Teaching geomatics to architecture students: low-cost modelling approach for critical interpretation of architectural design context

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Abstract

Although the practice of architects and urban planners often relies on the data and products of geomatics disciplines, such as digital technical cartography, orthophotos and sophisticated digital models, the information about the instruments, technologies and techniques that produce such contents are seldom extensively included in the curricula of the future architects. A "playground" at which teaching staff of different disciplines, for example design, planning and geomatics, can meet and interact with each other in a wider interdisciplinary context, has been identified in a laboratorial university courses. The paper reports on a three-phases teaching method applied within the module of "Digital modelling" at the final year of the Bachelor degree in Architecture at Politecnico di Milano (Italy). The method is illustrated using two case studies: (i) a contemporary XX century prefabricated building, hosting one part of the Municipality archives in Milan and (ii) an impressive example of neoclassical architecture, Albergo dei Poveri in Naples. The aim of the paper is to illustrate how geomatics techniques can be integrated with courses of architecture design and urban planning with notable results achieved in students' skill-development in terms of in-situ data acquisition using open data and low-cost instruments, data processing with low and no-cost state-of-the-art software and, finally 2D and 3D digital representation of built environment at building and district scale. Specifically, the method is used as a presumption to describe and discuss possible concrete contribution of the low-cost modelling approach in support to the critical interpretation of an architectural design context.

1. Introduction

Although the practice of an architect and urban planners often relies on the data and products of geomatics disciplines (digital technical cartography being just one of them), the information about the techniques and technologies that produce such contents are seldom extensively included in the curricula of the future professionals. A "playground" at which teaching staff of different disciplines, for example design, planning and geomatics, can interact with each other in a wider interdisciplinary context, has been identified in a laboratorial experience i.e. the architectural studio courses. In this type of courses two or more disciplines can be integrated together, with equal or different amount of training credits and therefore different time dedicated to each discipline. Such approach has as objective to expose students to several academic disciplines organised around one common topic i.e. one planning challenge to which novel solutions should be proposed. The main focus of the studios remains on the project research and design, based among else on a stimulation of critical thinking.

In the recent development of professional figures, the interdisciplinary approach has been highly valued, if not explicitly requested, even at the first job experiences. Hence, the experience of studio courses in which different disciplines have occasion to interweave, have become of great interest to students. In addition, such courses provide a fertile ground for experimentation of training methods to the teaching staff. This paper illustrates the approach implemented and it examines the results obtained in two different design scenarios across two academic years. The examples illustrated regard the projects developed in two Italian cities across two different academic years, specifically: (i) Area of Niguarda (Municipality 9), the city of Milan in aa. 2022/2023; and (ii) Area of S. Carlo all'Arena (Municipalities 3 and 4), the city pf Napoli in aa. 2023/2024.

2. Geomatics for architecture students in a multi-disciplinary environment: a proposal of a teaching method

Use of geomatics techniques, such as photogrammetry and laser scanning, is being increasingly employed in higher education that regards the domain of the built environment such as architecture design and urban planning, including analysis of pre-existing contexts, recording and digitalisation of historic buildings and so forth. Numerous examples range from the use of smartphones for creating 3D abacus of single technological elements (Beltramini et.al) until the use of UAV devices and data processing for entire buildings (Chatzistamatis et. Al, 2023). Cases of 3D modelling applications illustrate the use of digital repositories and metaverse for storytelling and education for students from different Cultural Heritage disciplines (De Marco, 2024), or low-cost methods immersive and interactive virtual reality experience of entire historic cities (Walmsley and Kersten, 2019).

Paper here proposed replicates the logic of an earlier work, advocating the importance of problem-based learning (Cuca, 2018), when teaching geomatics techniques and data acquisition and processing within curricula that focus on built environment such as architectural design, urban planning or landscape mapping and management.

The experience described is hosted within a university course entitled "Laboratorio Finale" (Final Design studio) and it is offered at the third and final year of the Bachelor degree in Architectural Design at Politecnico di Milan (School of Architecture Urban Planning and Construction Engineering – AUIC). The duration of this type of Studio is one semester (12 teaching weeks). There are several such interdisciplinary laboratories with different combination of subjects and students compete for one of their preferred choice. The activities described were conducted in the Studio held by the colleagues Tommaso Brighenti (main teaching reference of the course), Nicola Petaccia and the author of the paper on respective modules: Architectural design, Urban design, and Digital modelling. The final exam requirement foresees that the students produce digital models of their project proposals inserted in a specific urban context. Hence, “Digital modelling” set the aim to provide a three-dimensional description of the architectural design context in a digital environment to allow positioning of the newly planned and designed interventions envisaged by the students during project research activities. The method proposed by this teaching module focuses on the virtual reconstruction of the existing surroundings and adopts an agile workflow based on a low-cost/no-cost approach. The method was developed on three main teaching/learning objectives to be fulfilled by the end of the course:

- Students should be able to search, select, collect and use the available (open) geospatial information;
- Students should acquire new technical skills on in situ surveying using low-cost instruments and solutions;
- Students should acquire (or consolidate) technical skills on specific software dealing with geospatial data and 3D modelling to create (simplified) 3D models of the urban and architectural context.

Such method was then translated into three main phases of work, based on different scales for context interpretation:

- Phase I: Collection, selection, analysis and use of Open geospatial information. The scale considered here was territorial and/or city scale (e.g. 1:5000, 1:2000).
- Phase II: a) On-site visit for direct surveying and geometry recording using low-cost solutions and b) production of rectified imagery. The scale considered in this phase is a single building scale and architectonical (e.g. 1:200, 1:100, possibly 1:50 scale for details).
- Phase III: 3D modelling of urban context at architectural building/district scale (e.g. 1:200, 1:500, often depending on students previous modelling skills).

The number of students involved each academic year was around 40, subdivided in 10 working groups of 3 or 4 members.

3. Teaching process: case studies, methodology and data

All phases of the process are described in two different scenarios i.e. two case studies in two subsequent academic years. The following paragraphs illustrate details on the available materials and the instruments used.

3.1 Case studies used for the teaching method testing

3.1.1 **Cittadella degli Archivi (Archives Citadel), Milan:** The project area is located near the historic centre of the Niguarda district and it consists of the current Cittadella degli Archivi and the lost property building. This area is characterized by a large three-bays pavilion covered with a lowered-barrel structure, used as a main documentary building and hosting that hosts “Eustorgio” a sophisticated archiving robot, by a "monoblock" building with a prefabricated structure, containing part of the archive and the deposit of "lost objects" and another pavilion also with three bays, currently in a state of abandonment. The design of the two pavilions are attributed to the architect Arrigo Arrighetti (Brighenti, 2023).

The building used as a specific case study for in-situ survey and modelling activities was the modern “monoblock” construction , build in 1970s with dimensions of circa 60x60m at footprint and circa 20m in height (Fig.1, central part). No existing digital (CAD) drawings were available for this case study. Several digital scans of the archive paper technical drawings dating to ca. 1970 originally edited in a scale 1:100, have been used a reference of the overall geometry of the buildings. One of the students’ tasks was to produce such support in terms of digital plans and elevations.

Figure 1 Cittadella degli Archivi di Milano (Case study 1), as seen in Lombardy Region GIS Geoviewer (Regione Lombardia, 2024)

Geometric recording exercise was implemented though a dedicated on-site session was organised for all students of the course. The equipment used in this case was: rigid meters, tape measurers, common digital cameras (compact and reflex), laser disto (range finders, Leica various types) and a laser level (type Boch PLL360). The students had received a clear set of instructions prior to the on-site visit, while the overall process was supervised by the teaching staff.

3.1.2 **Bourbon Hospice for the Poor (Albergo Reale dei Poveri), Naples:** Albergo Reale dei Poveri also known as “Palazzo Fuga” was built in from XVIII century by Arch. Ferdinando Fuga in neoclassic style. It is located in eastern Naples with impressive dimensions of ca. 380x140m at footprint and 25-30m in height of various volumes (Fig 2). This extraordinary architectural example is characterized by complex design and construction events that, since 1751, have characterized its conception, partial construction and, finally, its current configuration (Giordano, 2014).

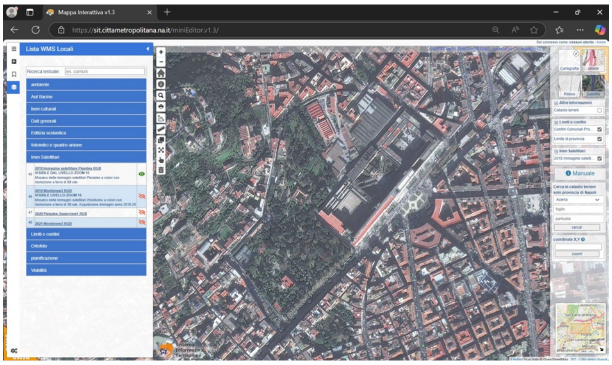

Figure 2 Albergo Reale dei Poveri and its botanical garden (Case study 2), as seen in Naples Municipality GIS Geoviewer (Citta di Napoli, 2024).

For purposes of the course, several digital (CAD) up-to-date drawings were made available to the students (plans, facades, sections), edited in scale 1:100. Students had only a couple of hours for autonomous information collection using rigid meters, tape measurers, common (amateur) digital cameras, including reflex ones. The students had received a clear set of instructions prior to the on-site visit. The process was not supervised by the teaching staff.

3.2 Low and no-cost software employed

In both academic years, the list of software used by the students was composed of low or no-cost solutions, as collected in Table 1. The typology of the software range from commercial ones with educational licence, commercial low-cost software acquired by teaching staff to those fully free and open source software available online.

Software / Product	Cost
QGIS (QGIS Dev. team, 2004)	Open-source software available at:
Perspective rectifier©	Low cost Ca. Euro50 for a number of licences, available in French, English and Italian (solution provided by teaching staff)
Raddrizzamento Digitale Fotogrammetrico (RDF) (IUAV, 2024)	No cost Developed by University of Venice (IUAV), CIRCE Lab (in Italian language only)
Autodesk AutoCAD (Autodesk, 2024)	No cost Educational licence for Polimi students
Blender (Blender Foundation, 2024)	No cost Free and open source software for rendering, modelling and animation
Rhinoceros® (McNeel and Ass., 2024)	No cost - educational licence for Polimi students
Photoshop and Light Room (Adobe, 2024)	No cost - educational licence for Polimi students

Table 1 List of software available to all students during Digital Modelling course

3.3 Geospatial Open Data for urban context modelling

The modelling of the case study environments at urban and territorial scale (Phase I) was based mainly on publicly available cartographic information (Open geospatial Data). In Italy, such datasets are collected, structured and made available following the indications of the INSPIRE Directive (European Parliament and Council, 2007), successively implemented through a national law decree (MASE, 2010). The geospatial information is hence distributed through geoportals owned and maintained by public administrations of different administrative levels.

Due to Open Data policy applied also on such data and datasets, students were able to search, consult and download data at no cost from main geoportals relevant to the two case studies, namely:

- Geoportal of Lombardy Region (Regione Lombardia, 2024) and Geoportal of Milan Municipality (Città di Milano, 2024) for Milan case study;
- Geoportal of Campagna Region (Regione Campagna, 2024) and Geoportal of Naples Municipality for Naples case study (Città di Napoli, 2024).

Additional information for 3D modelling of the facades and extensive urban fronts (specifically the elevations details of single buildings) were produced and integrated by students themselves, as a result of on-site photogrammetric recording and direct measurements.

4. Results of the teaching method and practical outcomes

Each phase of the method was translated into two specific products (boards): one board presenting the data analysis and processing and a second board representing the final results of the exercise. Concretely, the results for the two case studies are collected in the table below:

Course Work Phase	**Product num. and title**	**Link to other two modules of the Studio**
Phase I	Board 1. Use and management of geospatial (open) data: process illustration	Urban Design
	Board 2. Thematic maps	Urban Design
Phase II	Board 3. Geometric recording using low-cost techniques: process illustration	Architectural Design
	Board 4A. Rectified imagery in scale 1:100 Board 4A. Technical drawings in scale 1:100	Architectural Design
Phase III	Board 5. 3D modelling of the urban surroundings at district/building scale: process illustration	Urban design and Architectural Design

	Board 6. Views of 3D model at urban, district and building scale	Urban design And Architectural Design

Table 2. List of the final products requested for the examination: phase number, contents and connections with other two teaching modules of the Final studio course

Regarding the urban and territorial scale of analysis, the students have learned how to (i) search for and access Open data and their metadata through a geoportal structure; (ii) how to consult Web Map Services (WMS) and (iii) how to structure a simplified database in an open-source environment (Quantum GIS-QGIS). In addition, students learned to (i) interact with such a database to create specific thematic maps and (ii) create first 3D simulations for visualisation purposes, relevant for their case study and specifically to the module on Urban design.
During modelling of 3D architectonical features and urban environment experience the students have learned how to (i) import and use georeferenced cartographic base within a modelling environment; (ii) use cartographic information (height survey) to model buildings and districts; (iii) import and use rectified imagery and/or integrated CAD elevations for full 3D modelling of the facades, at various degree of complexity.

Figures 3-6 illustrate some graphical results produced by the students on the Case study 1: Archive Citadel in Milan.

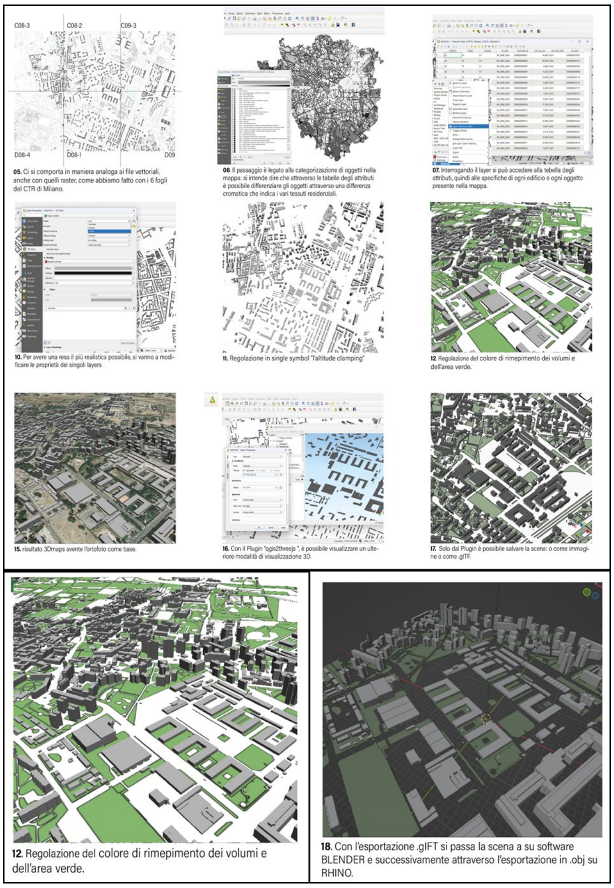

Figure 3 QGIS project of the Milan Archive Citadel: visualisation of open geo-spatial data collection (above); a 3D scene of the case study area (below left) and a view in Blender software

Specifically, Figure 3 illustrates selected steps of the Phase I i.e. of the QGIS project of Milan Archive Citadel construction, with some first 3D views produced from georeferenced digital cartography. All facades of the archive building have been surveyed with low-cost photogrammetry methods, using common amateur cameras already owned by students of by teaching staff (Phase II).

After completing rectified imagery for the four façades, students have vectorised all elevations in 1:100 scale at 2cm level of detail. Figure 4 illustrates the work completed for the north (main) façade of the "monoblock" building, wide circa 60m. In addition, the technical vector drawing shows the sides of the main staircase, the so-called "Boccioni" tower.

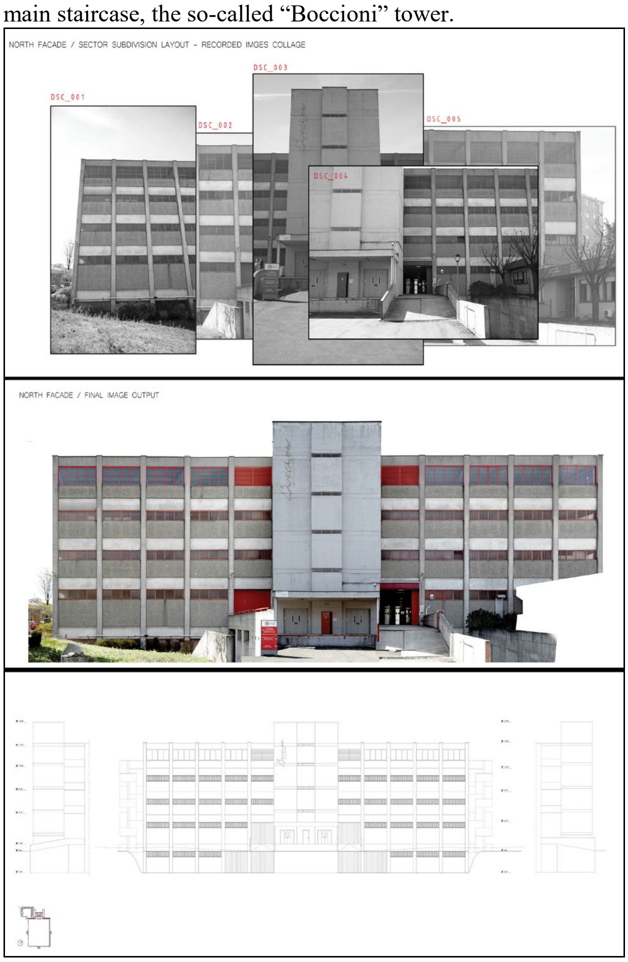

Figure 4 In-situ photogrammetric survey set-up (above), rectified image of the north (main) façade (middle), vector restitution of the north façade (below).

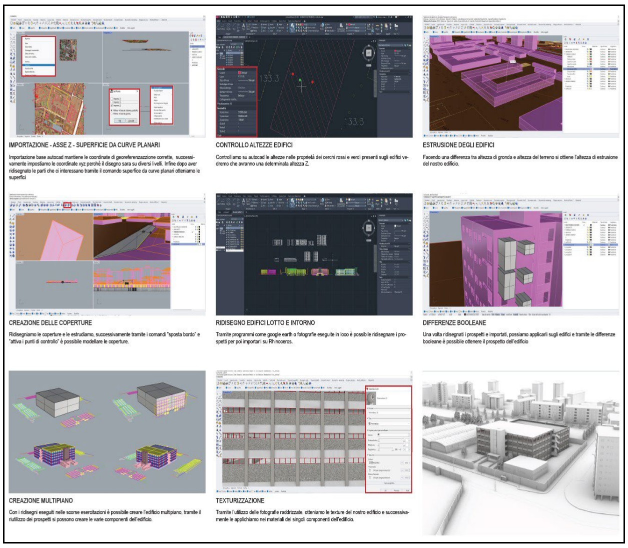

Figure 5 Detailed urban and architectural 3D modelling using digital cartography, rectified imagery and vectoral CAD elevations: selected steps

Figure 6 Selected views of 3D modelling phase: photography of the real-life situation (left); wireframe model (middle) and final views (right), latter two developed in Rhino© environment.

Three-dimensional modelling of the urban surroundings at district and building scale (Phase III) resulted in a board describing the modelling process, developed by each group (Figure 5). The final results are presented as views depicting the real-life situation, modelling process and, finally, a rendered view of the urban and architectural context that will host the students' design projects (Figure 6).

Following images (Figures 7-10) illustrate some boards (graphical results) produced by students for the Case study 2: Albergo Reale dei Poveri in Naples.

Specifically, in the Phase I, the QGIS project was developed structuring the selected georeferenced digital cartography available for the city of Naples. Successively, some first simulations have been produced in QGIS as a 3D view to provide a visual reconstruction of Albergo dei Poveri and its urban surroundings of a very specific morphology, including the hills of Capodimonte situated to the north-east.

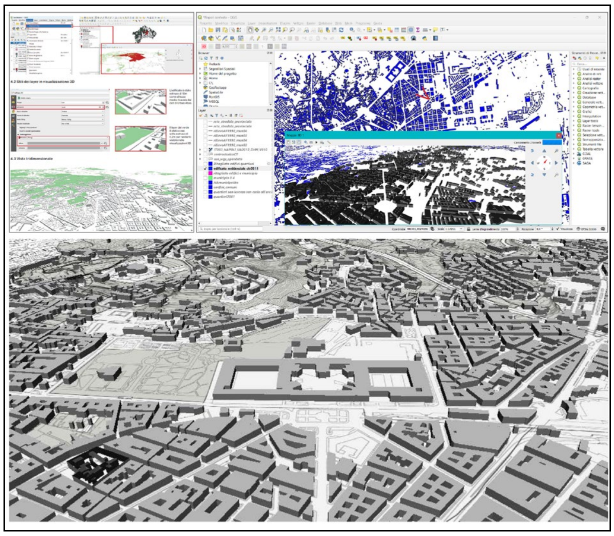

Figure 7 QGIS project of the Municipality of Naples: visualisation of open geo-spatial data collection (above) and a 3D visualisation of the case study area (below).

Furthermore, all facades of the complex have been surveyed using low-cost photogrammetry and measuring methods, with common amateur cameras already owned by students or teaching staff (Phase II).

As in the previous year, after completing rectified imagery for the four façade, students have vectorised the elevation in 1:100 scale. It is important to mention that two facades of this impressive complex were very scarcely accessible due to a ditch 15m wide and more than 10m high present on the north-east and south-west side of the building. However, these facades were still surveyed and described by the students very successfully and at the requested level of details, as shown in, Figure 8 depicting the selected steps process and some final results.

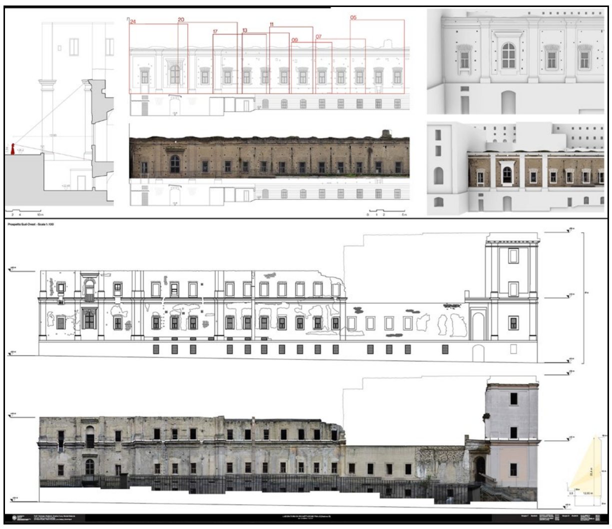

Figure 8 In situ photogrammetric survey organisation, the rectified image reconstruction and 3D modelling of the north-east façade (above); vector restitution of the south-west façade and its rectified image (below).

The final phase of the work (Phase III) again focused on the 3D modelling at urban, district and building level scale of entire area that provides the context to novel architectural project proposal. One of the assets of this case study was the urban morphology characterized by uphill, often narrow streets surrounding Albergo dei Poveri palace and by the topography of Capodimonte hill in the background (Figure 9).

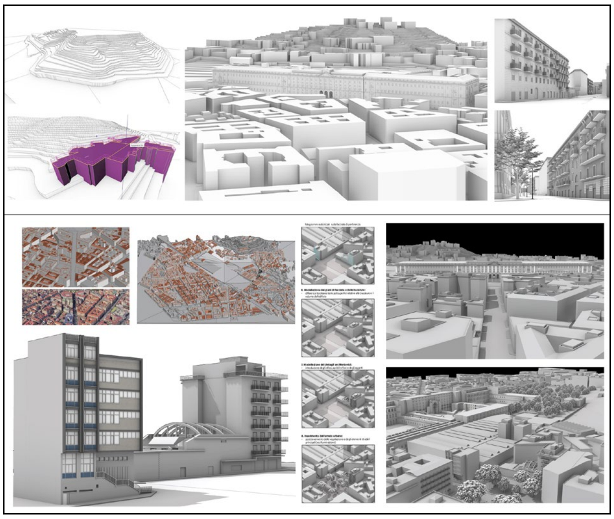

Figure 9 Modelling of architectural and urban context of Albergo dei Poveri: Capodimonte hills and surrounding areas.

The work conducted on Palazzo Fuga itself provided the opportunity to study this admirable neoclassical construction at high level of detail. Hence, students were encouraged to provide several examples of detailed modelling of elevations, showing thus the façade broken further down into its technological elements (Figure 10).

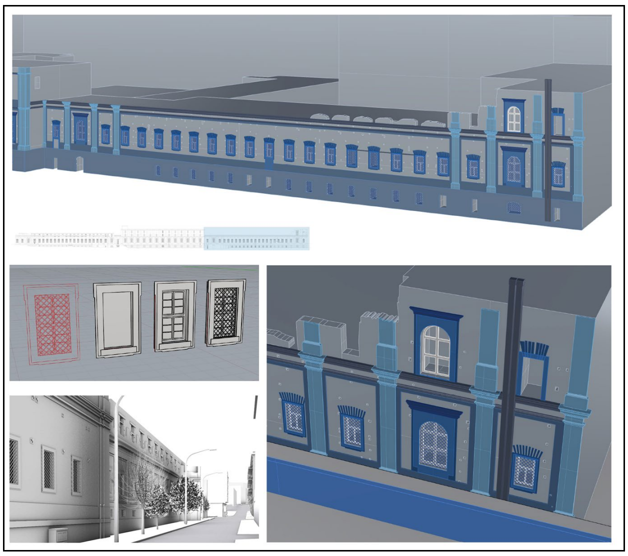

Figure 10 Low-cost 3D modelling of Albergo dei Poveri using CAD drawings and rectified imagery: north-east façade (above); close-ups on single technological elements (below).

5. Contribution of low cost technologies to the 3D modelling over an architectural design context: a discussion

The results of the teaching method here proposed put attention to two main objectives that were achieved in this kind of "learning-pipeline":

(i) **Problem-based learning for 3D modelling:** the first aspect regards a description and illustration of the modelling process (specifically Boards 1, 3 and 5 in Table 2). Such practice is not so frequent when it comes to the transferring of the so-called "digital skills". It seems that a reason for this could be a common conviction that a quality of the model depends on the correct functioning of the software, that in turn is rather considered as a "given fact" (and often independent on the skills of the operator). Hence, the attempt of this two-foiled exercise was to raise awareness among the students of their role in the overall modelling process as expert operators and future professional architects. Critical thinking and "problem-solving approach" that highlights challenges, rather than the aesthetics solution relying on a digital visualisation, was always encouraged throughout the exercises.

(ii) **3D modelling as practice of architectural knowledge:** The second aspect regards the intermediate phase of data acquisition and processing to obtain rectified imagery and technical drawings (Phase II). Such material was requested for purposes of information integration in successive three-dimensional virtual models. In more detail, data collected consisted in photographic survey and measurements recording for further photogrammetric processing (image rectification). Students groups have used the no/low-cost software for data elaboration such as RDF and Perspective rectifier©. Once obtained, the rectified imagery was combined to create rectified imagery for all the façades. Successively, the respective CAD (vector) drawings in scale 1:100 (or even 1:50) have been produced by the students. Finally, all the material created was shared among all students of the course and used for 3D modelling in Rhinoceros© software.

It seems that the extraction of technical drawings from easily generated 3D models is becoming a usual practice among students (and sometimes beyond), because it is often considered as a time or cost- efficient process. On the contrary, the exercise of transposing rectified imagery of urban fronts into technical drawings of elevations in a requested scale (and hence at a specific Level of Detail) requires very careful reading and interpretation of the technological elements that compose single facades. This process, that must go beyond simple tracing and/or object recognition and reconstruction (ORR), is a learning experience that refines the skill of thinking (and hence comprehending) the three-dimensional logic of a single component, of a technological element and possibly of the construction logic of a building as a whole. Therefore, the reason to introduce this intermediate step was the need of a specific teaching objective i.e. to create a direct connection between geomatics surveying and restitution disciplines with the discipline of architectural and urban planning. According to the method experimented, it was only after the two crucial steps were completed (i.e. Phases I and II) that it was found appropriate to engage students with a three-dimensional digital modelling at urban and architectural scale.

In addition, two other achievements in terms of "soft-skills" can be highlighted, namely:

(iii) "Peer-for-peer" collaboration process: all technical and drawing material was produced, tested and approved directly by the students for the students (peer-to-peer), simulating the requirements in professional practice;

(iv) Collaboration instead of competition: the rivalry between the groups was substituted by a more collaborative environment because producing high quality results of the single products was in the best interest to all students. In this way, geomatics techniques were employed with a purpose of being used in support of further work, a method that helped to lower (or to overcome) the learning barriers of single students.

6. Conclusions

Geomatics technologies are increasingly employed in professional practice and transversally in many scientific disciplines regarding planning and management of built environment. However, due to the lower cost of sophisticated technologies (for example digital cameras and UAVs) and a high demand of digital skills, sometimes it seems that there could be a risk for university degrees to generate highly-skilled "software dependent operators" rather than professionals that should be skilled in fully comprehending urban landscapes and modular construction logics of built environment at various levels of details, within virtual 2D/3D modelling environments.

It was, hence, in this perspective, and in support to the two planning modules within Final studio course, that "Digital Modelling" module method was proposed: rather than results of software employment exercises, the requirements were seen as an opportunity for testing the full context surveying process, starting from the cartographic analysis and arriving to a comprehensive digital 3D modelling at technological element scale.
As a very last step, and in order to confirm the importance of digital environment as a support to the entire design process, at the end of the semester in both years the students were invited to take part in a visit of LaborA, a modelling experimental laboratory at Politecnico di Milano. In these occasions, the students had an opportunity to visualise their own work using 360° Theatre device, capable of reprojecting digitally modelled environments to a physical cylinder that hosts groups of visitors. Such type of visualisation and interaction with a model provided students with a very last test of their work: a true physical experience of digitally developed modelling solutions based on the use of geomatics techniques.

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