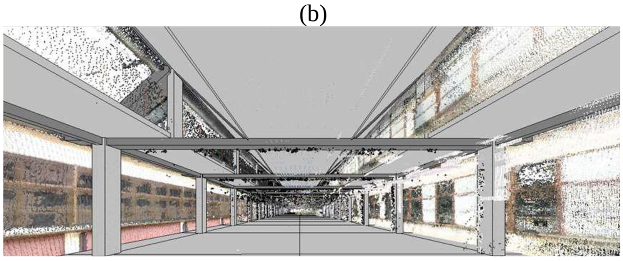
Nevertheless, it must be said that it was possible to easily benefit from the *As-built* plugin for the semi-automatic modeling of some architectural and structural elements, such as walls, pillars, doors and windows, thanks to the more massive load-bearing structure compared to the metal carpentry of the previous case study (Figure 16).



(a)



(b)



(c)

Figure 16. As-built plugin. Definition of the two insertion points for the pillars (a); vertexes selection for the window insertion (b) and the first result of the so-modeled structure (c).

Also in this case, once the structure was modeled, an analysis of the deviations between the model and the reference point cloud was then carried out. Figure 17 shows a portion of the building with results compliant with the established accuracies and tolerances.

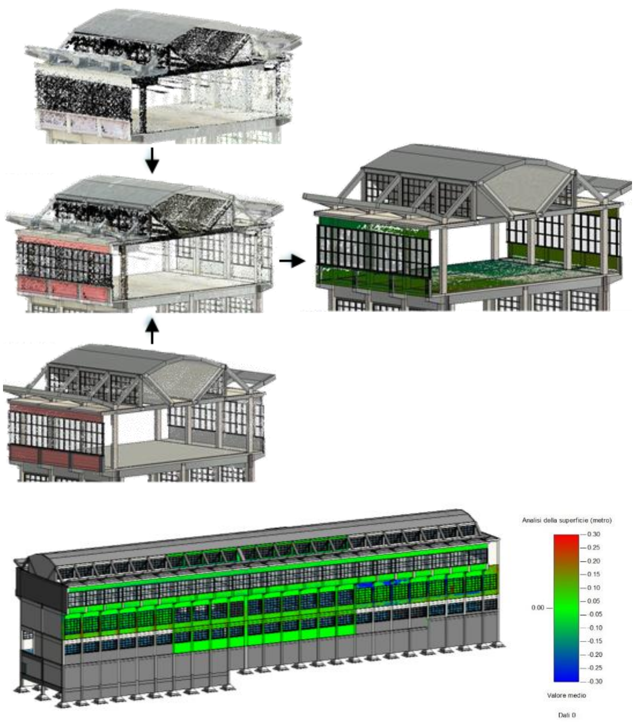


Figure 17. Surface deviation. Surface deviation. Greenish parts represent values close to 0, while reddish and bluish have positive and negative values respectively, according to the analysis range set.

Finally, as mentioned before, multiple sources were used for modeling. In this specific case, they were used: (i) data fusion with outdoor (UAV and TLS) and indoor (MMSs) point clouds; (ii) .dwg plans of the current state or project plan; (iii) fire prevention documentation, including plans and reports produced by the Provincial Fire Brigade Command; (iv) documentation related to renovation works, including the acceptance report, graphic drawings, constructive details, found at the Archive State Monopolies. For this reason, the resulting model's reliability is the synergy of geometric accuracy (LoA) and the quality of information sources (LoQ) (Maiezza, 2019). The two parameters were assigned to each source using a three-level basis (low, medium, high). From the sum of the values, the LoR (Level of Reliability) was defined, as shown in Figure 18. In this regard, the MMS point cloud has played a fundamental role in determining the veracity of existing 2D drawings, any inconsistencies, and supporting their updating, especially for indoor environments.

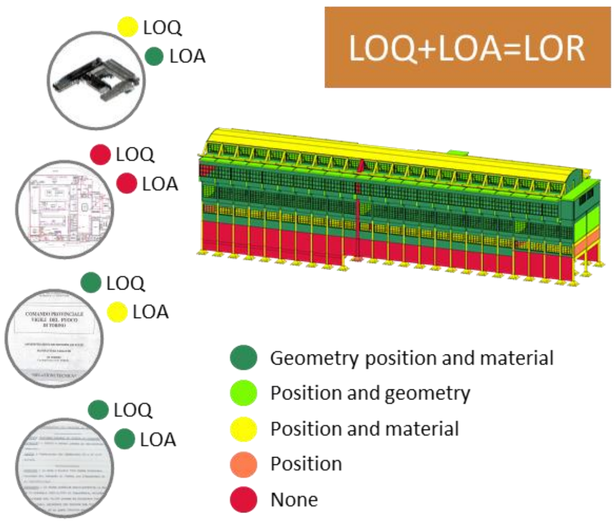


Figure 18. Mapping the Level of Reliability (LOR) for the elements of the model.

4. DISCUSSIONS AND CONCLUSIONS

This contribution has shown the scan-to-BIM process carried out by the students of the Master's courses in Building Engineering at the Politecnico di Torino.

The choice of two case studies (the Mirafiori MRF Space and the ex Manifattura Tabacchi) made it possible to test the proposed methodology on buildings with different construction characteristics, materials, geometries, and ages, thus highlighting their criticalities and potential. A specific focus was dedicated to the processing and use of point clouds from MMSs, underlining the problems, showing how they were solved, their feasibility, and which quality checks were chosen to validate the final result. In general, it emerged that the use of multisource data guarantees, on the one hand, the completeness of the information on which the modeling is based, since if a piece of data is missing (e.g. the point cloud), another data source intervenes to integrate it, but on the other, it highlights the cruciality of the possible inconsistency and contradiction between the sources. Having an updated point cloud, therefore, made it possible to quickly establish which was the most reliable source at a geometric and dimensional level. Furthermore, the weight of the point clouds, even those of

MMSs, remains a weakness, which most of the time had to be bypassed by dividing them into several regions or subsampling for easy use. The drift of the Mirafiori point cloud, almost 300 m long, constituted an issue, when georeferencing it on the UAV reference point cloud, which remains open. In contrast, the misalignment of the ex Manifattura Tabacchi point cloud was easily solved during the post-processing phases. More in detail, the MMSs point clouds have proved to be very useful for defining the general geometries (walls) and for the positioning of elements such as pillars or beams, however, their noise (in some cases) and density did not guaranteed sufficient definition to a detailed modeling of architectural and structural components with smaller dimensions. Through these point clouds, confirmed by the analysis of the deviations, it was possible to achieve results compatible with a representation scale of 1:200 and, only sometimes up to 1:100, in any case with the support of point clouds from UAVs and TLS. During this experience, we have not achieved the accuracies of (Sammartano et al., 2021), and we are aware that a best-planned acquisition path would have helped the final MMS point clouds, though it has to be considered that all the data acquisitions were performed with the students, to implement a learning-by-doing approach, thus obtaining the best result was not the main purpose of the activity.

The metallic trusses constituted a criticality both in the phases of the survey and in those of the digital restitution. In the absence of other sources, the MMS point cloud would not have allowed a correct representation and modeling.

In the case of ex Manifattura Tabacchi, on the other hand, the integration of the point clouds of the BLK2GO and the ZEB Horizon did not lead to particular inconveniences or critical issues, highlighting a good integration capacity for our purposes, and the feasibility of both the solutions.

In all cases, however, the problem of the georeferencing of the MMS point clouds on the UAV and TLS ones remains. This step was carried out mainly manually, since only in some cases the ICP turned out to be effective. This operation decreased the general accuracy of the final result, nevertheless the latest MMSs are gradually leading to a more direct and easier georeferencing workflow.

Finally, difficulties remain regarding the interoperability of the software (many of them are still needed from the initial stages of data acquisition and processing up to the final modeling) and the ease of their use by professionals.

Nonetheless, the acquisition times have been drastically lowered thanks to the MMSs, leading to the conclusion that they are, currently, an excellent compromise for the massive modeling of buildings or architectural complexes that do not require a high level of detail (possibly integrable with TLS or UAV point clouds), also from an educational point of view. They, in fact, allow for defining the general geometries, both the envelope and the indoor environments, and granting a quick check of the current state with respect to the existing CAD drawings or projects. As a future educational direction, we will try to have MMS point clouds directly georeferenced, without further manual steps.

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