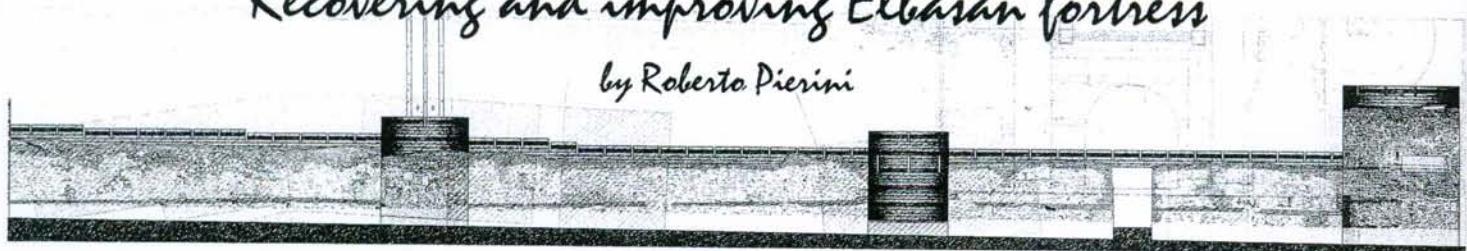


Recovering and improving Elbasan fortress

by Roberto Pierini



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SURVEY AND DIGITAL DESCRIPTION OF THE FORTIFICATION TROUGH LASERSCANNER AND PHOTOGRAMMETRY

GABRIELLA CAROTI, ANDREA PIEMONTE

RILIEVO LASER SCANNER E FOTOGRAMMATICO PER LA MODELLAZIONE DIGITALE DELLA FORTIFICAZIONE

La Sede di Topografia e Fotogrammetria del Dipartimento di Ingegneria Civile dell'Università di Pisa ha partecipato al progetto di ricerca Inter-Link dando un contributo alla conoscenza della Kalà in termini di posizione, forma, geometria e colore (georeferenziazione e rilievo). L'area fortificata si presenta oggi con muri perimetrali a forma di ferro di cavallo, intervallati da torri di difesa, per uno sviluppo lineare complessivo pari a circa 600 metri. È accessibile completamente nella sua parte esterna, anche se l'area prospiciente il lato sud è caratterizzata da un percorso pedonale alberato le cui specie arboree hanno costituito un ostacolo alla piena visione dei paramenti murari, mentre la sua superficie interna è quasi tutta in proprietà private e quindi difficilmente raggiungibile salvo il lato ovest che si sviluppa in un'area di svago e ristoro il cui proprietario ha autorizzato il nostro accesso e il rilievo delle cortine murarie e l'interno delle torri. Le nostre campagne di rilievo non si ponevano l'obiettivo di esaurire la gran mole di lavoro che la Kalà richiede: si è valutato di impostare un rilievo che possa essere sviluppato ed integrato nel futuro dai colleghi albanesi dell'Istituto Nazionale dei Monumenti di Tirana (che hanno collaborato durante i rilievi fotogrammetrici) dell'Università o dalla Pubblica Amministrazione.

Le nuove tecnologie di rilievo (GPS, laser scanner, fotogrammetria digitale, etc.) hanno i requisiti per ritenerle apparati conoscitivi consoni a rendere disponibile, in breve tempo, una base metrica corretta e affidabile e modelli restitutivi che consentano di coniugare il rigore conoscitivo dell'indagine metrica con l'esigenza di servire efficacemente da strumento di comprensione dei valori nonché di comunicare i significati del sito. Infatti, le tecniche e le metodologie proprie delle discipline geo-topo-cartografiche stanno vivendo negli ultimi anni un'importante fase di innovazione per quanto riguarda sia il momento dell'acquisizione del dato tridimensionale sia nel campo della rappresentazione di ciò che è stato rilevato, entrambe caratterizzate da un'evoluzione verso il digitale grazie alle possibilità offerte dall'elettronica e dall'informatica. Basta pensare come l'integrazione del laser scanner con la fotogrammetria digitale offra un valido strumento in grado di rispondere alle specifiche richieste di rilievo: è possibile, in questo modo, operare secondo diverse modalità e scale. Da un lato si possono ottenere modelli che documentano lo stato di fatto dall'altro possiamo disporre di una banca dati numerica (il modello 3D) che opportunamente strutturata e post processata, può essere adottata come base geografica tridimensionale per un vero e proprio sistema informativo spaziale per l'architettura e l'archeologia.

Nel predisporre il progetto e l'organizzazione del rilievo si è valutato di finalizzarlo ad una restituzione dell'intero complesso architettonico integrata da particolari delle zone di pregio e significato. Siamo partiti dall'analisi della cartografia vettoriale a disposizione del centro di Elbasan. Questa non risulta essere in un riferimento certo: si è innanzitutto di provveduto alla sua georeferenziazione mediante misure GPS. Allo scopo è stata indi-

RILEVIMI DHE PREZANTIMI DIGITAL I FORTESAVE: LAZER SKANER DHE FOTOGRAMMETRIA NE FUSHATËN E RILEVIMIT TË KALASË SË ELBASANIT

Qendra Topografike dhe Fotogrammetrike e Departamentit të Inxhinierisë Civile të Universitetit të Pizës mori pjesë në projektin e kërkimit Inter-Link duke dhënë kontribut në njohjen e Kalasë së lidhje me vendndodhjen, formën, gjemetrinë dhe ngjyrën (georeferencimin e rilevimit). Zona e fortifikuar, sot paraqitet me mure perimetrale në formën e patkot të kalit, me hapësira midis mureve me kulla mbrojtëse, për një zhvillim linear kompleks me treth 600 metra. Kalueshmëria është plotësisht në pjesën e jashtme, edhe pse zona që bie në anën jugore është e karakterizuar nga një rrugë këmbësorësh me pemë, llojet bimore përbëjnë pengesë në pamjen e të gjithë parametreve murore, ndërkaq sipërfaqja e brëndëshme pothuajse është e gjitha pronë private dhe për këtë e vështirë për t'u arritur, përvëç anës përendimore në të cilën ndodhet një zonë argëtimi e pushimi, pronari i të cilës na autorizozi hyrjen dhe rilevimin e kortinave murore dhe brendësinë e kullave. Fushatat tonë të rilevimit nuk kishin si qëllim të ezauronin të gjithë punën e madhe që Kalaja kërkon; u vlerësua vënia bazë e një rilevimi që mund të zhillohej e të integrohej në të ardhmen nga kolegët shqiptarë të Institutit Nacional të Monumenteve në Tiranë (i cili ka bashkëpunuar gjatë rilevimeve fotogrammetrike) të Universitetit ose të Administratës Publike. Teknologjia e reja (GPS, lazer skaner, fotogrametri digitale etj.) i kanë kushtet për t'i konsideruar aparate njohëse, për të bërë të mundur, shkurtimisht në kohë, një bazë metrike korakte e besueshme dhe modelet e rivendosjes në mënyrë që të lejojnë lidhjen e vështirësise së njohjes të kërkimit metrik me ekzistencën për të shërbyer me efikacitet si stument përbledhës të vlerave dhe përmes të cilës mund të komunikohen njësit. Në fakt, teknikat dhe metodologjite e disiplinave geo-topo-kartografike vitet e fundit po kalojnë një fazë rinovimi për sa i përket si momenti të marrjes së të dhënave tridimensionale ashtu dhe në fushën e përfaqësimit të gjithë asaj që u rilevua, të dyja janë të karakterizuara nga një evolumi drejt dixhitalizimit falë mundësive të ofruar nga elektronika dhe informatika. Mjafton të mendosh se si integrimi i lazer skanerit me fotogrametrinë dixhitale të ofroje një stument të vlefshëm në mënyrë që t'i përgjigjet kërkeseve specifike të kërkuar në rilevim: është e mundur, në këtë mënyrë, të veprohet sipas modalitetave e shkallëve të ndryshme. Nga njëra anë mund të merren modele që dokumentojnë gjëndjen faktike nga ana tjeter mund të disponojmë, në një qendër me të dhëna numerike (modeli 3D) i cili është në mënyrë të strukturuar posaçmërisht dhe post proceduar, mund të përshtatet si bazë gjeografike tridimensionale për një sistem të vërtetë informues hapsinor për arkitekturën dhe arkeologjinë. Në predispozicionimin e projektit dhe organizimin e rilevimit u vlerësua të finalizohej në rikthimin e të gjithë kompleksit arkitektonik të integruar në veçanti, të zonave me vlerë dhe me kuptim. U nisëm nga analiza kartografike vektoriale në dispozicion të qendrës së Elbasanit. Kjo nuk rezulton të jetë një riferim i sigurt: pikësëpuri u morën masa në gjoreferencimin e saj përmes masave GPS. Qëllimit iu dallua, si qendër e përshtatësime për predispozimin e Master GPS një pikë, nga ne

viduata come sede opportuna per predisporre un Master GPS un punto, da noi materializzato, sul tetto del Comune di Elbasan. Abbiamo sfruttato questa fase di lavoro per rilevare la posizione di punti caratteristici riconoscibili anche in cartografia e distribuire, nell'area circostante le mura, caposaldi materializzati e rilevati in modalità RTK che hanno successivamente costituito i vertici di una poligonale di riferimento per i successivi lavori di rilievo. La poligonale di inquadramento (costituita da 17 vertici) si sviluppa in adiacenza alle cortine murarie accessibili all'esterno e all'interno della fortezza e dai suoi vertici sono stati misurati i necessari punti di appoggio (per un totale di 290 punti), individuati da targets riflettenti, per i rilievi laser e per quelli fotogrammetrici. L'acquisizione laser scanner del complesso è stata eseguita con lo strumento Riegl LMS-Z420i integrato con la camera digitale calibrata Nikon D70s posto ad una distanza non superiore a circa 40m dalle mura. Sono state necessarie 27 scansioni con risoluzione media di 0.057 deg (che corrisponde ad una interdistanza dei punti sull'oggetto pari a circa 2 cm) per acquisire il completo fronte esterno, l'interno della parte ovest e delle due torri che vi sono presenti per un totale di 100.000.000 di punti. Per quanto riguarda i rilievi fotogrammetrici abbiamo focalizzato l'impegno su una parte significativa delle mura posta sul lato ovest della fortezza, dove sono più visibili le diverse tessiture murarie, sono evidenti alcuni particolari significativi dal punto di vista storico-architettonico, ed è anche l'unica libera da alberature frondose che ostruiscono la visione del paramento murario. In questa area le prese fotogrammetriche, finalizzate alla realizzazione di fotopiani, sono state progettate per una restituzione alla scala migliore di 1:50 e si è utilizzata la camera semimetrica Rollei Metric 6008. Sono stati elaborati i dati topografici e grazie a questi si è ricomposto l'insieme delle nuvole di punti acquisite con il laser in unico sistema di riferimento: si è prodotto il modello digitale tridimensionale ricco di informazioni e molto complesso della Kalà dal quale iniziare ad estrarre le informazioni metrologiche, morfologiche e colorimetriche. Le prospettive di utilizzo di questo prodotto sono innumerevoli: come nota si può mettere in evidenza che se la fase di rilievo è stata relativamente breve (nel totale 7 giorni) la sua restituzione è a tutt'oggi ancora in fase di sviluppo.

Le prime elaborazioni hanno riguardato la pulitura del modello da quei dati che non riguardano propriamente la Fortezza. Successivamente abbiamo estratto polilinee significative, sezioni e profili che hanno permesso di leggere l'andamento del paramento murario, le sue diverse altezze, i diversi livelli di calpestio, di valutare la conformazione delle torri, di leggere lo spessore delle murature, di interpretare le connessioni tra le diverse parti, etc.... Parallelamente si è proceduto a realizzare un modello tridimensionale digitale basato su superfici (mesh) la cui creazione richiede un'interpretazione del modello rilevato nonché una adeguata riduzione dei punti acquisiti per renderlo gestibile dalle strumentazioni informatiche, sia hardware sia software, funzionale, fruibile e versatile per l'esplorazione e la rappresentazione. Questo prodotto è stato "colorato con le immagini digitali acquisite dal laser e orientate nel sistema di riferimento del progetto (*texture mapping*) e si è creato un filmato che permette di percorrere la fortezza nei suoi spazi interni ed esterni. Uno degli ultimi risultati che abbiamo realizzato è l'ortofoto sui dati *laserscan* di alcune parti del modello. Per quanto riguarda invece i rilievi fotogrammetrici questi hanno permesso di realizzare un fotomosaico alla scala 1:50 che riproduce la porzione di parete ovest nella sua completezza grazie all'utilizzo delle immagini acquisite e raddrizzate.

La successiva restituzione vettoriale del fotopiano, ricomposti spazialmente in ambiente CAD, ha consentito di evidenziare graficamente le tecniche costruttive, i degradi parietali, i diversi materiali utilizzati, nonché la loro posizione sulla parete fornendo elementi di immediato supporto per lo studio e la catalogazione del bene e per le successive operazioni di pianificazione delle indagini diagnostiche nonché per gli interventi di conservazione e manutenzione.

e materializar, nē çatine e Bashkisë së Elbasanit. Shfrytëzuam këtë fazë të punës pér rilevimin e pozicionit të pikave karakteristike të dallueshme në kartografi dhe në shpërndarjen, nē zonën pérreth mureve, fillimisht të materializuar dhe të rilevuar nē modalitetin RTK të cilët nē vijim kanë pérberë majat e një poliginal referimi pér punët e mëtejshme të rilevimit. Poliginalja inkadruess (e pérberë nga 17 maja) zhvillohet nē përafërsi me kortinat murore të kalueshme nga jashtë dhe nga brenda fortësës dhe nga majat e saj ku u matën pikat e mbështetjes (në një total 290 pikë), të gjetur nga targets pasqyruese, pér rilevimet laser e pér ato fotogrammetrike. Përdorimi i lazer skaner nē kompleks u përdor me mjetin Rigel LMS-Z420i i integruar me kamerën dixhitale të kalibruar Nikon D270s të vendosur nē një distancë jo më shumë se rreth 40m nga muret. Na u deshën 27 skanime me rizgjdhje mesatare prej 0.057 deg (që korespondon me një interdistance pikësh mbi subjektin rrëth 2cm) pér të marre kompletin ballor të jashtëm, brendësinë e anës lindore dhe të dy kullave që janë të pranishme pér një total prej 100.000.000 me pikë. Për sa i përkët rilevimeve fotogrammetrike kemi fokalizuar impenjimin nē një anë të mureve të vendosura nē anën pérëndimore të fortësës, ku janë më të dukshme pérberjet e ndryshme të mureve, janë evidente disa kuptime të veçanta nē pikëpamjen hisoriko-arkitektonike, eshtë e vërtëja e lirë nga pemët ballore që zënë shikimin e parametrit muror. Në këtë zone marrijet fotogrammetrike, të finalizuara nga realizimi i fotoplaneve, u projektuan pér një rikthim në shkallën më të mirë 1:50 dhu u përdor kamera simetrike e Rollei Metric 6008. U hartuan të dhënat topografike dhe falë tyre u ribë bashkësia ereve të pikave të marra me lazer nē një sistem unik referimi: u prodhuva modelli dixhital tridimensional i pasur me informacione dhe shumë kompleks i Kalasë, nga i cili të fillohet nxjerra e informacioneve metodologjike, morfoloġjike dhe klorometrike. Prespervikat e përdorimit të këtij prodhimi janë të panumëta: si mund të vihet re faza e rilevimit ka qënë relativisht e shkurtër (brenda 7 ditëve) dhe sot rikthimi i saj eshtë akoma nē fazën e zhvillimit. Hartimet e para kishin të bënin me pastrimin e modelit nga ato që nuk i përkasin Fortesës. Në vijueshmëri kemi marrë polilinja me kuptim, ndarje dha profile që kane lejuar leximin e ecurisë të parametrit muror, lartësitë e ndryshme, nivelet e ndryshme të ecjes, vlerësimin, pérberjen e kullave, leximin e spesoreve murorë, interpretimin e lidhjeve midis pjesëve të ndryshme, etj... Paralelisht u procedua nē realizimin e një modeli tridimensional dixhital të bazuar në sipjëffaqt (mesh) krijimi i së cilës kërkon një interpretim të modelit të rilevuar nē përpunje me një shkurtim të përshtatshëm të pikave të marra pér ta bërë të përdorshëm nga studentat informatike, si hardware ashtu dhe software, funksionale, të përfitueshme dhe të kthyeshme pér eksplorimin dhe prezantimin. Ky produkt i "ngjyrosur me imazhet dixhitalë të marra nga lazeri dhe të drejtuarë nē sistemin e referimit të projektit (texture mapping) ku u krijuva një filmin i cili lejon përshtatje e fortësë nē hapësirat e saja të brëndëshme e të jashtme. Një nga rezultatet e fundit që realizuam eshte ortofotografik nē të dhënat laserscan nē disa pjesë të modelit. Për sa i përkët rilevimeve fotogrammetrike, këto kanë lejuar realizimin e një foto-mozaiku nē shkallën 1:50 që riprohon sasinë e mureve lindore nē teresine e tyre falë përdorimit të imazhevë të marrë e të modifikuara. Rikthimi vektorial i fotoplanit, të riperbëre nē hapësirë nē ambientin CAD, lejoi evidencimin grafikshët të teknikave ndërtuese, degradimet murore, materialet e ndryshme të përdorura, pozicionin e tyre nē mur duke dhënë elemente mbështetës të menjëherëshëm pér studimin dhe katalogimin e pasurisë pér veprimet e mëtejshme të planifikimit të hetimeve diagnostiguese, madje dhe pér ndërrhyrjet e ruajtjes dhe mirëmbajtjes.

INTRODUCTION: METHODOLOGICAL AND TECHNICAL-OPERATING CHARACTERISTICS IN CULTURAL HERITAGE SURVEY.

Cultural heritage, particularly historical-architectural one, is rich in features related to the work's historic evolution and is often tightly bonded with the land, including not only the ground surface, but also the sum of environment- and human-related elements and of every feature related to the same geographical context.

Thus historical buildings show up as the result of a stratification of structural and functional changes, to be studied on the basis of completion time and procedures, in order to identify the most suitable strategies for their conservation and valorisation.

The effectiveness of protection, conservation and valorisation is based on a deep and detailed knowledge of the manufacture and its related context, to be centred on the georeferentiation (i.e. the attribution to each element of spatial coordinates relative to a known reference system) and the survey of the building. The multidisciplinarity of the study between humanistic and scientific-technological research sectors has in fact been the main goal of the Inter-Link research project for years 2004-2006 titled "Progetto pilota per la conoscenza, conservazione e valorizzazione della Kalà di Elbasan - Albania", coordinated by Prof. Roberto Pierini, in which both authors have taken part (inspection and first run of measurements in April, 2006 and final, full measurements campaign in February, 2007), contributing to the knowledge of this heritage in terms of position, shape, geometry and colour (georeferentiation and survey).

Current researches dealing with the Italian 'Carta del rischio del patrimonio culturale' (Cultural heritage risk map) show the urgency of the need to program cultural heritage conservation especially through damage prevention, so lending primary importance to the establishment of an informative system, identifying the manufacture on a map and rendering it in a georeferred survey whose data base should be oriented to the protection, conservation and valorisation of architectural heritage and allowing for a rendering of the risks the work is facing and the environmental conditions potentially threatening its conservation.

In order to fully exploit this complex procedure it is necessary to reduce to a minimum the time to step from the 'investigation' (identification of the work, survey, georeferentiation and inclusion in the cartography) up to the 'fruition' of the information, so to avoid the paradox of using the system when the data it contains are outdated.

The aspect of data georeferentiation is thus crucial.

New surveying techniques, such as GPS, laser scanning, digital Photogrammetry and so on, meet all the requirements to make available, in the short term, a reliable and metrically correct basis, as well as rendering models enabling to match the cognitive exactitude of the metric survey with the need to provide an effective tool to both understand and communicate the site's values and meanings.

In fact, techniques and methodologies, typical of the geological-topographical-cartographical disciplines, are lately undergoing important innovations both for 3-D data collection and for the rendering process, featuring a strong trend towards digital technologies, thanks to the advances in electronics and information science.

Using up-to-date digital measuring technologies allows for new possibilities in the rendering of the collected metric data, no more limited to orthogonal projections, but also 3-D surface models, from which subsequent post-processing could generate solid models; these, in turn, would be the basis for the generation of contour line planimetry, sections, 3-D views, 3-D models with texturized surfaces, videos of the 3-d model obtained by the real-life object, each with a great impact for creating specialised documentation and extracting new information, as well as for widespread divulgation.

This provides new operating possibilities as well as new ways to face the many problems related to surveying and rendering in terms of accessibility, precision, logistics and operating procedures.

PHOTGRAMMETRY

The role of Photogrammetry in the sector of cultural heritage surveying is well established and its current spreading is definitely widened thanks to digital technologies. The features that have fostered its application in this particular sector include the ability to operate without direct contact with the survey object, the limited requirements for field operations, in spite of the complexity of the features these include, a relevant

flexibility of use and an outstanding precision in the metric definition of geometry and shape for objects of any kind, ensuring the ability to set up recurring and systematic checks for protection and conservation of natural, cultural and environmental heritage.

As the term 'photogrammetry' is used to identify the set of procedures collecting metric information by photographs, it follows that it also encompasses applications that, although different from stereoscopic photogrammetry, share the same goal.

These include so-called 'non-conventional photogrammetry' applications, such as, for instance, photoplans and photo mosaics, which have always been considered of lesser importance and accessories to the primary subject. Anyway, thanks to the ever-evolving digital technologies, these applications are currently under check for their suitability as both operating methodologies and effective tools in architectural surveys, as a supporting tool for current and deterioration state documentation and for planning of restoration and maintenance operations.

As regards these sectors, modern, highly interesting products include orthophotos, whose implementation obviously requires available digital models of the surface to be rendered. Such models are currently implemented not only with photogrammetry-related techniques, but also through those typical of laser scanning (i.e., orthophotos with object surface model derived from a laser scan). Besides, thanks to the links that have been established between photogrammetry and other imaging-related sectors, aspects related to 3-D modelling and rendering of metrically exact, VR-explorable products. Exact superimposition and interaction between photographic images and 3-D models, in an environment providing the ability to perform measuring operations, generates high impact results, with many possible uses, e.g. in architecture and archaeology.

Laser technology

In particular, laser scanning technology is holding an ever important role in the survey sector, due to the unquestionable advantages it offers, most of all in terms of time consumption, data amount yet with the ability to instantly provide a 3-D rendering of the object. Surfaces computed via laser-scanned cloud points not only describe dimensions and position of architectural elements, but also return their matter consistency, highlighting wall features, deteriorations and cracks, and allow for a logic segmentation of data, separating architectural structures in simple elements to which many surface modelling procedures can be applied. This last point is of particular interest inasmuch the complexity of the survey object often requires different data collection and processing procedures.

Integration of laser scanning with digital photogrammetry provides an effective tool for specific survey requirements, allowing to operate in different modes and scales. On one hand, it is possible to obtain models to document the current state, and on the other there is a numeric data base (the 3-D model) which, if adequately structured and post-processed, can be used as a 3-D geographical basis for a genuine spatial information system for architecture and archaeology.

THE SURVEY OBJECT-GOALS



Fig. 1. GPS and traditional framing.

The fortified area currently features horseshoe-shaped outside walls, spaced by towers, for a total length of 600 meters. It is fully accessible on its outer side although some trees, lining a pedestrian path, haven't allowed for an unimpeded sight of the walls, while its inner side is almost entirely dispersed in private properties and therefore practically inaccessible, save the West side, totally occupied by a recreational space attached to a restaurant whose owner has granted access to (and survey of) the walls and the interior of the towers.

THE SURVEY DESIGN

Framing

The approach to the survey of the fortification walls has had to deal with the peculiarities of this historical and architectural work which, unlike other protected cultural heritages, is currently used on a daily basis, subject to destination variations, restoration and maintenance operations, so that survey campaigns would not cover the huge amount of work required by the Kalà (as shown by the relevant diggings carried out on the West side of the walls between the first and the second campaign). In consequence, it has been decided to set up a survey design so that it could be developed and integrated by the personnel of the Tirane National Monument Institute (who also collaborated during the photogrammetric survey), Universities and public authorities.

Survey design and management have been oriented to a rendering of the architectural complex in its whole, integrating it with details of particular value or meaning and allowing for future development and/or integrations. It has also been provided, as possible, for the obvious need for data georeferentiation as stated in the research project, and finally it should be the basis to provide support to Public Authority in the planning of restoration operations as well as to reorganize bibliographic, iconographic, historical and survey material.

The first step has involved a careful analysis of the available vector cartography for the city of Elbasan, which has shown to lack a definite reference: this has been georeferred by means of GPS measures. An adequate location has been identified, expressly for the purpose, to set up a master GPS point, which has been materialised on the roof of the Elbasan town Hall (fig. 2). In order to define the coordinates of this point in the WGS84 reference system, a static survey has been carried out for about 48 hrs using the permanent GPS station of Orid (Macedonia), a node of the EUREF network, as a master station. This has also been exploited to define the position of landmark points, easily identifiable in maps, and to adequately distribute, around the walls, datum points which, after having been materialised and measured in RTK mode, have formed the vertices of the framing traverse for the following survey jobs.

The framing traverse, formed by 17 vertices, runs along the accessible sections on both the outer and the inner side of the walls; related measures have covered all the necessary support points (totalling 290), identified by reflecting targets for photogrammetric and laser surveys.

Finally, one further relevant advantage due to the use of the absolute reference system is given by the ability to join different surveys without the need of sharing the same round-level traverse and referring to objects placed in distant spots.



Fig. 2. master GPS point on the Elbasan Town Hall roof.

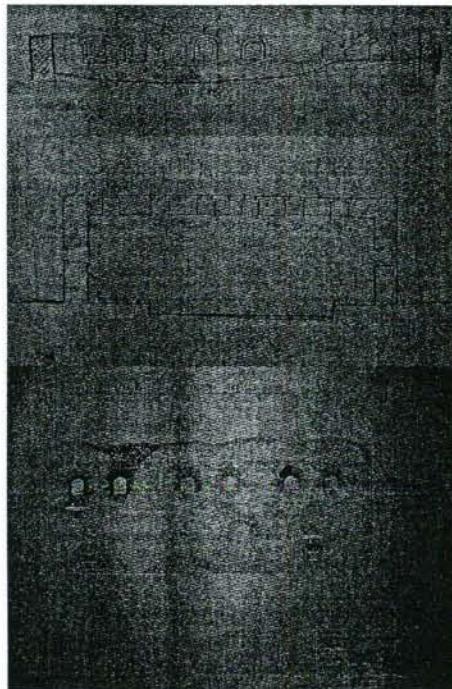


Fig. 3. archival documents, Tirane National Monuments Institute.



Fig. 4. the West survey area in 2006.

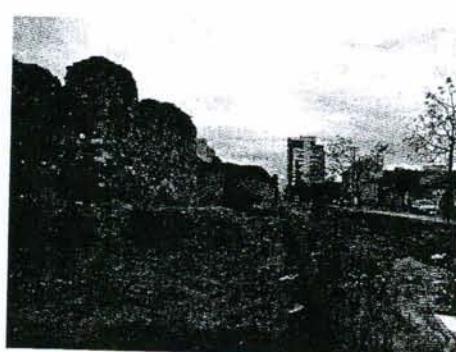


Fig. 5. the West survey area in 2007.

THE PHOTOGRAMMETRIC SURVEY

The photogrammetric survey has been carried out on a relevant wall section on the West side of the fortification, which, lacking the tree lining present along the South and East Sides, has allowed for clearer vision of different wall textures as well as of some historically and architecturally meaningful details. Besides, a research in the files of the Tirane National Monument Institute has provided the graphical documentation related to a 1:50 survey of the same area carried out in 1990 by engineers of the Institute. During the April 2006 inspection, a photogrammetric survey of the façade of the building partially projecting out of the walls in the west side has been carried out in this area to obtain a higher-quality rendering compared to the existing 1:50.

Prior to the February 2007 campaign, however, the entire area had been profoundly modified: diggings carried out for rearranging purposes have brought to light new wall structures and changed significantly the current state as of the previous April.

Mainly due to this reason, the same area has been again, and more thoroughly, surveyed during the February, 2007 campaign, in order to document current states prior to and after the digging operations.

Photogrammetric takes for the generation of photoplans have been carried out using a Rollei Metric 6008 semimetric camera, with objective lenses with $f=40\text{mm}$ and $f=80\text{mm}$.

Photoplans enable to transform the object's image (the photogram) from central projection to a metrically exact image, i.e. one lacking perspective distortions that take place during the shot (particularly those due to the non-normality of the shot), having the features of an orthogonal projection. The final product, in this case, is a 2-D, metric photographic document, projected on the average plane of the object, with an uniform scale which allows for correct reading and measuring of any of its features.



Fig. 6. Photogrammetric survey.

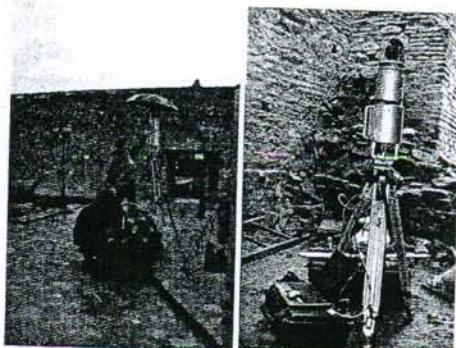


Fig. 7. Laser scanning surveys.

THE LASER SCANNING SURVEY

The complex has been scanned via the Riegl LMS-Z420i laser scanner, integrated with the calibrated Nikon D70s digital camera, at less than 40m from the walls. Thirty scans have been performed with an average resolution of 0.057 deg (equivalent to about 2cm on target) to scan in the entire external front, as well as the two towers and the interior of the walls in the West side, for a total of 100.000.000 points. Knowing beforehand the internal camera calibration and of its position relative to the scanner, the achievable images are already oriented in the reference system of each scan, and, these being georeferenced in the project's topographical global reference system, the images also will be oriented in the project reference system.

| | Scan positions | Points number | Photos number | Data dimension |
|---------------------------------------|----------------|--------------------|---------------|----------------|
| <i>West side (inside wall's)</i> | 3 | 16.946.744 | 25 | 720 MB |
| <i>West side (outside wall's)</i> | 9 | 39.026.630 | 70 | 1859 MB |
| <i>South side</i> | 9 | 23.933.640 | 65 | 2430 MB |
| <i>South tower</i> | 3 | 12.418.904 | 30 | 2649 MB |
| <i>West tower</i> | 3 | 9.381.692 | 24 | 1260 MB |
| TOTAL | 27 | 101.707.610 | 214 | 8918 MB |

Table 1. Database properties.

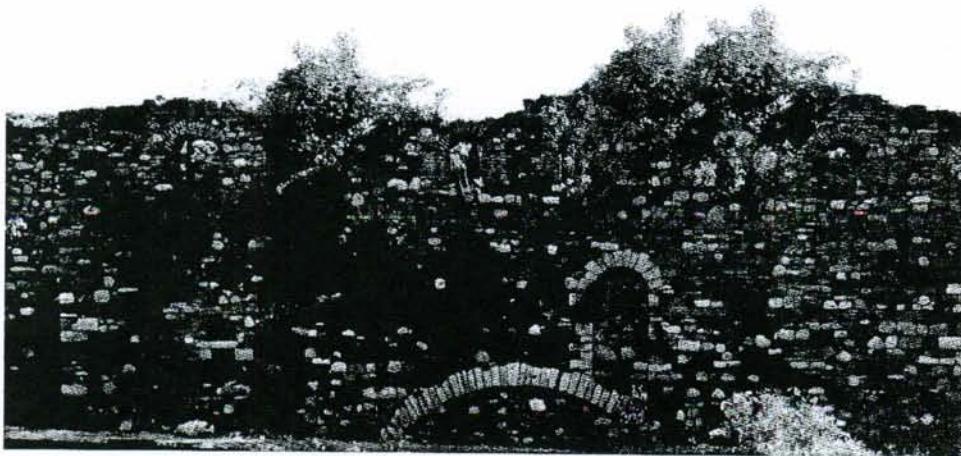


Fig. 8. APR 2006 photo plan.

RENDERING

Treatment and processing of the relevant amount of raw data have been carried out by the authors and the CED technical staff as well as by two students, who have used the processed data as part of the object of their degree thesis.

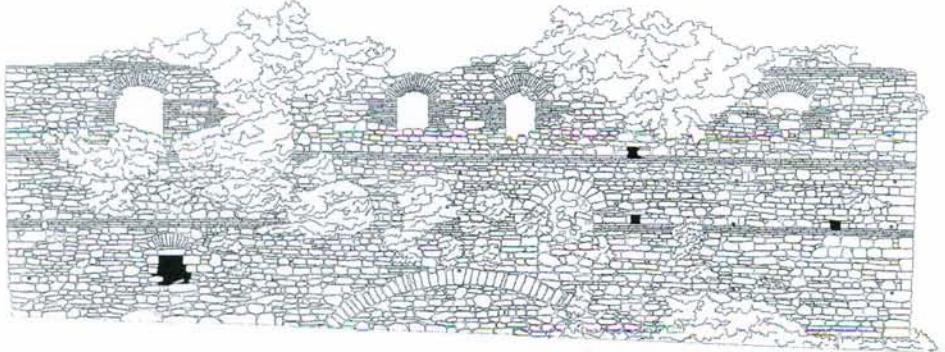


Fig. 9. Rendering of the APR 2006 photo plan.

Processing of topographical data has allowed for the merging of the laser-scanned point clouds in a single reference system, generating the information-rich, highly complex 3-D digital model of the Kalà, which has then been queried for metrology, morphology and colour. Exploitation perspectives for this product are quite high: it can be noted that, while the surveying phase has been comparably short (7 days total), rendering is currently being carried out.

Photogrammetric

Photogrammetric survey has output a 1:50 photo mosaic of the West section of the walls. Subsequent vector rendering of the photoplans, spatially rearranged in CAD environment, has allowed to highlight graphically many features, such as building techniques, wall deterioration, different materials used and their position in the wall, providing readily available support data for analysis and cataloguing of the work and for subsequent planning of diagnostic researches and conservation and maintenance operations. As previously stated, the building on the west side of the walls have been surveyed at two distinct times (April 2006 and February 2007). Two photo plans – one per each survey – have then been rendered, thus providing rendering and measuring documentation both prior to and following the digging operation (figg. 8-9-10). The 2007 survey has covered a much wider area than the 2006 one, also including a relevant section of the west side walls, which have then been rendered based on the full photo plan (fig. 11). Finally, the photo plans have been composed in three dimensions, obtaining a model which has improved the spatial and dimensional perception of the object (fig. 12).

Laser

Laser scans have been set up in order to collect the maximum amount of data available during the survey operations, with rather small point resolution on the object and rather wide field angles. Raw laser scanned data not directly related to the Kalà have so firstly been filtered out. Filtered data, rather than just trashed, are placed in their own layers, in order to view just the relevant sections of the wall structure (fig. 13). However, the ability to process original point clouds, which files are kept, to query new features of the structure itself or of the surroundings is still a strong point held by laser scanning. Rendering operations can be performed, to a certain extent, on point clouds which have been colored via the oriented photographs shot with a digital camera.

Fig. 10. rendering of the FEB 2007 photo plan (details).

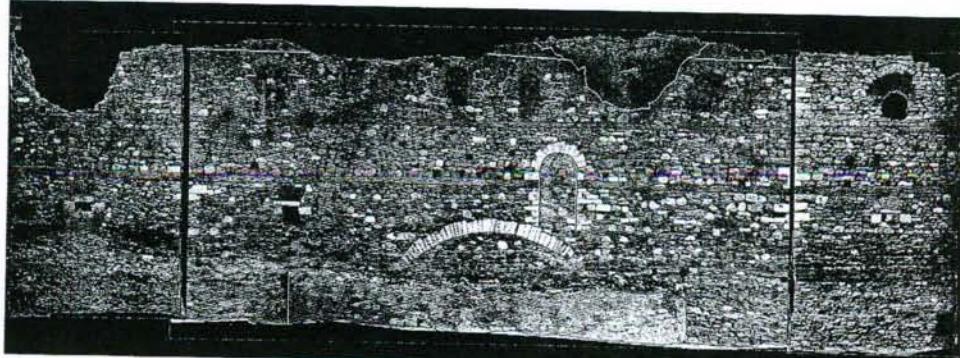
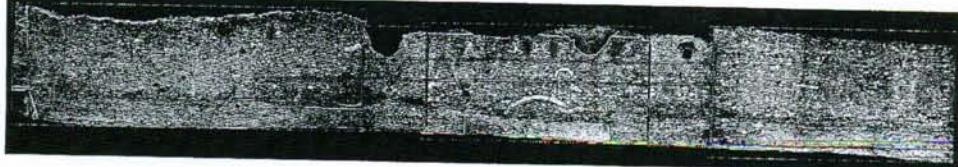


Fig. 11. rendering of the FEB 2007 photo plan (wide representation).



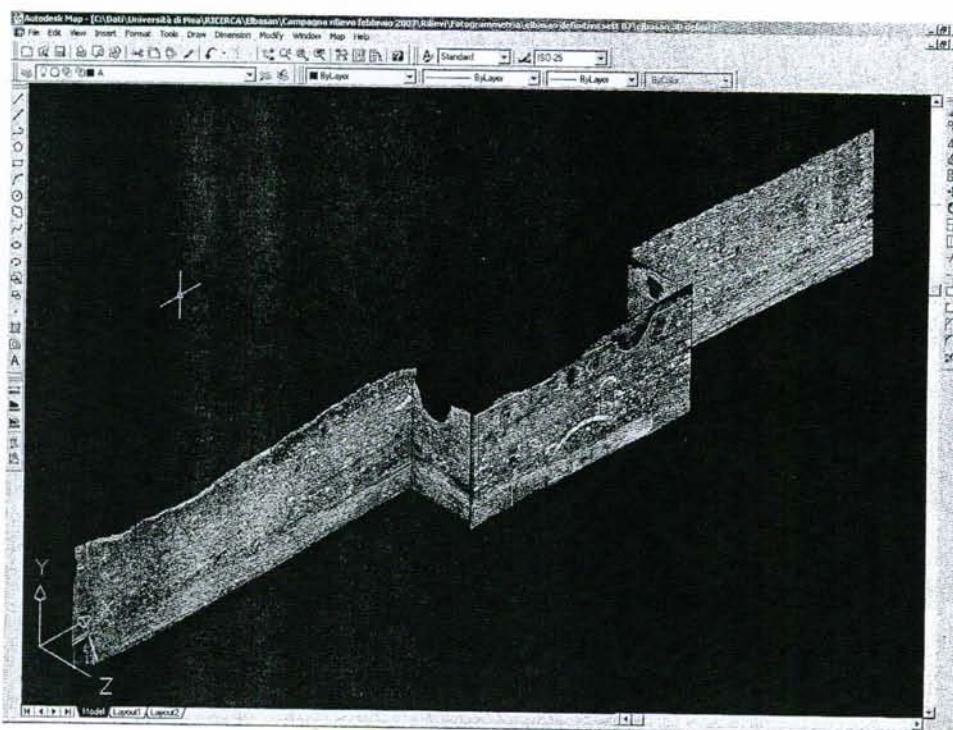


Fig. 12. FEB 2007 photo plan in 3-D.

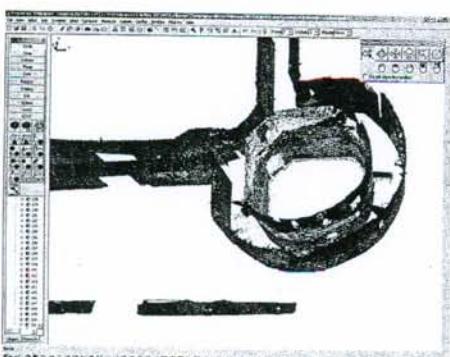


Fig. 13. Points cloud filtered – 3-D view.

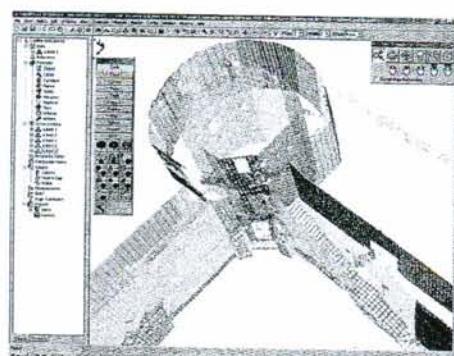


Fig. 14. Sections from points cloud – 3-D view.

Subsequently, significant polylines, sections and outlines which have allowed for accurate readings of trends of the wall faces, its different heights, pavement levels, tower morphology and structure, wall thickness, joints between adjacent sections and so on.

Besides, these intermediate products allow for sectioning the model along any given plane or sheaf of parallel planes, as well as along planes orthogonal to a given curvilinear path (fig. 14).

A 3-D section model, lighter and easier to explore (in three dimensions), is then obtained. Sections can in turn be exported in vector formats for further investigations in familiar CAD environments (figg. 15-16).

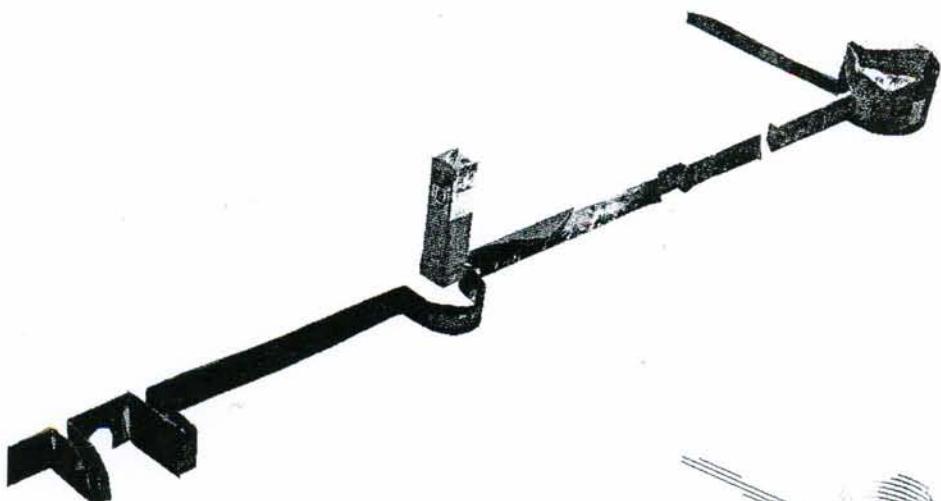


Fig. 15. Walls South side points cloud – 3-D view.

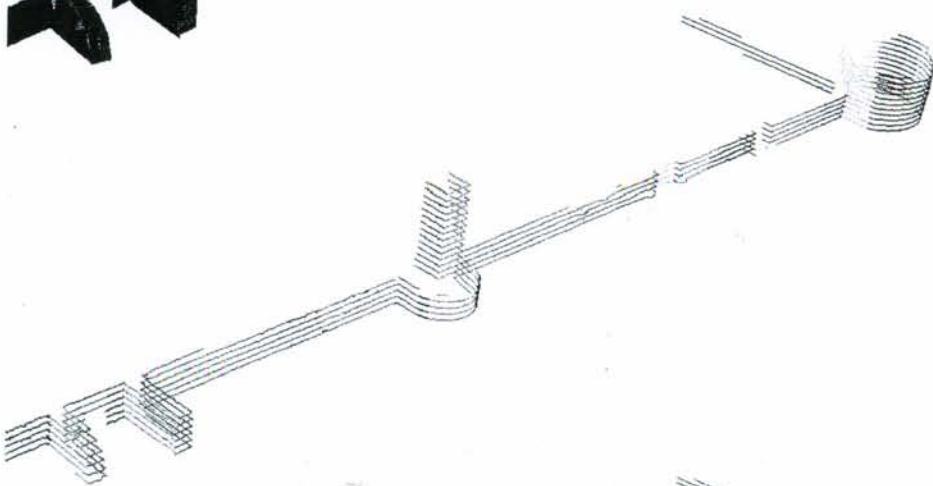


Fig. 16. Walls South side sections – 3-D view.

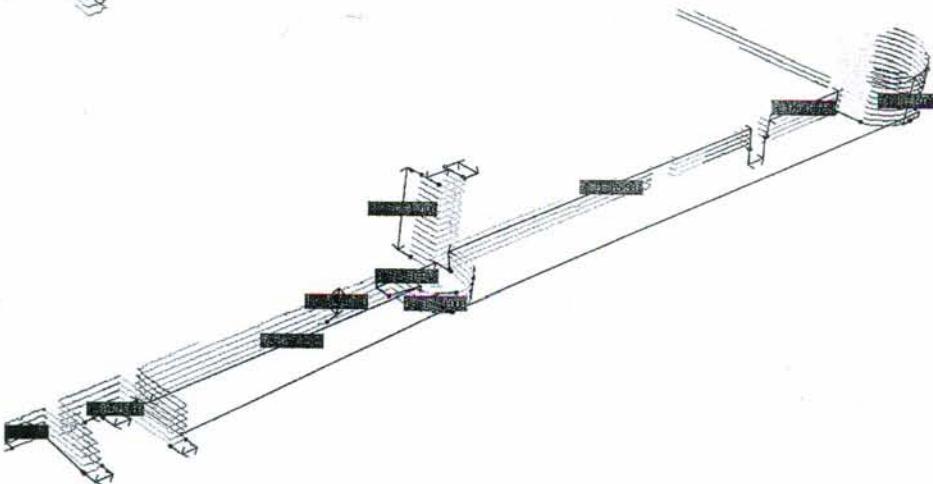


Fig. 17. Walls South side measure on 3-D model.

Investigations by more strictly laser-related tools enable querying of the model for coordinates, distances, areas, volumes, etc (fig. 17).

Point clouds have been processed for the reduction of the number of points, in order to allow for an exact reading of data and the subsequent generation of an easily manageable surface(mesh)-based 3-D digital model, which retains good functionalities, usability and versatility both for exploration and rendering purposes. This intermediate product has been coloured via the georeferentiated digital images acquired by the scanner-mounted digital camera (texture mapping), and a movie covering all the Kalà both on its inside and outside has been generated.

Finally, orthophotos have been generated starting from laser scanned data of some parts of the model.

CONCLUSIONS

New technologies provide the ability to survey a work with very low time requirements and high degrees of detail and precision.

The quality of modern instrumentation, their integration capabilities, the operating flexibility they allow as well as their ability to provide the basis for dedicated information systems merge with the output potentialities of modern rendering techniques. From a technical point of view, there currently are the conditions for exact surveys to become routine in the cultural heritage field.

The different survey methods used in Elbasan have allowed for the creation of a 3-D model of the fortification which, in spite of its complexity, provides a starting point for the development of further processing. This has allowed, for instance, to start up metrological, diagnostic and morphological studies and more generally to output specialized documentation and to extract new information and to process the collected data for divulgation and multimedia fruition.

Digital photogrammetric survey of the West side of the walls provides an example of how laser and photogrammetry can respond to the need of different experts to analyse the same work at different scales.

Laser scans have also allowed for effective, visually significant placing of the study subject as a whole in its urban context, and for rendering of the whole architectural unit. In fact, subsequent processing of point clouds have generated not only orthogonal projections, but also 3-D mesh models, polygonal models, contour lines cartography, outlines, sections, 3-D views, 3-D models with texturized surfaces and explorative videos of the 3-D model as surveyed.

Digital photoplans of details of relevant areas, and their rendering (at architecturally adequate scales) respond to the need to integrate the documentation with information related to greater scale renderings.

In any case, it must be pointed out that each and every measure is comparable with each other and referred to the global reference system of the digital model that, for this reason, takes on the function of 3-D geographical reference base and in turn stands as requirement for a true spatial information system for historic-architectural heritage.

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Finally, a hearty thank you to Arber Hasa, for assistance and invaluable support during the survey.



Fig. 18. Surveying team.