3D DATA FUSION AND MULTI-RESOLUTION APPROACH FOR A NEW SURVEY AIMED TO A COMPLETE MODEL OF RUCELLAI'S CHAPEL BY LEON BATTISTA ALBERTI IN FLORENCE

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KEY WORDS: Cultural Heritage Documentation, Laser Scanner, Photogrammetry, Technique Integration, 3D Model

ABSTRACT

Leon Battista Alberti planned, in the middle of XV century, the renovation of Rucellai's family Chapel in Florence and designed the Holy Sepulchre temple as a Renaissance reinterpretation of the Jerusalem original one. In the occasion of the 5th century anniversary of his birth, new studies have been performed on his works. A complete survey of the Chapel has been done in 70's and some years ago a survey of the temple has been published too. The results are very interesting from the documentation point of view, even if both survey campaigns have been performed with traditional measurement techniques.
This work presents a new complete survey, aimed to support new restoration task. Several kinds of data have been collected to store an almost complete geometrical and radiometric documentation of the Chapel: information given by classical topographic survey and analogical stereo-plotting have been integrated with new technology skills offered by 3D scanning systems.
The structure appears to be as a little precious building within another simpler space defined by a barrel vault, pilasters and a complex pediment; consequently, a multi-sensor and multi-resolution approach in collecting data has been used and is here described.
Multi-resolution approach has been performed "zooming" our attention, and consequently choosing the most appropriate measurement instruments and survey techniques for: a) the whole chapel, b) the little temple, and finally c) on a very close-up point of view on a round inlay detail. Multi-sensor approach has been useful to complete geometrical data (by vector and surface description) with radiometric ones.

1. L. B. ALBERTI AND THE RUCELLAI CHAPEL

The Rucellai Chapel has been built in subsequent stages; the last one is related to the Leon Battista Alberti plan, sponsored by Giovanni di Paolo Rucellai.
The Chapel is rectangular in plan. Under a barrel vault, in the middle of the Chapel, there is the Holy Sepulchre. This little, precious temple is covered by 30 marble panels with rounded inlays representing geometrical drawings and the heraldic devices of the Rucellai and Medici families; at one end there is a semicircular apse. The pilaster, with Corinthian capitals, supports an ornate entablature and a frieze carrying an inscription which circumscribes the Sepulchre. Above there are a crown of lilies and a ciborium with a spiral relief decorated dome.
Alberti increased the height of the pre-existent external walls and built over them the thin round vault; he opened the three windows facing via della Spada and a triforium toward the adjoining church of San Pancrazio. He lined the walls with new columns and pilasters under a continuous trabeation. Those structures, as well as the floor (composed of rectangular panels bordered by plane *pietra serena* strips), project the geometry of the little sepulchre on the whole chapel.
The transformation work was concluded in 1467, according to an inscription over the door of the Sepulchre.
In 1808 the triforium has been closed and the two columns and the upper trabeation have been moved to the church façade; also the original portal facing piazza San Pancrazio has been closed, and a new entrance has been opened in via della Spada.
On account of the lack of original documentation about Alberti's transformation plan, iconographical sources documenting the Rucellai's Chapel condition before '800 transformation are fundamental documents, even if there is sometimes a considerable discrepancy between the drawings and the real building. As a matter of fact, those drawings have been often made after a visit and sometimes they have been based on sketches, notes or memories; their authors are usually strangers travelling through Toscana and documenting the most important building making drawings of them.

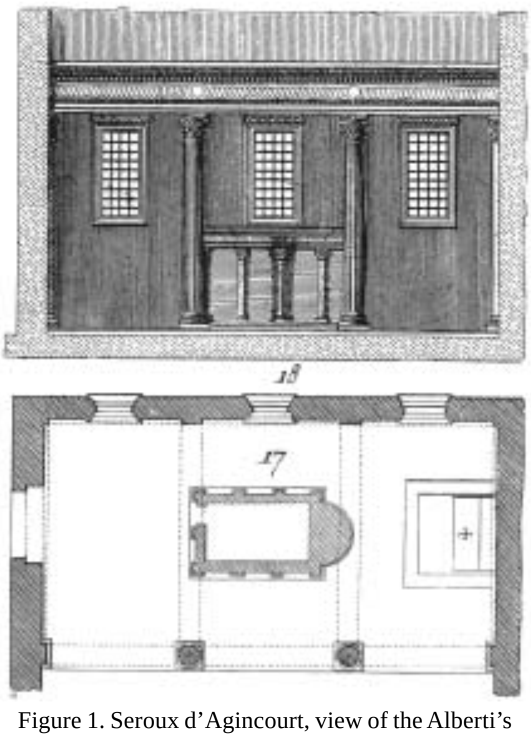

Figure 1. Seroux d'Agincourt, view of the Alberti's configuration of the chapel, 1779 (published in: G. B. L. G. Seroux d'Agincourt, Storia dell'Arte, vol. I, Prato 1826).

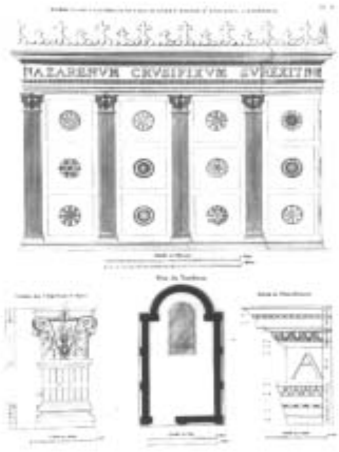

Figure 2. A. Grandjean de Montigny, A. Famin. Side elevation of the Sepulcher, plan and some details. The more evident "mistake" is visible in the plan, where the Sepulcher apse is drawn as it would be empty, while the internal wall is actually plane – published in: Renaissance Italienne, Architecture Toscana, Paris 1814.

Since studies aimed to analyze the geometrical ratio of Alberti's plan couldn't refer to original graphical or textual documents (as often happens in Alberti's architecture), the building itself, as well as the historical sources, are the only documents that could be examined. In fact, objective remarks could arise only starting from a building model without presumptive geometrical hypothesis. Careful studies on Rucellai's Chapel started in '60 (carried out by M. Dezzi Bardeschi): the new survey showed a worrying statical condition. They indeed highlighted critical cracks and lesions due to the vault's drift, which caused, in the meantime, the outwards rotation of the external wall.
After precautionary works (planned by P. Sanpaolesi), in the last '80 G. Petrini has been in charge of the restoration project: four carrying steel frames have been inserted over the vault and connected to the external walls. Then, the vault has been partially raised again by some screw jacks and a mobile centering.
Through new survey techniques we can investigate the building, reading on its surface its history, finding confirmation or raising new questions. Laser scanning survey can be enough accurate, from a metric point of view, as well it can provide the needed level of detail, to notice on the model some particular signs, related to Alberti's transformation or to more recent decay facts.

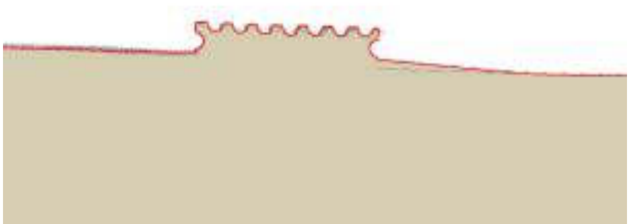

Figure 3. Orizontal profile of a pilaster.

A first example can be done inspecting an horizontal profile of the external wall of the Chapel, focusing near a gray stone pilaster: as shown in Figure 3, one can see the plaster filleted on either side of the pilaster. In fact Alberti's pilasters cover the preexistent walls, but they are not structurally inserted in them.
Looking at the vault, the actual profile shows its variable curvature radius. But, modifying the curve, raising it on its top to retrieve the structural lowering, and shortening its diameter to retrieve the out of plumb of the external wall (as documented in Petrini's analysis and consolidation plan) we'll find a quite perfect round vault, as Alberti recommended to build.
In fact, related to both presented examples, we can find interesting quotation from De Re Aedificatoria. Therefore, the new survey,

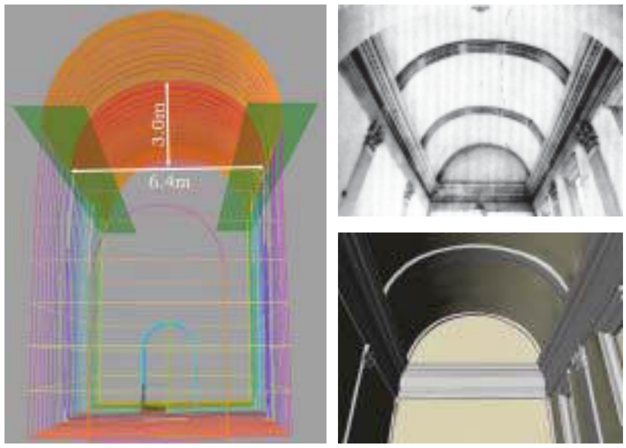

Figure 4. Analysis of the vault curvature, based on sections from laser scanning survey (left); a photo documenting the vault decay before restoration works in '70 (right, top) and a view of the 3D model (right, bottom).

combined with historical and critical analysis, can be useful to confirm the rule of Leon Battista Alberti in Rucellai's Chapel planning.

2. PREVIOUS SURVEY – TRADITIONAL MEASUREMENT TECHNIQUES

The recent surveys, related to the Chapel since '60, move their attention from the architecture image to the analysis of its matter. Adopting *(a)* well-established graphical and geometrical conventions, they pay a great attention to the correspondence of graphical representation to the analyzed architecture.

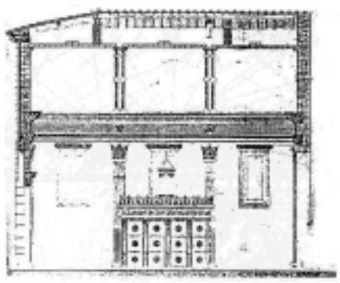

Figure 5. Side elevation of the Rucellai's Chapel, by M. Dezzi Bardeschi.

These surveys have been done by classical direct measurement systems, so they well describe the chapel's space only on the predefined cutting planes (horizontal and vertical); they were required to produce a suitable graphical documentation about the building conditions, in order to plan consolidation and restoration works.Recently a very detailed survey of the Holy Sepulchre (plan and side elevations in scale 1:5, by C. Mele) has been published. The thorough analysis of the present situation required an impressive amount of direct measurements, connected one another by trilaterations. This demanding work carried out two-dimensional graphical representations with a very high level of detail, related not only to the temple geometry but also to its material description and preservation.
Instead, the Alberti Group directed its efforts towards the attainment of a different aim: the study of the original Alberti's idea about the Chapel and his, maybe never drawn, plans.
The 3D model built by the researchers is constructed on a geometrical synthesis of the analyzed space. The impressive reconstructive model need to know the ratio between architectural

Figure 6. A very detailed bi-dimensional drawing (left, by C. Mele) and a rendered view of the reconstructive model (right, by Olivetti/Alberti Group).

objects, the Chapel and the Sepulchre. On the other hand, it can leave architectural deformations out of consideration, even if in the real building they are perceptible from a dimensional point of view. Therefore, until now surveys and analysis about Rucellai's Chapel make use of the detailed description of the actual state of the building, but restricted to specific cutting planes, or rather of 3D models (virtual ones or rapidly prototyped) geometrically describing the building, without considering its matter.
Integrated application of innovative survey techniques allow to combine high level of detail with effective communication tool as a 3D model, also assuring a projected metric accuracy.

3. NEW SURVEY INNOVATIVE MEASUREMENT TECHNIQUES

Multi-resolution and multi-sensor approach has been performed "zooming" our attention, and consequently choosing the most appropriate measurement instruments and survey techniques for the whole chapel and the little temple. Some architectural details have been acquired at very high resolution.
Different kinds of instruments need specific criteria on planning acquisition. Metric accuracy and level of detail (represented by scanning resolution) are, both in time of fly and laser radar systems, independent of the distance between the instrument and the object (almost in a quite wide operative range). On the other hand, photogrammetry (and 3D scanning system based on triangulation principle too) relates metric accuracy to instrumental position and geometry in acquisition step.
So, with 3D scanning systems, the resolution setting only require to adjust it from time to time by the control software (obviously within the instrumental range). Instead, triangulation systems need to modify suitably the distance to the object surface.
Moreover, all presented measurement techniques are related to the instrument field of view: only the object surface that the instrument can see can be measured.
Moreover, topography and photogrammetry require a preliminary analysis of the building in study. In fact, both techniques allow to measure detailed and exact points or break lines, useful as reference to model the object and to locate it in a frame system. In this case, the geometries are preliminarily identified and the measurements are a quantification of them (as well as a verifying tool, obviously). Instead, 3D scanning systems allow to postpone analysis to measurement. The whole point cloud could be considered in fact as a very detailed storage of geometric information: shape analysis, cutting planes position and so on, could be defined on the 3D point model instead of the real building. Anyway, we mustn't forgot that a range map is always a discrete representation, even if it's very dense, and consequently it's only an approximation of the object surface – architecture is something more.

3.1 Multi-sensor approach in acquiring data

A topographic network was arranged, defining a local frame system; from its vertex a detail survey was performed, by reflector-less total station, in order to complete the external walls and the nearest chapel of San Girolamo, and to acquire some targets and natural control points on the Sepulchre and on the Chapel floor.
Digital and analytical photogrammetry systems have been used to document the external surface of the Sepulcher. Digital images rectification has been useful to texture the plane surfaces of the temple model, while vectorial stereo-plotting (obtained with StereoView - by Menci Software - digital system, and LS2000 - by Leica Geosystems - analytical stereo-plotter) supply 1:20 side elevations.
Two different laser scanners have been employed. First of all we acquired the whole chapel surfaces with a time of fly laser scanner (HDS2500 by Leica Geosystems - 0.6 cm accuracy). The more detailed description needed for capitals, bases, … and cornices suggested laser radar employment (LR200 by Leica Geosystems that can reach a submillimeteric accuracy). A common frame system allowed to combine all acquired data and, in same cases, to carry out further elaborations in an independent way. In order to manage better a huge amount of data, we built separately three kinds of 3D models: 1 - the surface model of the interior of the Sepulchre; 2 - its external marble covering; 3 - the whole Chapel.

Figure 7. Photogrammetric plotting of a capital (left) and a detail of the same, scanned by laser radar (right).

3.2 Multi-resolution approach in acquiring data

Very small room available among the Sepulchre and the Chapel walls makes sometimes really hard the work with cumbersome instruments; in order to avoid geometrical shadows we acquired the Sepulchre by many range maps from all around it. Range maps measured from instrument position near the external surface of the temple show a small and quite plane area of its marble covering. As well known, range maps registration require significant overlapped area and (or) control points. This condition would have implied a huge increase of the amount of data and, consequently, an increasing time in acquisition and elaboration too. Therefore, we acquired some low resolution and wide field

Figure 8. A low resolution and wide field of view scan (used in the first registration project) and a high resolution one (subsequently connected to the frame point cloud).

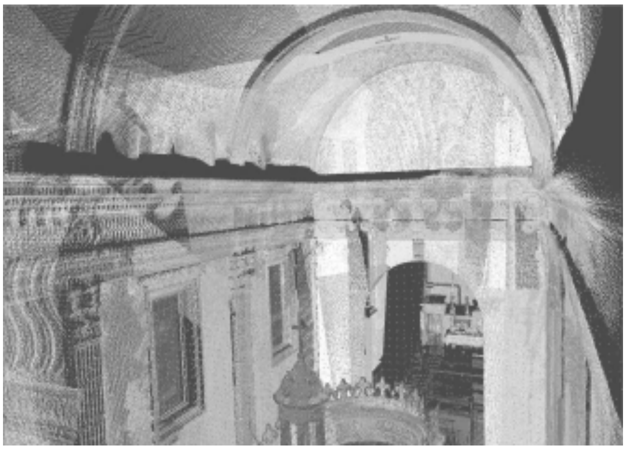

Figure 9. Point cloud of the whole Chapel, acquired with time of fly laser scanner (upside) and a detail of a cornice slice, obtained by a laser radar range map (left).

of view range maps, as far as possible far away from the temple, framing two consecutive sides.
Then range maps registration was performed in two steps:
- a low resolution range map registration, that produced a "frame point cloud" of the whole Sepulchre;
- a second registration step, connecting the high resolution scans (with a very small, and quite plane, overlapping area) to the previously computed frame point cloud.
Architecture studies always require a multi-resolution approach, to well describe flat and uniform surfaces as well as detailed decorations. With 3D scanning systems we usually obtain a uniform, discrete, uncritical point model, with exuberant data in some parts but hardly reaching the needed level of detail in some others. While point decimation procedures might help to solve the first problem, it's important to plan scan resolution in order to describe complex surfaces with the requested level of detail. We acquired the whole Chapel with a medium scan resolution of about 1.5 cm, while the scan resolution on the Sepulchre was set to 0.6 cm (the highest value related to instrumental accuracy). We also scanned, at high resolution, some samples of Chapel pilaster, capitals, trabeation, moulds, etc. Other sample areas have been acquired by laser radar, with quite the same resolution. Better instrument accuracy and a low data noise allowed to extract accurate profiles of architectural details.
The external covering of the Holy Sepulchre is made of marble slabs with inlay of geometrised stars in white, serpentine and crimson. Although the stone panels seem flat, with a uniform surface, the stones set into the marble present some small differences in height. Laser radar could reach a very high accuracy, even if acquisition speed falls off. We tested 1 mm scan resolution on a round inlay: the surface model clearly shows the small shims produced by the inlay technique and by the stone decay.

4. SURVEY RESULTS

Vectorial data, surface model and raster images concur to build different kinds of two-dimensional and three-dimensional graphical representations.

4.1 Plan drawing and photo-mosaic of the marble and travertine floor

The floor of the Chapel is deeply damaged; as a useful instrument to plan future restoration works, a photo-mosaic was carried out. Digital images have been analytically rectified, thanks to a set of topographic control points. The controlled mosaic was completed with the walls plan, coming from the laser scanning survey. Moreover, the photo-mosaic has been used as a texture in rendered views of the interior of the Chapel.

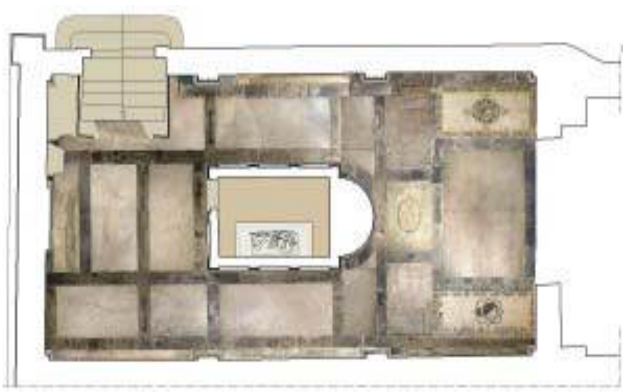

Figure 10. Plan with photo-mosaic (original drawing on scale 1:20).

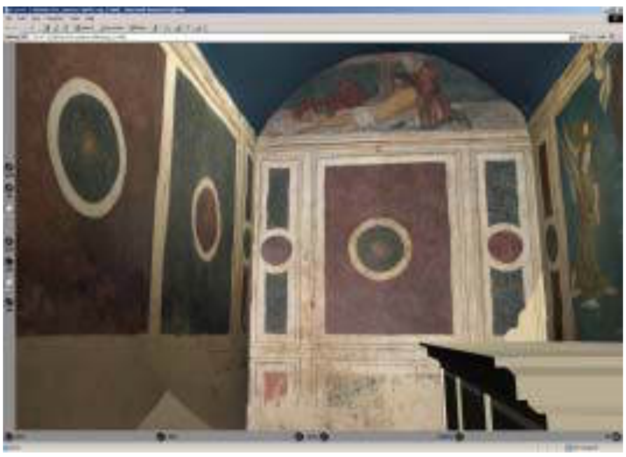

Figure 11. The VRML model of the Sepulcher interior: the walls of the chamber are frescoed (possibly by Alessio Baldovinetti) and depicts scenes of the *Descent from the Cross.*

4.2 3D texturized and interactive model of the interior of the Sepulchre

VRML is a suitable modeling language to create 3D worlds with photographic texture. In a web browser one can explore the object, moving through a 3D space. Some predefined points of view have been set up: the user could choose from which of them starting the real time exploration. VRML model is a very interesting tool to popularize building with restricted accessibility, as it is the Holy Sepulchre. To get available on line a 3D model it's obviously important to carefully evaluate files size, both those related to the object geometry and those with texture images. This problem might be often hard to solve when we work with models built from laser scanning data. In fact, we applied surface reduction procedures aimed to reduce data (from 1.300k polygons to 10k), preserving edges description. In this way, we built a "light" model of about 1.2 MB, plus about 400 kB for photographic textures.

4.3 Rendered views of the 3D model of the whole Chapel

Some perspective views of the interior of the Chapel have been rendered. Different textures applied to the object surface are related to the specific level of detail (and consequently, to the metric accuracy) of different kinds of models:
- photographic textures (obtained from analytical photo-rectification) on Sepulchre model;
- a uniform color on the walls of the Chapel and on the gray stone decorative elements, in order to remind their original appearance, without rendering a false photorealistic effect.

4.4 Architectural side elevations (bi-dimensional drawings)

We couldn't leave two-dimensional drawings out of consideration, as they are a well-established graphical language as well as a standard that cannot be disregarded in architectural studies.
Plan and side elevations could be made out of a 3D model: in this case they can represent not only the building geometry, but also information about virtual lights and synthetic or photographic textures. To carry out a section from a 3D model doesn't mean simply slice it with predefined, horizontal or vertical, cutting planes. It is necessary to follow the same rules and conventions that, in 2D architectural drawings, shift and move the cutting plane through the doors and windows, and avoid structural

Figure 12. Rendered views of the interior of the Rucellai's Chapel.

elements, in order to better describe the whole space. Slicing a 3D model, in fact, could require to cut it with a number of different planes and, in the end, to put together the right part obtained from each of them.Besides, the high resolution models of Rucellai's Chapel are too heavy to compute them all together. Thanks to the common reference frame of the models (the one of the interior of the temple, the one of its exterior, and the whole Chapel one) we could, after defining cutting planes positions (in the same frame system), render every single model in an independent way. Final side elevations have been obtained keeping from every slice only the elements that would be represented in an analogous side elevation constructed by traditional techniques.

Figure 13. Cross section of the Rucellai's Chapel and the Saint Sepulcher, from the 3D model (original drawing on scale 1:50).

ACKNOWLEDGEMENTS

The research has been financed by Italian Ministry of Education, University and Research (MIUR), project PRIN2004 (Nat. Resp. Prof. Carlo Monti - Research Group Resp. Arch. Grazia Tucci). The authors gratly thank Prof. Bruno Astori, coordinator of the Research Group in Geomatic at the Faculty of Architecture 2 (Politecnico di Torino); Reverendo Don Germano for his helpfullness and Ornella Bucolo e Daniela Miron (from FOTORIL - CISDA Laboratory - Politecnico di Torino) for their cooperation in photogrammetric acquisition and stereo-plotting.

Figure 14. Long section of the Rucellai's Chapel and the Saint Sepulcher, from the 3D model (original drawing on scale 1:50).

REFERENCES

Boehler, W., Marbs, A. 2004. *3D scanning and photogrammetry for heritage recording: a comparison*, Proceedings of 12th Conference on Geoinformatics – Geospatial Information Research: Bridging the Pacific and Atlantic, University of Gavle, Sweden, 7-9 giugno.

Tucci, G., Bonora, V., Sacerdote, F., Costantino, F., Ostuni, D., 2004. *From the acquisition to the representation: quality evaluation of a close range model*, International Archives of the Photogrammetry, Remote sensing and Spatial Information Sciences.

Tucci, G., Algostino, F., Bonora, V. , Chiabrando, F., 2003. 3D *Modeling and restoration: from metric to thematic survey. The case study of San Francesco al Prato in Perugia*. Proceedings of the XIX CIPA International Symposium New perspectives to SaveCultural Heritage. Antalya, Turkey, pp. 543-548.

Balzani, M., Pellegrinelli, A., Perfetti, N., Russo, P., Uccelli, F., Tralli, 2002. *Laser scanner nel rilievo dei vicini: applicazioni, verifiche e test di precisione*, Bollettino SIFET 3/2002.

Hancock, J., Langer, D., Hebert, M., Sullivan, R., Ingimarson, D., Hoffman, E., Mettenlaiter, M., Froehlich, C., 1998. *Active laser radar for hig-performance measurements*, Proceedings of the IEEE International Conference on Robotics & Automation, Leuven, Belgium.

Tavernor, R., 1998. *On Alberti and the art of building*, New Haven and London.

Rykwert, J., Engels, A. (a cura di), 1994 *Leon Battista Alberti*. Catalogo della mostra, Electa, Milano.

Grayson, C., 1994. *Studi su Leon Battista Alberti*, in Rykwert, J., Engel, A. (a cura di), "Leon Battista Alberti", Catalogo della mostra (Mantova, 10 settembre-11 dicembre 1994), Olivetti-Electa, Milano.

Borsi, F., 1980. *Leon Battista Alberti. Opera Completa*, Electa, Milano.

Alberti, L. B., *L'Architettura [De Re Aedificatoria]*, Testo latino e traduzione a cura di Orlandi, G., 1966. Introduzione e note di Portoghesi, P., Il Polifilo, Milano.

Mele, C., 2002. *Il Sacello del Santo Sepolcro nella Cappella Rucellai*, in Rocchi Coopmans de Yoldi, G. (a cura di), "Post Gotico e Rinascimento", Alinea, Firenze.

Petrini, G., 1981. *La cappella del Santo Sepolcro*, Catalogo della mostra sul restauro, Firenze.

Dezzi Bardeschi, M., 1967. *Il complesso monumentale di S. Pancrazio a Firenze e il suo restauro*, "Quaderni dell'Istituto di Storia dell'Architettura", serie XIII, n. 73-78, Roma.

G. B. L. G. Seroux d'Angicourt,1826. *Storia dell'Arte*, vol. I, Prato.

Grandjean de Montigny, A., Famin, A., 1814. *Renaissance italienne, Architecture Toscana*, Paris.