From massive lasergrammetry to accurate and rational digital models

The case of the “Dado Arnolfiano” in Palazzo Vecchio, Florence

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Introduction

Palazzo Vecchio is the city hall of Florence, an architecture defined starting from the end of the thirteenth century. It kept its rule of government building since the early construction of the *Palagio dei Priori* (the so-called *Dado Arnolfiano*). The author of its first version was the architect *Arnolfo di Cambio*. The first important restoration works, entrusted to *Michelozzo* by Cosimo il Vecchio, date back to the mid-fifteenth century. *Under Cosimo I*, the direction of the construction site passed from *Giovanni Battista del Tasso* to *Giorgio Vasari*, who worked on the reorganisation of the building. In the early nineteenth century, *Giuseppe del Rosso*, began the first heavy transformations bringing on the work started by *Carlo Falconieri* during the period of “Firenze Capitale” (in the second half of the XIX century, when Florence was elected temporary Italian Capital after the national unification). The following two centuries in the life of this building were instead dedicated to restoration, preservation, and consolidation. The intervention presented in this contribution stands in the group of the many complex example for the knowledge and digitization of a monumental building with an extreme articulation. *Palazzo Vecchio mixes an extended stratigraphy of phases in integration, expansion, and reconstruction*. The 3D laser scanner technology made possible carrying out this total survey, contributing to the accurate geometric knowledge of the building; the BIM methodology has allowed the digitization of the geometry and the creation of a 3D container functional to the collection of data from the diagnostic campaign.

The digital survey

Given the level of uncertainty of the existing surveys of the Palace, it was decided to operate a completely new 3D laser scanner campaign in order to obtain a more trustable result. The previous survey works were clearly lacking in the description of the many internal spaces, of the numerous interspaces and in the correct alignment of structures passing in between levels (Paoletti et al., 2020). The 3D survey, in fact, allows a remarkable reduction of the time needed and of the typical errors of the traditional survey methods. Palazzo Vecchio is an extremely articulated building which occupies an entire city block with the spatial organisation of the interiors reaching a considerable level of complexity.

Checking the previous floor plans produced by a past survey works, it was possible to carefully plan all the activities, subsequently refined by preliminary inspections. The work, which lasted for over one year, with effective 25 days of operation using up to four 3d laser scanner units at the same time, was carried out according to an accurate planning defined to conciliate the activities from the museum and the municipality offices with the survey operations. The scanning positions were decided considering the morphological and dimensional characteristics of the rooms, leaving freedom of decision to the various survey teams that have, however, followed an accurate framework, but have corrected each group of scans to an efficient optimization. A minimal number of targets were used, preferring cloud-to-cloud alignment in most of the situations. Specific attention was paid to the reduction of occlusion areas, looking for good overlaps between successive scans. The lack of data may be certainly a problem, but it is also necessary to avoid an overabundance of information, especially during surveys of such large buildings, where there is a risk of producing extremely troublesome dataset.

Organization and data processing

3D laser scanners acquire information about the location of their surroundings at high speed, automatically and regularly, measuring the position of hundreds of thousands of points per second. The coordinates of the points on the surface of the objects intercepted by the laser signal are recorded into a three-dimensional virtual space, creating the well-known geometrical entity called point cloud, each point is recorded with its coordinate and RGB value according to the reflectance of the materials (Verdiani, 2019). The zero is always set in the centre of the 3D scanner unit for each single scan.

Fig. 1. Palazzo Vecchio and its surroundings. The global point cloud in Autodesk Recap Pro 2020

Each point cloud then represents a “scanworld”, where every point is identified by a set of polar coordinates. In further processing each different point cloud is aligned with the other by roto-translations, allowing the creation, in the end, of a complete point cloud referred to a single coordinate system coinciding set in one of the scan stations or assigned on a specific point in the whole survey. The software Autodesk Recap Pro is able to automatically search for a match between the scans using the overlapping areas, some reference points, or both. However, it is always important to check that the point clouds from the different portions of the building are matching correctly. If Recap is not able to find a match or if it is necessary to search it manually, the following step consists in choosing and marking three points common to both scans displayed on the screen. Once obtained the final aligned point cloud, the project can be finally post processed and eventually exported keeping all the original data or applying some resampling to allow a dataset suitable for generic CAD software and less performant workstations. The scans collected in the entire building are about 5500; it could be said that this is a huge amount of data, it actually occupies a little more than 1500 GB in its “as scanned” version. The project of the “Dado Arnolfiano” includes approximately 3400 scans for a total of almost one TB. The optimized version is less demanding in terms of disk space, the subsampled version of the whole building, with a grid of one centimetre is about 90 Gb.

The HBIM Model

The modelling is based on the imported point cloud into the Autodesk Revit environment and used as a guide and on the notions obtained from the other survey phases. Some structures are modelled using system families (walls, floors, roofs). A specific custom library, made according to the modelling needs, was used to shape the other parts of the building. It consists of loadable families and in-place elements. According to the “BIM Forum Level of Development Specification” the cases history can be framed in a LOD 300: the elements are represented in their dimensional and morphological aspects, with correct position and orientation and it is possible to add graphic references and metadata to them. The vast and varied information contents can be organised in a logical manner, following previous case studies on smaller subjects (Coli et al., 2019; Forcellini et al. 2019) and enhancing their methodology, resulting in a readily consultable collection of contents.

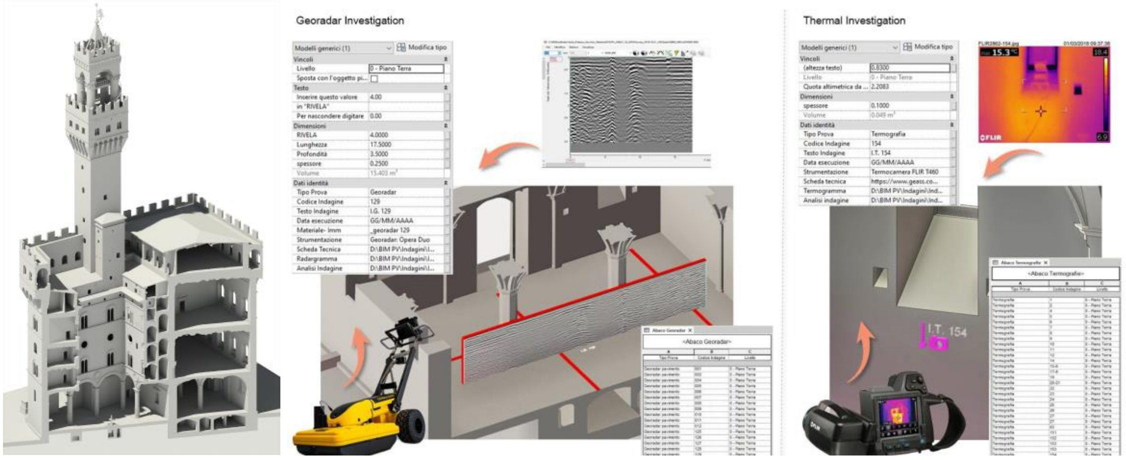

Fig. 2. Axonometric cross-section of the 3D Model of Palazzo Vecchio and two examples of custom parametric families for georadar and thermal investigation.

An intelligent object characterised by dimensional rules is prepared for each category of information: in some parameters the data have a direct access, while URLs – corresponding to the different external files kept in specific folders – are assigned to other parameters. These families, designed for the rational storage and display of information, have also been provided with shared parameters used to generate text tables where data content is arranged and filtered. The storage of information within the 3D model takes place by preparing, for each type of test, a customised parametric family in which the geometry of the object is related to the characteristics of the test itself and which will then be placed at the exact point where the investigation was carried out. By containing all the information related to the analyses, it is also possible to quickly compare the results of the different tests conducted on the same structure. Thanks to the text table the unified picture of the investigations will be instantly available and, selecting an element in the table, this will be highlighted in the model allowing the immediate identification of its exact location (see Fig.2).

Conclusions

This contribution describes the 3D laser scanning survey and the following digitisation and archiving process using BIM methodology applied to a very special case study of cultural heritage, Palazzo Vecchio in Florence, with a specific focus on its older core, the so-called *Dado Arnolfiano*. The result is a 3D model describing the current geometric state of this built heritage, containing information on the construction evolution, interventions, past and current investigations, and monitoring in a simple and accessible way. The construction of the information system has allowed: 1) the definition of a 3D model on which to insert the diagnostic investigations; 2) the study of the constructive evolution of the building by means of a rapid and intuitive visualisation of the phases. Also in this particular case, solutions coming from BIM systems have been a valuable tool for the creation of an active database that allows the creation of a model for the management and conservation of a building of our historical heritage.

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Conflict of Interests Disclosure

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