Archeologia e Calcolatori
28.2, 2017, 507-519

DIGITAL ACQUISITION: REFLECTIONS ON DATA QUALITY

1. Introduction

In recent years new research areas have developed concerned with the speedy acquisition of data that contain a high quantity of information and the use of low cost instruments that ensure results comparable to those obtained with the 3D laser scanner within a single acquisition and restitution campaign. This is precisely the principal area of inquiry of our research, which aims primarily at realizing models obtained through a survey that integrates traditional and low cost methodologies for non-contact surveying. The study seeks to integrate the process of surveying with that of cataloging by structuring out models obtained through digital photographic images in a documentary archive (Minto, Remondino 2014; Siotto *et al.* 2014).

Nowadays the techniques and instruments of digitization have made possible the large scale production of 3D objects belonging to Cultural Heritage (Remondino *et al.* 2008). In the last years the Structure from Motion (SfM) technique has become quite a valid instrument for surveying and representing cultural heritage and data archiving has been a central issue in so far as works of cultural heritage are concerned (Bourke 2012; Remondino *et al.* 2014). It is precisely in this domain that the methodologies of digital 3D models representation were significantly applied. The main feature that transforms physical objects into digital ones involves the construction of photorealistic 3D models close to geometric, metric, structural, chromatic models geometrically, metrically, structurally, and chromatically closely resembling real objects. These models provide a much more articulated and complex representation than others because they can be used as bases to construct knowledge systems (Brunetaud *et al.* 2012; Micheletti, Chandler, Lane 2015).

The definition and management of 3D model become the crucial point of the problem for the solution of which it is fundamental to define an operative methodology that could be referred to a standard (Costantino *et al.* 2014). It must be inevitably observed how a knowledge system is lined to information acquisition, interpretation and filing. The characteristic feature of this process is the equilibrium of the quantitative component connected to the mass of data acquired at the stage of surveying[1] and the qualitative component related to the choices taken at the stage of elaboration meant

[1] This refers to the measurement operations effected almost exclusively by applying methodologies of 3D integrated surveying as well as to the instruments for massive data acquisition (3D scanner, Structure from Motion, digital photogrametry, topography), sometimes integrated with data obtained through direct surveying.

for constructing a survey. Nowadays the survey, understood as the process serving the building of 2D and 3D models, is a qualitative operation of deep cognition[2] of the investigated object and a result of a quantitative process of massive data acquisition (surveying).

The concepts of data quality[3] and scientificity[4] alongside that of uncertainty control turn out to be fundamental in the processes of acquisition and elaboration. These processes are necessary when we move from the objective datum to the subjective one in order to transform quantitative data (information on coordinates, position, geometry) into data that express the quality of the object studied. In order to be able to verify this condition, all the acquisition activities ought to be directed towards defining material points, indicating the uncertainty level of the measurement and showing the metadata (information on the acquisition process). These data ought to be archived and sharable so that they ensure easy circulation within the community of researchers as well as allow for the repeatability of operations on the set of analogous data. However, the construction of qualitative models which will ensure a profound cognition of the artifacts is linked not only to the great amount of points that it is possible to collect on the surfaces but also to the quality and the typology of information (metric, positional, geometric, chromatic) related to each of them and to their correspondence to reality (Hess *et al.* 2014; Styliani *et al.* 2016).

Taking into account the numerous campaigns of research carried out for years, this study suggests a *modus operandi* that seems to be essential for the standardization and the regulation of data collection, processing and recovery procedures applied by the research group, to make the final scientific results more objective and correct (Bartolomei, Ippolito 2014; Ippolito, Bartolomei 2014). The methodology applied is composed of the critical component – which leads toward the definition of the object through the geometric and morphological features – and of the objective component – which guarantees that the data will always be amenable to critique, open and susceptible to successive readings and interpretations.

To correctly establish an operational protocol, the survey concept has to be properly identified and this involves merging two separate kinds

[2] The approach to knowledge expressed by the philosopher René Descartes distinguishes between normal knowledge, achieved only by our senses, and profound knowledge, achieved by scholars using only study methods and techniques that can demonstrate to the mind what is precluded to the senses.

[3] Quality is a description of contingent or permanent properties of an object. It designates any concretely determined formal aspect of a given reality.

[4] Scientificity is the modality with which science proceeds to cognise reality. It must be objective, reliable, verifiable and sharable. It consists in acquiring experiences by experimental observation, and in formulating hypotheses and theories whose efficacy is tested by experimentation.

of survey: "critical survey", which defines the object using its geometric and architectural characteristics, and "objective survey" which consists in ensuring unbiased data to allow for an in-depth specialist interpretation (Bianchini *et al*. 2014). The survey will therefore depend on two consequential but inevitable aspects: "complex 3D surveying"achieved by using a combination of different tools, and "complex 3D survey" achieved by combining different models. The "complex 3D surveying" involves acquiring the data and collecting any useful information about the object, which can also be studied to acquire greater understanding and knowledge: an analytical phase focusing on collecting qualitative and quantitative data. The second step, the "complex 3D survey", involves turning the 3D surveying into a 3D survey by "combining the models", turning objective data (surveying) into data containing all the information required to interpret and study the building (survey).

In the Digital Age, the model concept is based on digital techniques now present in all architectural representation tools, techniques which have also invaded the field of architectural survey (Gaiani 2015). In particular, with regard to the model, 2D and 3D representations have created a new kind of model no longer only static, but also dynamic. The model concept must therefore be redefined and updated. It allows to move around it and shift from outside to inside the model using the 2D and 3D elaborations in a transitive manner (Hess, Petrovic, Meyer 2015).

2. Bologna Gates

The experiment concerns a study focused on the Bologna Gates. The ring road of Bologna is dotted with ten of the original twelve city gates, which in ancient times were part of the third circle of city walls. These were built in the 13th century and completely destroyed at the beginning of the 20th century. Some of them have been preserved in their original form, others were partially demolished or rebuilt in a completely different style, while still others were razed to the ground. Nowadays they are just monuments of the past and do not belong to any unified system of architectural structures. Each of them tells its unique story composed of demolitions, superimpositions and architectural interventions, undertaken also for social and economic reasons.

In this urban context, the survey serves as an instrument which can probe into the unity of the place and into the unique identity of the buildings regardless of the superimpositions of later interventions, without the risk of abstracting from the architectonic reality fused into its spatial context – which would destroy the sense of these structures so unique exactly for their collocation (De Luca *et al.* 2010).

3. Data capture

The experiment seeks to integrate the process of surveying with that of cataloging by structuring out models obtained through digital photographic images with the aim to create a documentary archive. Acquisition operations are linked to the correctness of the processes followed and to the concept of metric accuracy (Cipriani, Fantini 2015).

Lord Kelvin claims that: «[…] when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind» (Thomson 1889, 73). Thus, a metrological setting is qualitatively described by an aggregate of parameters that define the characteristic of measure: uncertainty, repeatability and accuracy (Bianchini 2012). The stage of data acquisition should always be considered as an application of a scientific method based on a collection of empirically observable and measurable data, which can be archived and subjected to external verification to be validated. The applied procedure should be replicable in order to acquire a new aggregate of data comparable to the preceding one (Remondino, Campana 2014).

The data capturing stage has been conducted with the aim to test the validity of a procedure that assumed that only low-cost instruments will be used for surveying and building 3D models, contrasting diverse systems. The experimented procedure was aimed at constructing qualitatively controllable 3D and 2D models where it is essential to define the uncertainty level of the models linking it to the model scale. An attempt to define *a priori* the scale of the model requires the knowledge of the maximum detail level such models can reach.

In order to verify the accuracy of the survey data as well as to control the level of uncertainty of the model scale, it is fundamental to confront the data obtained by making photo images with those obtained by direct surveying. The reflex Nikon D300 camera with CMOS sensor of 12 megapixels with automatic focusing and manual zoom procedures is used in the surveying campaign. The surveying project[5] had been defined in order to guarante cover of the whole object and each photograph overlapped with the successive one in at least 30-40%.

[5] Since each architectural object has its peculiarities, is impossible to establish an absolute rule regarding the way a survey should be performed. Nevertheless, all the methodological options are analyzed and developed during the survey project in order to optimize the operations vis-à-vis the objective. The survey project is a key stage in the whole process. It establishes the instruments, the 2D model scale, and the number and position of the various stations. A correct survey project (partly) guarantees the quality of the data later used to produce the survey drawings; it also ensures the accurate gathering of numerical data obtained only from the measurement operations and still not processed. The operative phase comes after the survey project; this is the moment when all the planned operations, and any unforeseen operations, are formalized *in situ*.

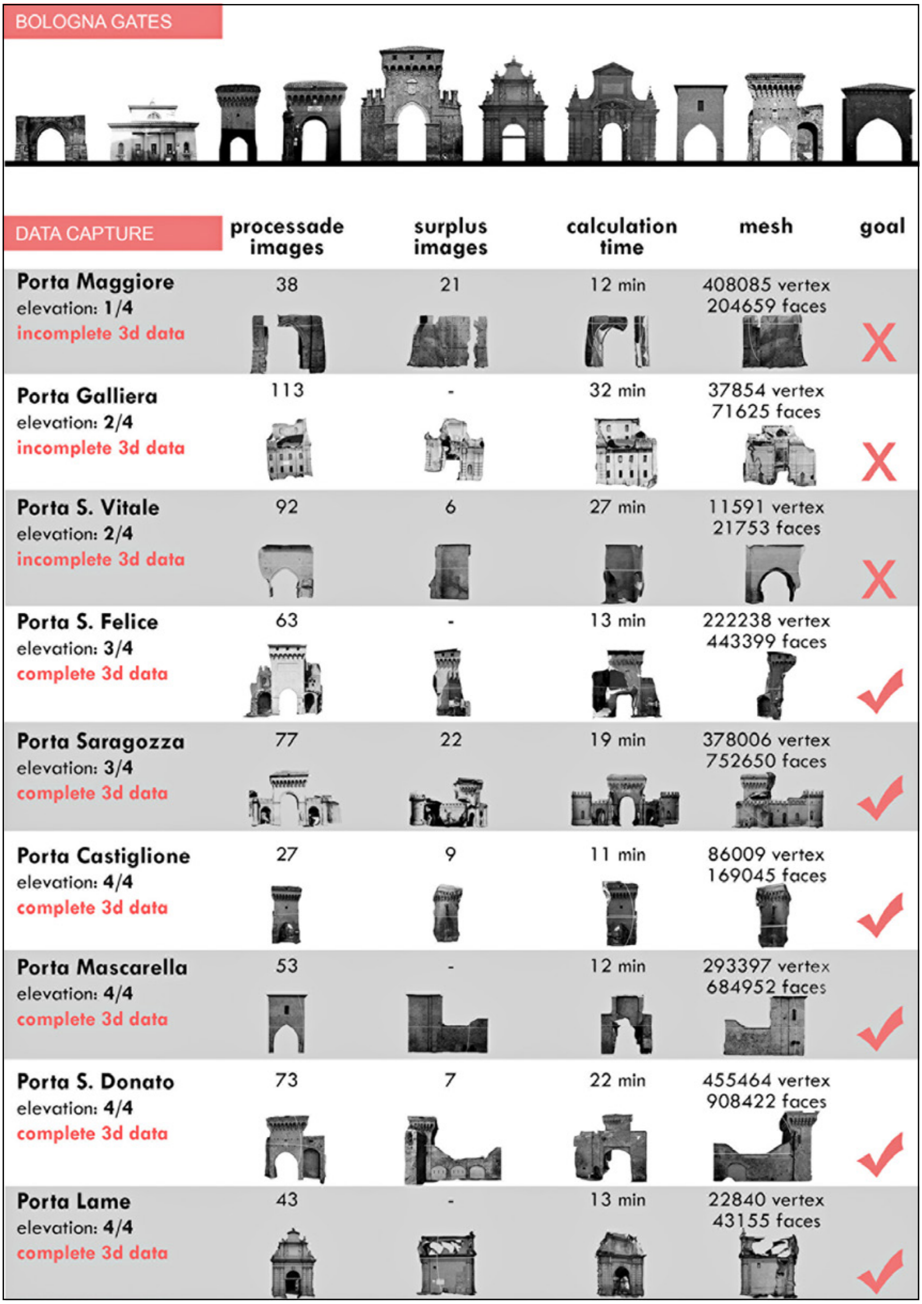


Fig. 1 – Bologna Gates: Structure from Motion surveying and results obtained.

The final representation scale of the data was fixed in advance at 1:50 while – in order to get all the elements of the object precisely in the selected scale – the distance was calculated based on the lens focus and the characteristics of the camera used (Fig. 1).

4. Data processing

The data obtained were elaborated by comparing the data acquired by photomodeling with a commercial software (Agisoft Photoscan) and open source software (Photosynth, Arc3D, 123D Catch) with the aim of calculating uncertainty and accuracy using the same dataset.

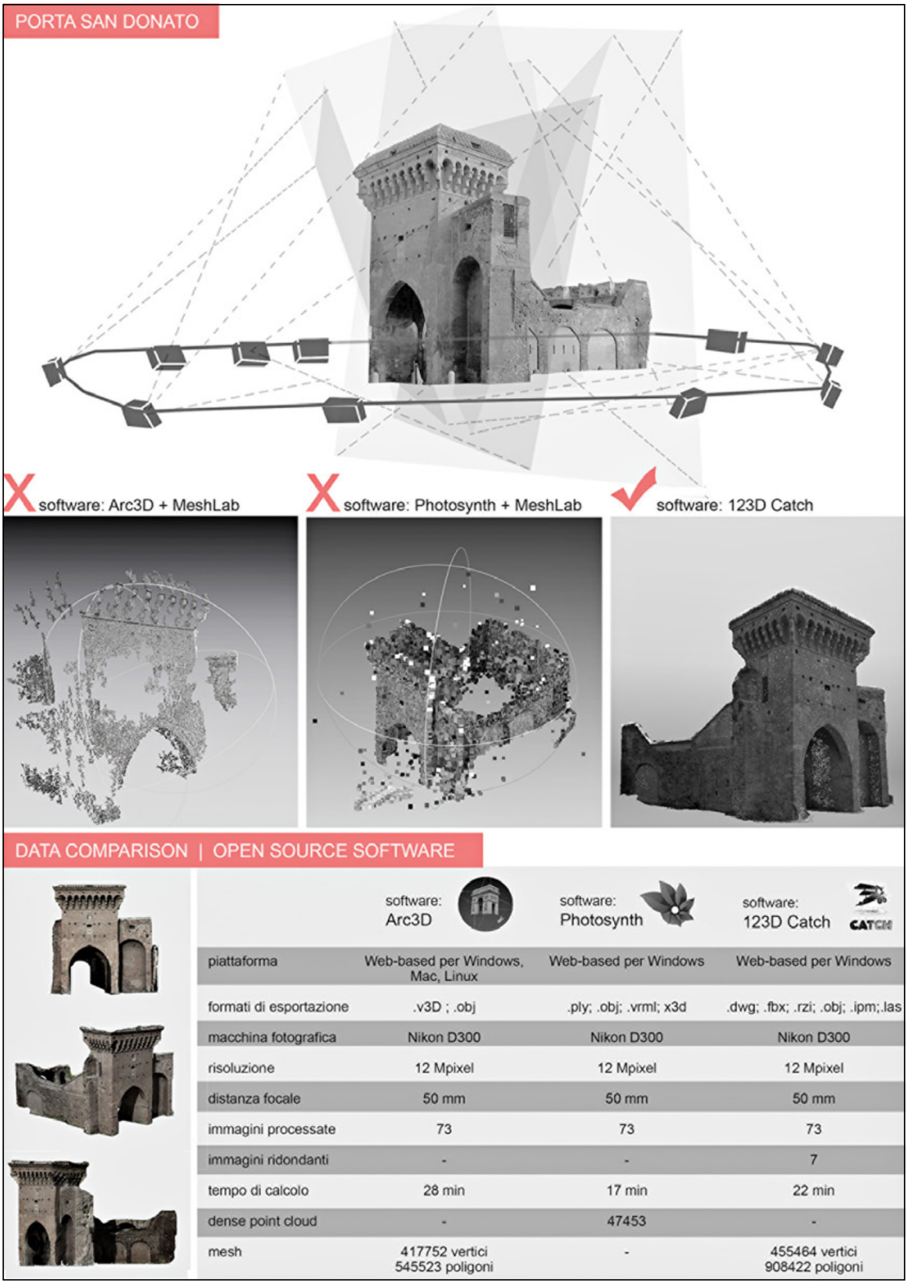
The tests demonstrated that a homogeneous distance from which photos are taken determines the construction of the model. In the main cases it has been observed that among open source software Microsoft Photosynth yielded a point cloud too scattered to define a mesh coherent with the surveyed structure; Arc3D proved to be insufficient to define a partially constructed model; 123D Catch turned out to be the most precise in constructing models and textures. It yields a mesh to which it is possible to attribute three definition levels, although the resolution approximation was not left to software (Fig. 2).

Verifications have been conducted on the model obtained with the Agisoft Photoscan and 123D Catch in order to control metric accuracy, i.e. to compare model measures with those acquired with direct surveying. Prior to effecting metric verification horizontal section planes had been created. This made it possible to obtain a profile thanks to which the model could be oriented and establish scales in order to compare the dimensions. In both cases the waste – in comparison to the quantities surveyed with traditional methods – reached 2 cm maximum.

Considering that in any surveying operation it is necessary to determine the level of uncertainty also in relation to the representation scale, fixed preventively at 1:50, the difference would amount to 2 mm, a value perfectly acceptable because it falls within the graphics error. Extra confirmation has been obtained by calculating the deviance value with Cloud Compare, an open source software used for elaborating and comparing 3D cloud points: also in this case the value obtained from the section of the surfaces that make up the model in the two dimensional plane proves to fall within millimeters (Fig. 3).

5. Construction of models

Constructing a high quality 3D model – the effect of surveying an object or an architectural structure – comprises a series of different steps which are partially independent (Callieri, Dellepiane, Scopigno 2015). The main steps of the procedure necessary for constructing a 3D object are the



	software: Arc3D	software: Photosynth	software: 123D Catch
piattaforma	Web-based per Windows, Mac, Linux	Web-based per Windows	Web-based per Windows
formati di esportazione	.v3D ; .obj	.ply; .obj; .vrml; x3d	.dwg; .fbx; .rzi; .obj; .ipm;.las
macchina fotografica	Nikon D300	Nikon D300	Nikon D300
risoluzione	12 Mpixel	12 Mpixel	12 Mpixel
distanza focale	50 mm	50 mm	50 mm
immagini processate	73	73	73
immagini ridondanti	-	-	7
tempo di calcolo	28 min	17 min	22 min
dense point cloud	-	47453	-
mesh	417752 vertici 545523 poligoni	-	455464 vertici 908422 poligoni

Fig. 2 – Case study: Porta San Donato. Data processing and open source software comparison (123D Catch, Arc3D, Microsoft Photosynth).

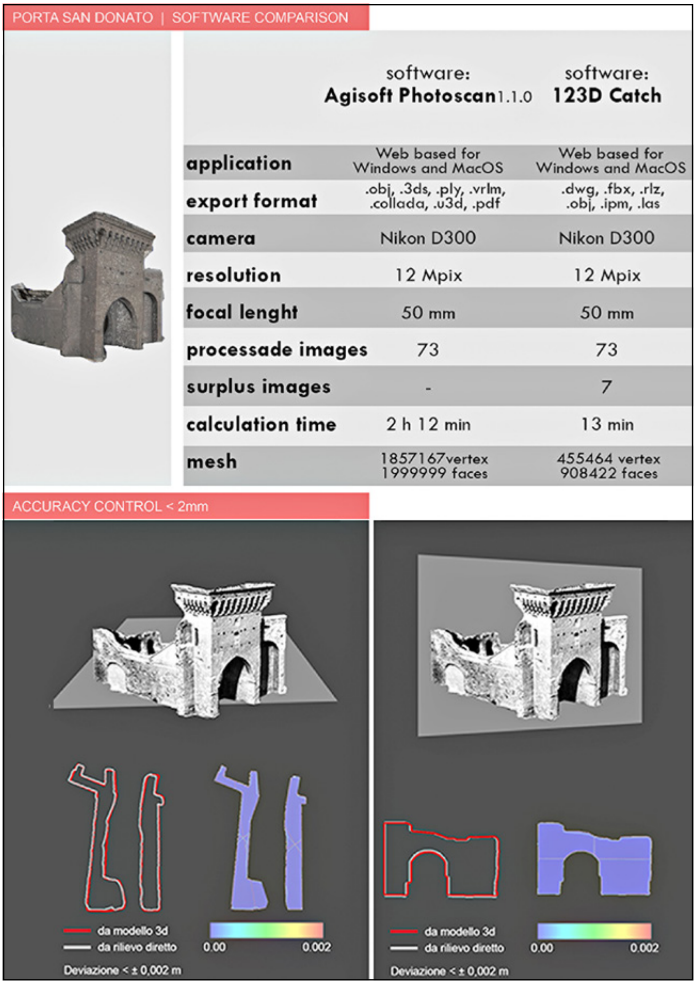


Fig. 3 – Case study: Porta San Donato. Data acquisition phase: comparison between open source (123D Catch) and commercial software (Agisoft Photoscan). Data elaboration: analysis of metric accuracy and standard deviation (software: CloudCompare).

following: acquisition of the geometry as well as the material and chromatic component, managing the forms of representation, systematization of Level Of Detail (LOD).

The results achieved shows that the models obtained with Agisoft Photoscan can be considered to be better for describing surfaces. In fact the 123d Catch software has a limitation in terms of megapixels: regardless of

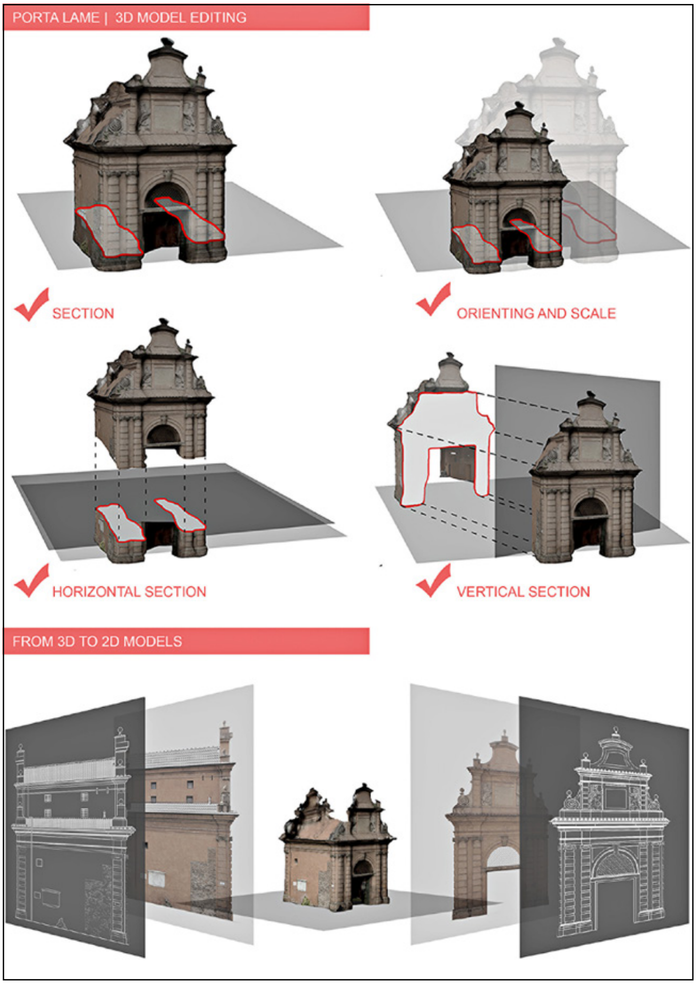


Fig. 4 – Case study: Porta Lame. Data elaboration and editing: from 3D texturized model to 2D geometric and architectural models.

the megapixels of the photographic images, in the upload, every image is still reduced to 3 megapixels. This obviously affects the quality of the 3D models created in terms of resolution and quality of information.

The level of uncertainty has been managed by correcting the optical aberrations of individual photograms (this stage directly preceded the creation of the 3D model) and using some markers on the obtained point cloud to found the correspondence of the salient points measured with the methodologies for direct surveying.

MeshLab visualizer has cleaned the data gained from the survey. Then the numerical model obtained by processing photographs was first positioned and properly scaled in CAD environment on the basis of the measurements acquired during the campaign of direct surveying.

The 3D and textured models worked out (Fig. 4) were taken as the point of departure for constructing 2D models. Such an operation is all but automatic: a high level of knowledge of the subject and the rules of the science of representation are indispensable in order to build 2D models able to effectively describe the object analyzed.

6. Conclusion

The study presented here allowed to analyze the potentialities as well as the limitations of an approach that uses low-cost methodologies for acquiring and constructing models worked out for the purpose of documentation and cataloguing. Case studies analyzed, stylistically and formally heterogeneous, have common features linked to the recognizably and repeatability of architectural and decorative elements as well as of the dimensions (El-Hakim, Beraldin, Picard 2004; Entwistle, McCaffrey, Abrahams 2009). The latter feature has been found to be critical to determine the choice of surveying methodologies applied and the analysis of the results obtained. In fact the SfM technique, tested on various cases of medium scale, seems to be effective in describing geometric, dimensional, material and chromatic features.

The obtained models[6], built with a view to various requirements, make possible an extensive knowledge of the case studies under analysis. Integration

[6] The numeric model (point cloud, mesh) represents a synthesis of the datum that registers every single information acquired – metric and chromatic. The form of such a model is described by means of the x, y, z spatial coordinates of single points. The geometric model is a geometric abstraction composed of simple entities (points, lines, surfaces). It is a reduction of an object to its geometrical essence, to which a 3D model can correspond – either non material or conveniently scaled to the measure of support and, subjected to the procedures of projection and section, it becomes a 2D model. 2D models have no chromatic features nor do they bear information on the preservation state of the object surveyed. Thus they are useful for understanding the geometry, proportions and mutual positioning of the elements that make up the object and of the method applied for data acquisition as well. The architectural model as related to the conventional differentiation of surveying elaborates, describes – on the basis of the geometric model – the configuration of the elements measured as interpreted by the surveyor in terms of material and chromatic features of surfaces. Textured models are obtained with the techniques based on digital elaboration of images. This takes advantage of texture mapping to define in detail the formal aspects and the state of preservation of the organism, establishing a continuous exchange between the object represented and the user. In this way a biunivocal relation is created between the iconic representation and the visualization of the organism surveyed. It is precisely this aspect that makes the model textured and adapted to generic users –, since the generic representation is very similar to reality, as well as to specialized users, because the photographic degree is related to metric information.

of instruments for 3D surveying, re-elaboration of study methodologies, like the definition of 2D models, together with the integration of the digital representation techniques, provided a valid support in investigating all the elements leading to the understanding of the complex system of the Bologna gates.

It becomes ever clearer that the technologies of massive acquisition ought to be integrated in their potentialities with the objective to construct heterogeneous models. There emerges, moreover, the fundamental importance of the survey project in planning the activities to be undertaken and likewise in selecting the instruments used in relation to the desired scale of the model.

Alfonso Ippolito, Martina Attenni
Sapienza Università di Roma
Dipartimento di Storia, Disegno e Restauro dell'Architettura
alfonso.ippolito@uniroma1.it, martina.attenni@uniroma1.it

Cristiana Bartolomei
Alma Mater Studiorum – Università di Bologna
Dipartimento di Architettura
cristiana.bartolomei@unibo.it

REFERENCES

Bartolomei C., Ippolito A. 2014, *Low-cost cataloging methodologies for architecture: The system of gates in Bologna*, in M. Ioannides, N. Magnenat-Thalmann, E. Fink, R. Žarnić, A.-Y. Yen, E. Quak (eds.), *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. Proceedings of the 5th International Conference EuroMed 2014 (Limassol 2014)*, Cham-Heidelberg-New York-Dordrecht-London, Springer, 249-257.

Bianchini C. 2012, *La documentazione dei teatri antichi del mediterraneo*, Roma, Gangemi.

Bianchini C., Borgogni F., Ippolito A., Senatore L.J. 2014, *The surveying and representation process applied to archaeology: A quest for invariants*, in P. Di Giamberardino, D. Iacoviello, R. Natal Jorge, J.M.R.S. Tavares (eds.), *Computational Modeling of Objects Presented in Images. Fundamentals, Methods, and Applications*, Berlin, Springer, 1-29.

Bourke P. 2012, *Automatic 3D reconstruction: An exploration of the state of the art,* «GSTF Journal of Computing», 2, 3, 71-75.

Brunetaud X., De Luca L., Janvier-Badosa S., Beck K., Al-Mukhtar M. 2012, *Application of digital techniques in monument preservation*, «European Journal of Environmental and Civil Engineering», 16, 5, 543-556.

Callieri M., Dellepiane M., Scopigno R. 2015, *Remote visualization and navigation of 3D models of archeological sites*, in *3D-ARCH. 6th International Workshop on 3D Virtual Reconstruction and Visualization of Complex Architectures (Avila 2015)*, «International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences», 40-5/W4, 147-154.

Cipriani L., Fantini F. 2015, *Modelli digitali da Structure From Motion per la costruzione di un sistema conoscitivo dei portici di Bologna. (Digital models of Structure From Motion for constructing a knowledge system for the Bologna gates)*, «Disegnare Idee Immagini», 50, 70-81.

Costantino F., Poggi D., Callieri M., Dellepiane M., Scopigno R. 2014, *San Leonardo in Arcerti: innovazione tecnologica per la gestione integrata dei beni culturali*, in *Atti della 18a Conferenza Nazionale ASITA (Firenze 2014)*, Milano, Federazione ASITA, 381-388.

De Luca L., Busarayat C., Stefani C., Véron Ph. 2010, *An iconography-based modeling approach for the spatio-temporal analysis of architectural heritage*, in J.-Ph. Pernot, J. Rossignac, M. Spagnuolo, B. Falcidieno, Ph. Véron (eds.), *SMI 2010. International Conference on Shape Modeling. Proceedings (Aix-en-Provence 2010)*, Los Alamitos, IEEE Computer Society, 78-89.

El-Hakim S.F., Beraldin J.-A., Picard M. 2004, *Detailed 3D reconstruction of large-scale heritage sites with integrated techniques*, «IEEE Computer Graphics and Application», 24, 3, 21-29.

Entwistle J.A., McCaffrey K.J.W., Abrahams P.W. 2009, *Three-dimensional (3D) visualisation: The application of terrestrial laser scanning in the investigation of historical Scottish farming townships*, «Journal of Archaeological Science», 36, 3, 860-866 (https://www.researchgate.net/publication/257154404_Threedimensional_3D_visualisation_The_application_of_terrestrial_laser_scanning_in_the_investigation_of_historical_Scottish_farming_townships; accessed: 31/03/2017).

Gaiani M. 2015, *I portici di Bologna. Architettura, modelli 3D e ricerche tecnologiche. (The Bologna Gates. Architecture, 3D Models and Technological Research),* Bologna, Bononia University Press.

Hess M., Meyer D., Hoff A., Rissolo D., Leira Guillermo L., Kuester F. 2014, *Informing historical preservation with the use of non-destructive diagnostic techniques: A case study at Ecab, Quintana Roo, Mexico*, in M. Ioannides, N. Magnenat-Thalmann, E. Fink, R. Žarnić, A.-Y. Yen, E. Quak (eds.), *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. Proceedings of the 5th International Conference EuroMed 2014 (Limassol 2014)*, Cham-Heidelberg-New York-Dordrecht-London, Springer, 659-668.

Hess M., Petrovic V., Meyer D. 2015, *Fusion of multimodal three-dimensional data for comprehensive digital documentation of cultural heritage sites*, «Digital Heritage», 2, 595-602.

Ippolito A., Bartolomei C. 2014, *La gestione del dato di rilievo attraverso software open source: il sistema delle porte bolognesi*, in P. Giandebiaggi, C. Vernizzi (eds.), *Italian Survey & International Experience*, Roma, Gangemi, 897-906.

Micheletti N., Chandler J.H., Lane S.N. 2015, *Structure from Motion (SFM) photogrammetry*, in L.E. Clarke, J.M. Nield (eds.), *Geomorphological Techniques (Online Edition)*, London, British Society for Geomorphology, 2, 2.2, 1-12 (http://www.geomorphology.org.uk/sites/default/files/geom_tech_chapters/2.2.2_sfm.pdf; accessed: 31/03/2017).

Minto S., Remondino F. 2014, *Online access and sharing of reality-based 3D models*, «SCIRES-IT», 4, 2, 18-27.

Remondino F., Campana S. 2014, *3D Recording and Modelling in Archaeology and Cultural Heritage. Theory and Best Practices*, Oxford, Information Press.

Remondino F., El-Hakim S., Baltsavias E., Picard M., Grammatikopoulos L. 2008, *Image-based 3D modeling of the Erechteion, Acropolis of Athens*, «The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences», 37-B5, 1083-1091 (http://www.isprs.org/proceedings/XXXVII/congress/5_pdf/186.pdf; accessed: 31/03/2017).

Remondino F., Spera M.G., Nocerino E., Menna F., Nex F. 2014, *State of the art in high density image matching*, «The Photogrammetric Record», 29, 144-166.

Siotto E., Callieri M., Pingi P., Scopigno R., Benassi L., Parri A., La Monica D., Ferrara A. 2014, *From the archival documentation to standardized web database and 3D models: The case study of the Camaldolese abbey in Volterra (Italy)*, in *CHNT 18. Proceedings of the 18th International Conference on Cultural Heritage and New Technologies (Vienna 2013)*, Wien, Museen der Stadt Wien – Stadtarchäologie, 1-9.

Styliani V., Doulamis A., Athanasiou G., Ioannidis Ch., Amditis A. 2016, *Multi-scale 3D modelling of damaged cultural sites: Use cases and image-based workflows*, in

M. Ioannides, N. Magnenat-Thalmann, E. Fink, R. Žarnić, A.-Y. Yen, E. Quak (eds.), *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. Proceedings of the 5th International Conference EuroMed 2014 (Limassol 2014)*, Cham-Heidelberg-New York-Dordrecht-London, Springer, 50-62.

Thomson W. Baron Kelvin 1889, *Popular Lectures and Addresses,* I. *Constitution of Matter*, New York, MacMillan and Co.

ABSTRACT

In the past twenty years archaeological survey has changed radically thanks to the progress in the field of technology, in particular concerning 3D massive acquisition methods. A variety of data acquisition modes, based on active and passive sensor systems, is increasingly easier to access and use to document cultural heritage. The scientific debate focuses primarily on two issues: the use of free or proprietary software, and the control over data quality, in terms of metric accuracy, by comparing 3D image-based acquisition methods with consolidated methods (laser scansion and/or topographic survey). Collecting, interpreting and filing a large amount of information helps to define a system we can use to understand our archaeological heritage. The system is based on the scientific process used to achieve a dual objective: first, to document acquisition using a heterogeneous set of data (x, y, z and RGB) and metadata (information processing) and guarantee repeatability; secondly, to ensure data quality during acquisition and processing. Data processing obtained using 3D massive acquisition methods makes it possible to build models characterized by a biunivocal correspondence to the real object, studied from a geometric and spatial point of view. The study focuses on the shift from quantitative data, acquired in a semi-automatic manner, to qualitative data, meticulously controlled as regards to uncertainty. In this framework, all branches of the Science of Representation ensure metric, spatial and formal control of the built models. The study of the 13th century Gates of the city of Bologna have so far led to the development of a scientific process providing important data about metric quality vis-à-vis, the scale of the model.