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Architectural Digital Photogrammetry

Panoramic Image-Based Interactive Modelling

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To My Father, ***Faysal Wahbeh***

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Contents

[1] *L'elaborati di tesi è scritto in lingua inglese. Per alcuni capitoli come riportato nell'indice viene proposta una sintesi in Italiano.*
This Thesis is writen in English. Some chapters have an Italian summery as indicated in the contents list.

I. Introduction

Photogrammetry is the science, and art, of determining the size and shape of objects as a consequence of analyzing images recorded on film or electronic media. It is an especially exiting field because the photogrammetrist is close enough to react with the environment which is being imaged.[1]

E.H.Thompson in the 1962 stated "photogrammetric methods of measurement are useful in the following conditions:

- when the object to be measured is inaccessible or difficult to access;
- when the object is not rigid and its instantaneous dimensions are required;
- when it is not certain, the measures will be required at all;
- when it is not certain, at the time of measurement what measure are required;
- when contours of the surface of the object are required; and
- when the object is very small, especially when it is microscopically small.

He also stated, "Photogrammetry can be useful only if direct measurement is impossible, impractical or uneconomical".

Photogrammetry has numerous positive attributes in Architectural survey.[2]

It provides a homogeneous level of recording a whole façade or structure, being largely independent of the level of detail on the façade.

- It provides definable accuracy across a whole façade. Indeed the absolute accuracy can be very high, although at cost.
- The application involves little site disruption.
- Results can be provided rapidly.
- The method is generally much safer than methods of hand survey, due to its non contact nature.
- Direct capture of digital data is ideal for input to CAD systems.
- It allows for the direct production of the three dimensional data.
- The stereo photography is an extremely valuable archival resource in its own right, and gives the possibility of future assessment.

However a matter of great importance is to recognize the limitations of the photogrammetric product.

- It is a complex technique, requiring the input of specialists. As such, it is often not very practical to apply on relatively small tasks.
- The plot quality of line drawings is not always consistent, and some forms of architecture do not plot well.
- The standards of accuracy thoroughness produced can be very high, but may on occasion be too high for the project.
- The absolute cost in relation to the project may just be too great.
- It is not possible to apply Photogrammetric techniques on all occasions, or even to ensure a complete cover.
- Representation of badly eroded or sculptural features is often unsatisfactory with present technologies.

In addition, this photogrammetry can be used with other technologies in some cases, the barriers between the different surveying disciplines are being broken and integration of the technologies is taking place.

The most widespread use of the photogrammetric technique was for the representation of the facades or elevation of the historic buildings and structures. The most common product was the line drawing which delineates architectural form. Such surveys are needed by the various disciplines involved in building repair and conservation.

But this field is much changed from the early years of development. In common with other close range applications and indeed the whole of photogrammetric methodology, the introduction of computers has very much changed the ways in which the technique works and is applied.[3]

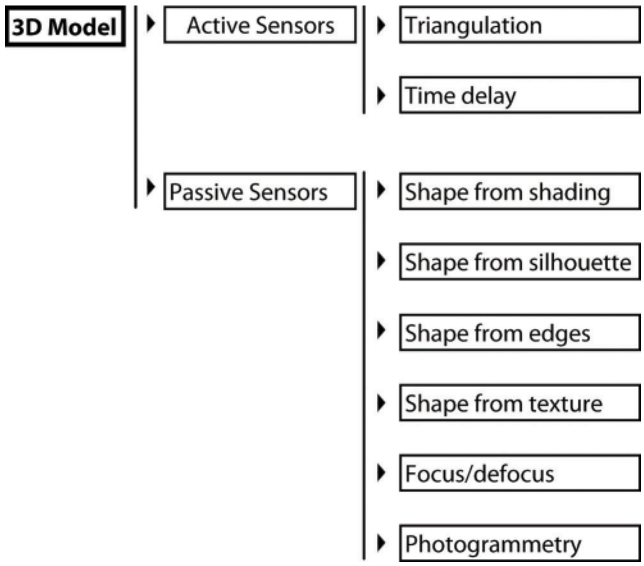
Image-based modelling (IBM): It is the widely used method for geometric surfaces of architectural objects[4] or for terrain and city modelling[5]. In most cases, the most impressive and accurate results remain are those that achieved with interactive approaches. Recently, image based models can be used also for virtual reality, tele-presence, digital cinematography and urban planning applications.

To frame the image-based modelling problem and this research field of study here is the classifications of three-dimensional shape acquisition systems for object measurement.

As a branch of many of 3D shape acquisition techniques, optical techniques (non-contact methods based on light waves) Methodologically fall into two distinct groups, an Active method (Projecting a light like 3D Laser scanners) and a passive one (just receive the natural light as photogrammetry).

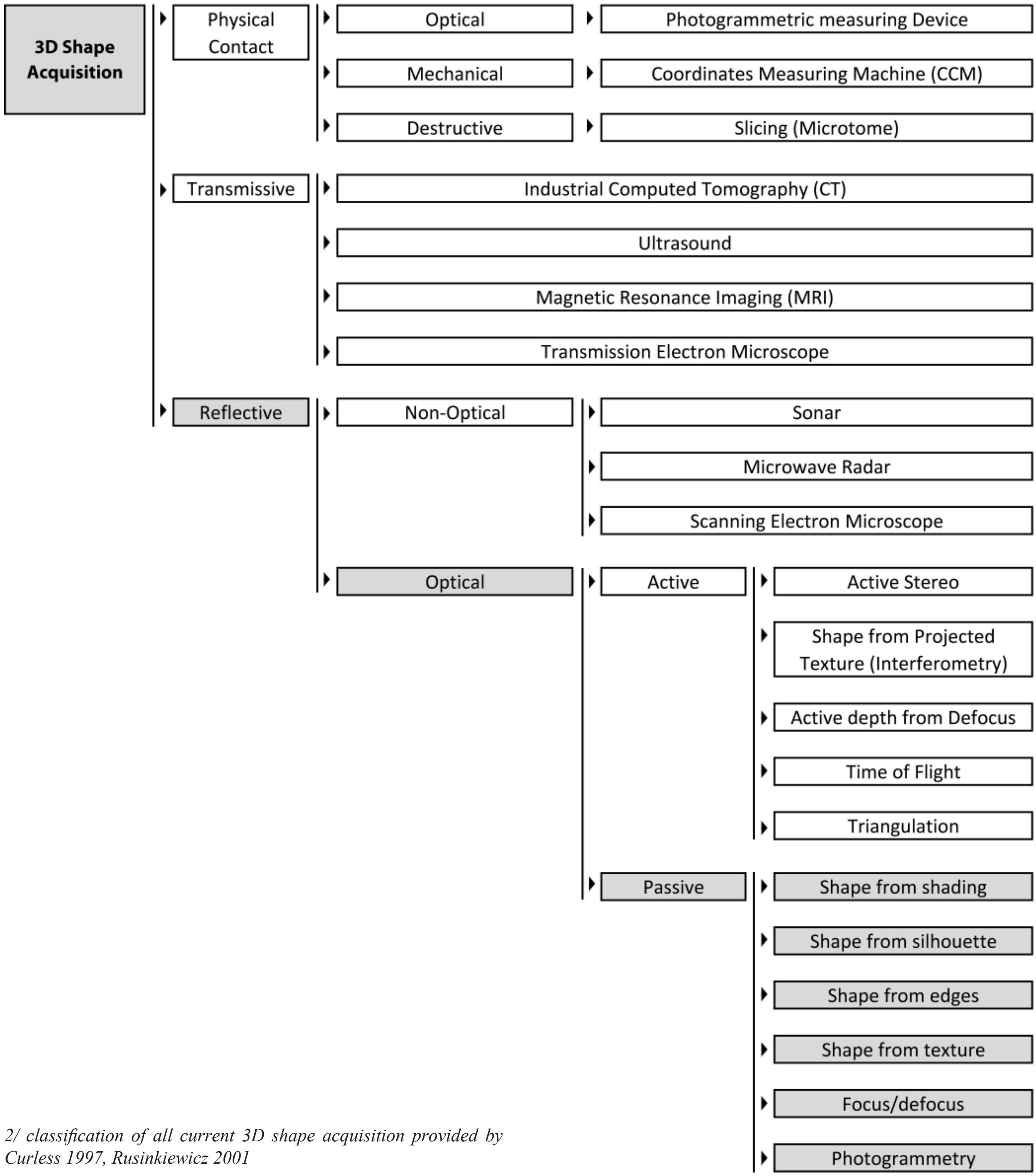
In active range scanning methods sensors determine depth either by measuring the time of flight or by triangulating the position of a projected laser pulse. The result is a point cloud which samples depths on a regular grid.

Passive methods could be automated techniques or not, do not contact the object being scanned physically and they require low cost equipment.



1/ Three-dimensional acquisition systems for object measurement using non-contact methods based on light waves according to El-Hakim and Remondino

Notes
1. J.G.Fryer, 1996
2. R.W.A.Dallas, 1996
3. R.W.A.Dallas, 1996
4. Streilein, 1994, Debevec et al. 1996, Van den Heuvel, 1999, El-Hakim, 2002
5. Gruen, 2000



2/ classification of all current 3D shape acquisition provided by Curless 1997, Rusinkiewicz 2001

Sintesi

"La fotogrammetria è la scienza e l'arte di determinare la misura e la forma degli oggetti dall'analisi di immagini registrate su un film o in un supporto elettronico. E' un ambito molto interessante anche perché l'operatore rimane comunque abbastanza vicino per interagire con l'ambiente fotografato". In questo modo la fotogrammetria è stata definita da J. Fryer; "interagire con l'ambiente fotografato". Anche se la maggior parte del lavoro nel rilievo fotogrammetrico deve essere eseguito in laboratorio, lontano da questo ambiente, permane nella fotografia, oltre alle informazioni di tipo tecnico, sempre un lato artistico attraverso cui interagire con l'ambiente fotografato.

Nel 1962 E.H.Thompson ha dichiarato che la fotogrammetria si rivela in molti casi uno strumento particolarmente molto utile. Quando l'oggetto fotografato è inaccessibile; quando l'oggetto da rilevare non è stabile e serve rilevarlo in un certo momento; quando non sono definite preventivamente tutte le misure da prendere nel rilievo; per rilevare i contorni o quando l'oggetto è troppo piccolo per cui si può rilevarlo usando le foto da microscopio; o anche quando, semplicemente, non è pratico il rilievo diretto.

Al pari di altri metodi di rilievo indiretto anche la fotogrammetria presenta vantaggi e limiti che occorre conoscere per progettare ed eseguire un rilievo che soddisfi le aspettative nei risultati. Secondo R. Dallas nel 1996 la fotogrammetria ha il vantaggio di produrre un modello omogeneo per il livello di dettaglio e di accuratezza; si basa su strumenti e tecniche maneggevoli e poco invasive sul campo; i risultati si ottengono velocemente; è una tecnica sicura essendo non a contatto con l'oggetto rilevato; l'immagine digitale può essere facilmente importata nei sistemi CAD; permette una produzione di modelli 3D diretta; le foto stereoscopiche sono una risorsa di archiviazione molto importante. Di contro però la fotogrammetria è una tecnica basata su procedure interne a volte complesse; non tutte le forme possono essere rilevate con la stessa precisione; per un rilievo di altissima precisione può essere anche costosa; non può essere applicata in tutti i tipi di rilievo; per il rilievo di certi tipi di superfici a prevalente carattere scultoreo e per le stesse sculture le applicazioni restituiscono dati ed informazioni non ancora soddisfacenti.

Questa disciplina, nata alla fine dell'800, ha subìto diversi cambiamenti nel tempo sia negli aspetti metodologici che applicativi; come molte altre discipline scientifiche, anche la fotogrammetria, con l'avvento dell'era digitale ha aggiornato le proprie procedure con sviluppi ulteriori indotti dalla potenza di calcolo del computer nell'automatizzare i diversi processi.

La modellazione basata su immagini si è molto diffusa nel campo dell'architettura per essere poi utilizzata in tanti campi affini dal cinema alla progettazione urbana.

Le tecniche di rilievo che si basano sull'immagine e sulla irradiazione della luce, cioè tutte quelle tecniche che fanno capo ai principi dell'ottica, hanno ciascuna delle specificità ma anche molti aspetti in comune. Per inquadrare il campo di studio di questa ricerca è stato definito il percorso dentro una classificazione di tutte le tecniche di acquisizione di informazioni tridimensionali di Curless e Rusinkiewicz, e questo percorso definisce le tecniche della modellazione a base di immagini come una tecnica riflessiva ottica passiva. A differenza delle tecniche fisiche e trasmissive, delle tecniche non ottiche come il radar e il sonar e delle tecniche ottiche attive in cui si proietta una luce come immagine (rete o retta) e si rileva la luce riflessa. Nel nostro campo, completamente passivo, si stanno sviluppando diverse tecniche di cui abbiamo sintetizzato i concetti principali.

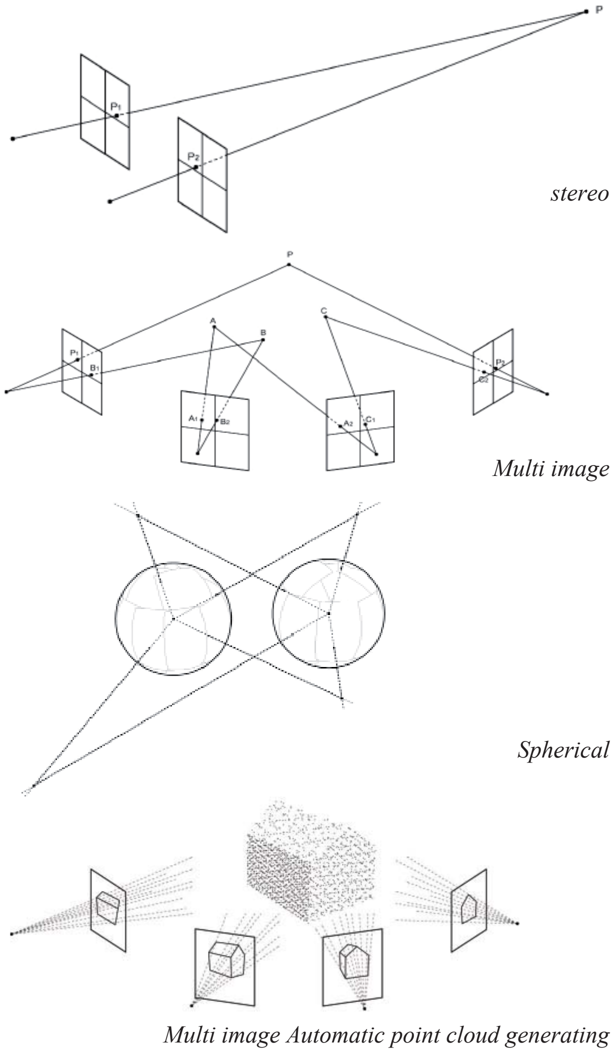
Wissam Wahbeh

II. Fundamentals

II.1. General classification by fundamentals

Technological devices may come and go, but for the scientist (and part artists) working in photogrammetry, success will only be achieved from a thorough understanding of the principles of Euclid .
With computer advancement, the photogrammetric field was changed in techniques and applications during the early years of its development. but the fundamentals remain the same. The projective geometry and epipolar geometry are always the base of all photogrammetric techniques. Whereas the close range of the photogrammetry becomes morve common with the digital photographing.
The success of the digital close range photogrammetric systems depends on its ability to automatically process image of varying complexity. The photogrammetric or vision processing consists of converting an iconic representation of an object (raster image, unstructured information) into a symbolic representation (vector and attribute data in structured form)[1].

Recently Photogrammetry could be divided into two categories:
1. **The non automated photogrammetry** could be divided into (a) stereo photogrammetry, which uses two photos and it is the only stereoscopic vision from all and, (b) Multi-image photogrammetry is multi-photos and spherical photogrammetry, which uses the panoramic photos as a virtual Theodolite.
2. **The automated Photogrammetry** which uses efficient and stable algorithm for the automatic extraction of feature points and the automatic determination of correspondences in images (homologous point matching), then with an automatic triangulation process it can generate a point cloud.
Nowadays, a full manual or a full automated photogrammetric survey is not a practice but a good trade-off between what is automatic and what is manual, it is to find the type of surveys depends on the aim of it such as input data, time, costs and many other aspects.

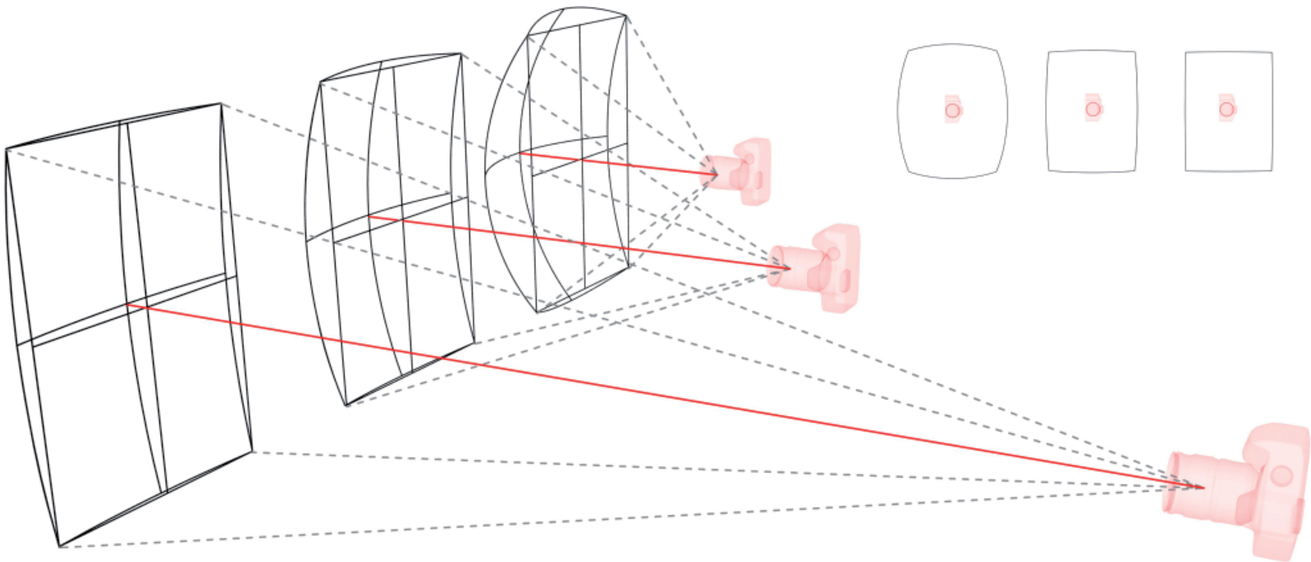


1/ photogrammetry techniques

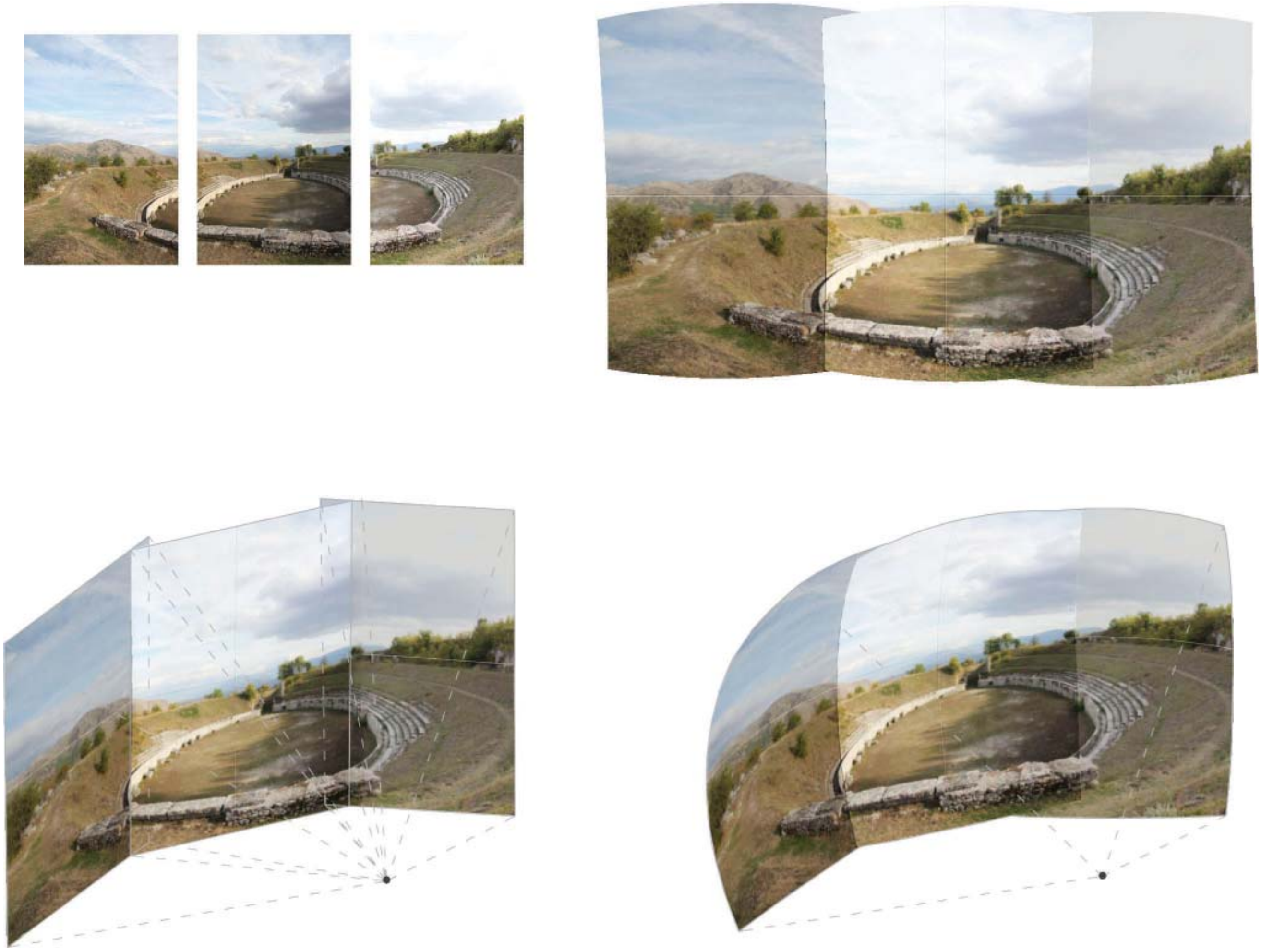
II.2. Panorama photographs fundamentals

The spherical panoramic photo is an exclusive outcome of the digital image. It has been developed by R. Szeliski in 1994 for the Apple Computers. Then, many stitching software came out to combine panoramas by registration, calibration and blending images.

Panoramas could be taken by using a panoramic camera or panoramic lenses, but these kinds of cameras have many limitations, especially the resolution, which is limited to the camera sensor resolution but, in case of multi-image panorama the resolution is unlimited, it depends on the focal length of the used lens. In addition, putting into consideration the economic and practice benefit in using the commercial amateur reflex camera to produce the panoramic photograph, that could be done by acquiring individual photos sequences and overlap those photos by certain percentage while rotating the camera around the "no-parallax" point of the lens by using a tripod and panoramic head. The pictures are stitched to form a panoramic image through stitching software. First of all, the flat image is projected to a spherical image using the focal length as a radius then, this surface will be developed flat as one of the projection types (spherical, cylindrical, etc.) to a panorama. Afterwards the software can define the overlapping edges (in automatic or manual way). To position the images in the overall Panorama that creates the multi-image panorama, usually software or plug-ins can calculate the calibration parameters of the camera when a 360° panorama is photographed. The panorama could be 360° panorama or less (just a portion). Nevertheless, the calibration parameters could be used in panoramas smaller that 360° after the first calibration.



2/ The relation between the focal length and the image projection



3/ Images Spherical projection for a panoramic stiching.

II.2.1. Stitching Process

Stitching algorithms have been used for decades to create the high resolution photo-mosaics to produce digital maps and satellite photos, with today's digital cameras it can be used to create beautiful high-resolution panorama images.

The major difference between options in the stitching software is in the way they choose to address the trade off between automation and flexibility. Generally speaking, fully customized stitching software will always achieve better quality than automated packages, but this may also result in being overly technical or time consuming.[3]

Software aligns Images using one of two methods, the Direct method or the Feature-based registration. In the direct it has to wrap or shift images relatively to each other and to look at how much the pixels agree, as opposed in the Feature-based method. This approach is to first extract distinctive features from each image to match individual features to establish a global correspondence. Early feature-based methods seemed to get confused in regions that were either too textured or not textured enough, but today feature detection and matching schemes are remarkable robust and most of stitching software use this method.

According to M. Brown and D. Lowe, Feature-based automatic panorama stitching algorithm follows these steps:
Input: unordered images

- Extract features from all images
- Find nearest-neighbours for each feature
- For each image:
    - Select candidate matching images that have the most feature matches to this image
    - Find geometrically consistent feature matches for the homography between pairs of images
    - Verify image matches by using the probabilistic model
- Find connected components of image matches
- For each connected component:
    - Perform bundle adjustment to solve for the rotations and focal length of all cameras
    - Render panorama using multi-band blending

Output: Panoramic image.[4]

II.2.2. Panoramic image Projections

To prepare panorama, it's significant to understand how a spherical panorama could be projected to a 2D image. The representation of a spherical surface in 2D map is a well studied problem especially to represent the map of the earth. There are several types of projections and several approaches attempt to classify projections.

The followings are some of the most used projections supported by generic photo stitching programs, in addition to the properties and the limitations of those projections;

Rectilinear: Rectilinear projection has the unique property of preserving all straight lines: any line that is straight in real world is displayed as a straight line in the panorama. So in theory a rectilinear projection is an ideal perspective (without distortions);

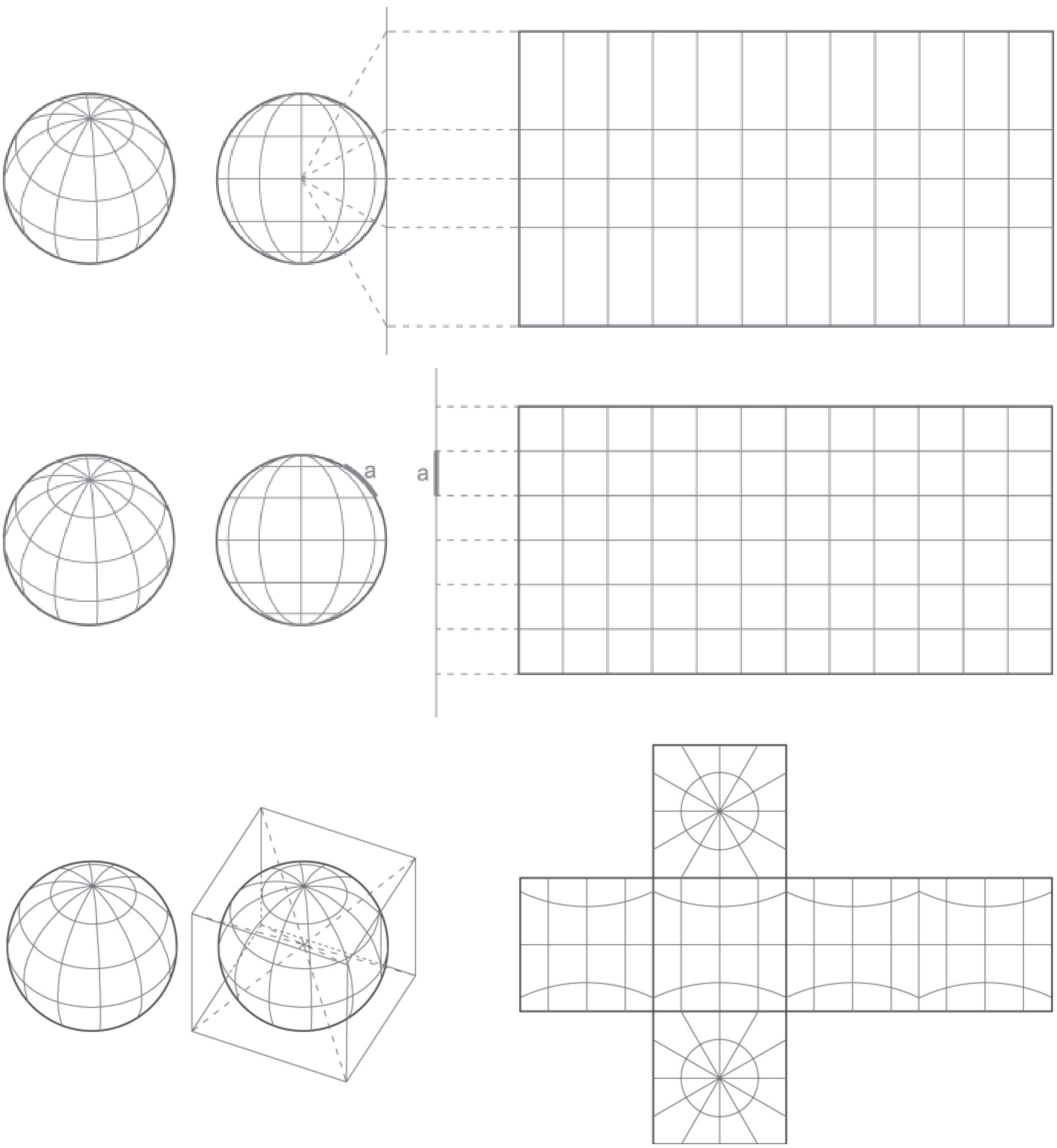
Cylindrical: In the cylindrical projection, vertical scale increases very fast far from the map's centreline, even faster than in Mercator's projection;

Mercator: Similar to Cylindrical, but with less 'stretching' at the top and the bottom at higher vertical field of views. A revolutionary invention of the cartographer Gerhard Kremer became famous with the Latinized name "Gerardus Mercator". This projection is widely used for navigation charts, because any straight line on a Mercator-projection map is a line of constant true bearing that enables a navigator to plot a straight-line course. It is less practical for world maps because the scale is distorted; areas farther away from the equator appear disproportionately large.

Equirectangular: This is a latitude/longitude projection of the panoramic sphere, among the oldest projections; it is invented by Marinus of Tyre around 100 AD and maybe the simplest of those projections. The poles of the sphere are represented by two segments of equal length to the circumference of the sphere, and therefore equator and poles have the same length. The height of the map is equal to the development of a meridian.

Cubic: The projection of the sphere to six flat rectilinear projections as faces of a cube cover front, right, back, left, nadir and zenith, the field of view of each of each is 90°x90°. It is useful in many cases because it covers 360° and for every rectilinear projection straight lines stays straight.

The Equirectangular projection is our field of interest as it is the projection to be used in the 3D graphic software to project spherical maps, and this projection is the one used in the orientation software as we will find later in the orientation chapter.



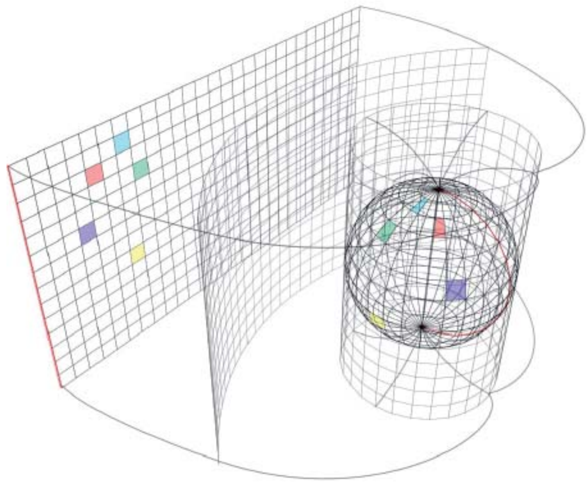
Cylindrical projection.

Equirectangular projection.

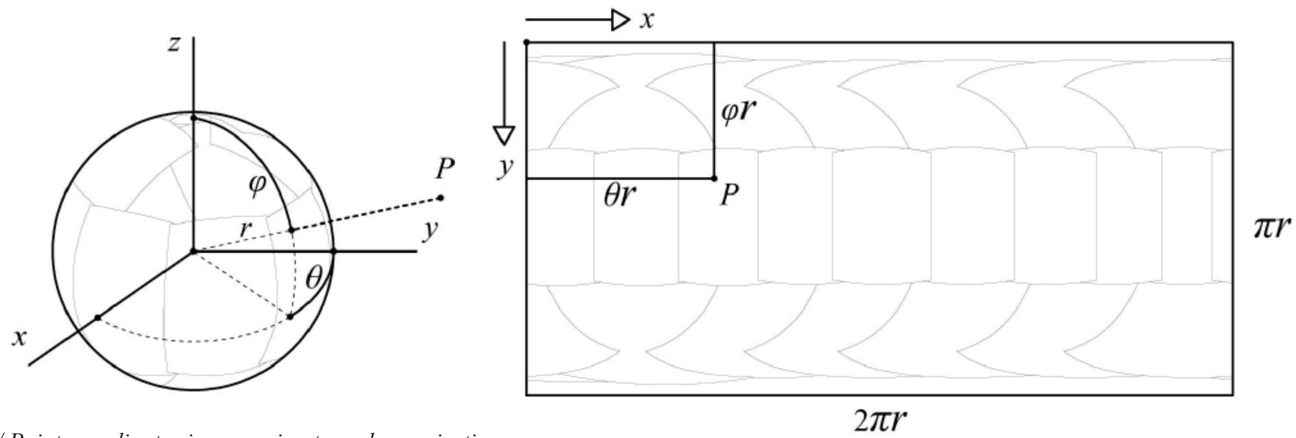
Cubic projection.

4/ Some projections types

Such representation is not conform, nor equivalent. As said before, the poles of the sphere are represented by two segments of equal length to the circumference of the sphere, and therefore equator and poles have the same length. The height of the map is equal to the development of a meridian. From such representation the angles of direction of the projective line can be drawn. In fact, knowing the extension, the radius of the generating sphere is derived.[5]



5/ Equirectangular projection



6/ Point coordinates in an equirectangular projection

Projection type	Horizontal Straight lines	Vertical Straight lines	Diagonal Straight lines	Horizontal angle max.	Vertical angle max.
Rectilinear	yes	yes	Yes	≈120°	≈120°
Vedutismo	no	no	Yes	360°	180°
Cylindrical	No	Yes	No	360°	≈120°
Mercator	No	Yes	No	360°	≈150°
Equirectangular	No	Yes	No	360°	180°
Cubic	Yes*	Yes*	Yes*	360°	180°
Circular/Fisheye	No	No	No	360°	360°

≈x° means that it can be bigger but it's a practical limit of about x degrees
** For every single face of the cube*

II.3. Digital Image formats

As soon as cameras which employed electronic sensors in the focal plane were first developed, they were used by photogrammetrists to record and measure. Since then computer technology has increased at a very rapid pace and the capabilities of digital system have been extended to the point where they are poised to replace analogue images in many fields, particularly for close range and satellite photogrammetry.

In close range work the flexibility and low cost of cameras has been a major driving force in the acceptance of such digital systems.[6]
There are many formats of image but the most used formats are JPEG, TIFF and RAW

JPEG (Joint Photographic Experts Group): The JPEG file format is the largely used file formats for photographic images. It is a compressed file format. With JPEG generally a file could be achieved with a 1/10th the size of an equivalent TIFF file without a noticeable loss of quality. For most surveys the JPEG format is an excellent option. With the right settings excellent results could be achieved, but overall the RAW format is better. Some high-end digital cameras have the ability to simultaneously produce a RAW and JPEG file, which is useful if enough memory is available.
TIFF (Tagged Image File Format) is mostly referred to as the industry standard for digital images. TIFF files can be compressed or uncompressed and come in a PC and a Mac version, both of which can be accessed on either platform. You can view and manipulate TIFF files on all computer platforms and in almost any image editing software.
RAW file is the untouched file which comes straight from the camera's CCD or CMOS sensor. Each camera manufacturer has its own version of the RAW format. Canon digital cameras produce CRF (Canon Raw Files), Nikon cameras produce NEF (Nikon Electronic Files) and many properties could be modified in post production as exposure, white balance, which can otherwise be extremely difficult with TIFF and JPEGs. It is very useful to use this format especially in particular light conditions as very contrasted photos (one part in the sunlight and another in the shadow) or in internal dark spaces with very bright windows. In many cases like those, it is possible to avoid losing data using the RAW image file format.

The Image file also contains metadata (EXIF) which is text based information stored within an image about the photograph, such as the camera used, lens, exposure, aperture and sometimes location data if the camera has GPS built-in. This information, as lens focal length, is useful for projecting the photo to create a panorama when no calibration parameters are available.[7]

Notes:
1. J.G.Fryer «Close Range Photogrammetry and Machine Vision» 1996
2. A. Gruen «Development of Digital Methodology and Systems» 1996
3. R. Szeliski «Image Alignment and Stitching» 2005
4. M. Brown, D. G. Lowe «Automatic Panoramic Image Stitching using Invariant Features» 2007
5. G. Fangi «The Multi-Image Spherical Panoramas as a Tool for Architectural Survey», 2007
6. I. J. Dowman «Fundamentals of digital Photogrammetry», 1996
7. Langford's Basic Photography, 2010

Sintesi

I dispositivi cambiano nel tempo ma l'utilizzo della fotogrammetria non può prescindere dalla conoscenza dei principi dell'ottica euclidea che rimangono invariati alla base di questo procedimento. Con lo sviluppo del computer il cambiamento ha investito principalmente la tecnica e, di conseguenza, sono cambiate le applicazioni che da questa scaturiscono ma i fondamenti sono sempre quelli, partendo appunto da Euclide per arrivare, in generale, alla geometria proiettiva ed epipolare.
Attualmente la fotogrammetria può essere divisa in due categorie. La prima è la fotogrammetria non automatizzata che è a sua volta suddivisa in quella stereo (l'unica con una visione stereoscopica) e quella multi immagine monoscopica. In quest'ultimo caso rientra come applicazione specifica quella fotogrammetria, cosiddetta sferica, che fa cioè uso di panorami sferici.
La seconda è quella automatizzata, sia stereo che monoscopica, che usa algoritmi per trovare i punti omologhi tra le diverse immagini e può produrre una nuvola di punti sul principio della triangolazione automatica.
I fondamenti della foto panoramica.
La foto panoramica è una specificità dell'immagine digitale. E' stata sviluppata da R. Szeliski nel 1994 per conto di Apple computers e da allora sono stati sviluppati molti software di Stitching cioè di quella procedura in grado di riconoscere automaticamente punti omologhi nella sovrapposizione di due immagini contigue, che è il principio su cui si basa la realizzazione di un panorama multi-immagine. Si può usare la macchina fotografica panoramica o una lente panoramica per produrre una foto panoramica multi-immagine ma questi tipi di macchine fotografiche hanno il limite della risoluzione del sensore mentre nel caso della foto panoramica si può aumentare la risoluzione aumentando la lunghezza focale della lente, e quindi la quantità di foto singole. In più va considerato l'aspetto economico nell'uso di una macchina fotografica commerciale, la cui tecnologia è in continuo cambiamento, per produrre la foto panoramica di alta risoluzione. Tale foto può essere prodotta dal montaggio di tante foto singole scattate dallo stesso punto intorno a cui ruota la macchina fotografica che si chiama il punto del "no-parallasse". Questa rotazione può essere possibile usando i tre piedi e una testa panoramica che permettono di ruotare la macchina fotografica in orizzontale e in verticale intorno a questo punto che si trova sull'asse ottico. Successivamente con i software di stitching si possono unire queste immagini in una immagine più grande per ottenere la foto panoramica sulla base di diversi tipi di proiezione: sferica, cilindrica, cubica.
Il software di stitching prevede una serie di passaggi. per montare la foto panoramica e poi rappresentarla in 2D in una delle proiezioni disponibili. Le più usate tra queste proiezioni sono la proiezione rettilineare, la cilindrica, di Mercator, la equirettangolare e la proiezione cubica. La proiezione utilizzata ed indagata in questa ricerca è quella equirettangolare. I poli della sfera vengono rappresentati con due segmenti di lunghezza uguale alla circonferenza della sfera e, quindi, equatore e poli hanno la stessa lunghezza. L'altezza della mappa è pari allo sviluppo di un meridiano e vale dunque la metà della larghezza, cioè metà della circonferenza. Per mezzo di tale rappresentazione si possono ricavare gli angoli di direzione della retta proiettiva per ciascun punto immagine.
L immagine digitale può essere salvata in tanti formati ma quelli più diffusi sono i JPEG, TIFF, e il RAW. Il formato più conveniente è quello JPEG da utilizzare nelle applicazioni fotogrammetriche essendo compresso, quindi molto leggero rispetto al TIFF. Il formato RAW, che è un formato nuovo in cui la macchina fotografica salva l'immagine, contiene i dati grezzi e non compressi, così come sono stati generati dal sensore (o con una minima elaborazione). In questo senso un'immagine salvata in formato RAW può essere vista come l'equivalente digitale del negativo della pellicola, ed è molto importante per l'elaborazione dopo lo scatto perché c'è la possibilità di evitare la perdita dei dati causati da un tempo di esposizione sbagliato o da fattori esterni non previsti al momento dello scatto; può essere utile ad esempio quando è difficile ripetere il servizio fotografico dell'oggetto.

III. Passive Close range techniques of the Digital Photogrammetry

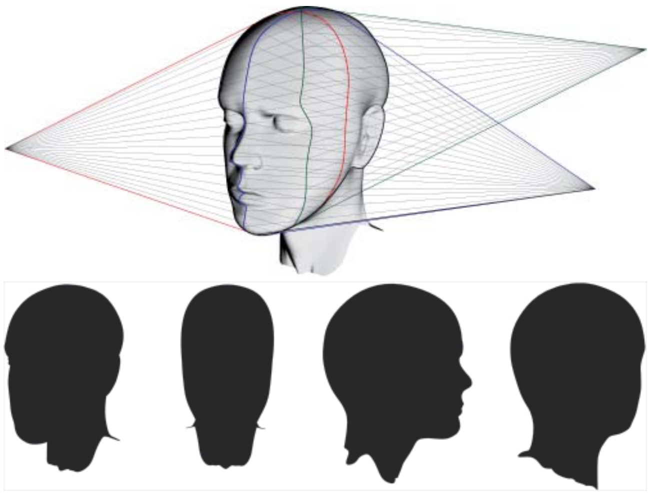
Various digital techniques are being developed to retrieve the three-dimensional information from two-dimensional images; those techniques are also called 3D imaging or Depth imaging

This chapter is a short introduction of some most interesting passive techniques (without any light or texture projection on the surveyed object) which fall into two categories. They can either retrieve only the depth of a surface in 3D space, as shape from focus/defocus and shape from shading, or allow for a full reconstruction of volumetric objects, as shape from silhouettes, motion, stereo and spherical photogrammetry.
The Digital Shape from stereo technique is nothing more than the Digital form of the analytical stereoplotter. The techniques that born with the new digital photographing and automatism, when the possibility of using the computer are various and being developed in computer graphics and engineering laboratories as shapes from focus and shading, but for some of them we can already find many commercial software as shape from silhouettes.
It is noticeable that triangulation is constitutes one of the basic techniques in geodesy and cartography. It is at the heart of a surprisingly wide variety of digital photogrammetry techniques like stereo, motion, focus and spherical photogrammetry. However silhouettes and shading techniques are based on different concepts which are useful in many cases.

Those techniques are:
Shape from silhouettes
Shape from stereo
Shape from focus
Shape from shading
Shape from motion
Spherical Photogrammetry

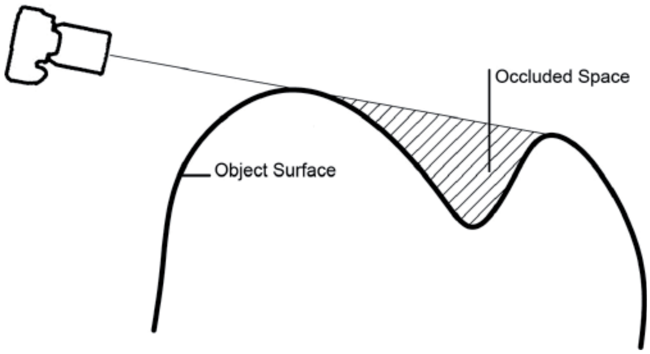
III.1. Shape from silhouettes (visual Hull)

The earliest attempts in reconstruction of 3D models from photos used the silhouettes of objects as sources of shape information. A 2D silhouette is the set of close contours that outline the projection of the object onto the image plane. Segmentation of the silhouettes from the rest of the image and combination with silhouettes taken from different views provides a strong cue for image understanding.
Typically, shape from silhouettes techniques start with an acquisition step where images of the object are taken from different locations around it. For each of these images the object silhouette is extracted using simple differencing or blue screen segmentation techniques. The computed silhouettes for every image along with the centre of the corresponding camera is then used to define a volume which if back projected to 3D space can be assumed to bound the object.
The intersection of these volumes associated with the set of acquired images yields a reasonable approximation of the real object. This intersection volume has been named the



1/ Silhouettes of a head model

visual hull by A. Laurentini, and described as the maximal object that gives the same silhouette with the real object from any possible viewpoint.
A property of the visual hull is that as the number of images used increases, its fit to the actual object volume and becomes tighter.
However, this number can be proved to be unbound for reconstruction of general polyhedral objects. Even if the acquisition of an infinite number of images was possible, silhouettes can be insufficient clues for fully compute the shape of non convex objects. The silhouette methodology will fail when there are concavities in the object geometry that cannot be resolved from any viewpoint unless additional information is provided.
The type of the object is not the only parameter affecting its corresponding visual hull form. The positioning of the cameras can significantly influence the computed model especially when the number of acquisition locations is small.
Shape from silhouettes is a particularly good approach if only a crude model of the real world is required. The methodology is intuitive and easy to implement and this is the main reason that systems generating and replaying 3D digital video as well as commercial object modelling packages are based on it. Nevertheless, reconstruction is restricted to small solid objects for which their whole geometry can be captured from photos around them and thus are not applicable to scene modelling.

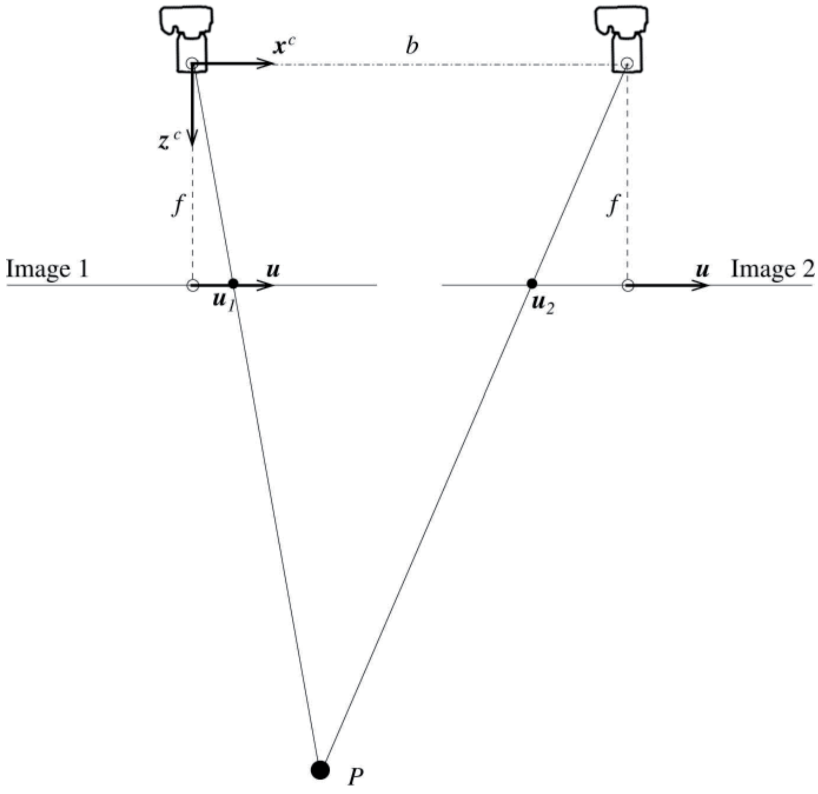


2/ It is not possible to get the silhouettes of the concave surfaces so it cannot be modelled using this technique


3/ shape from Silhouette model using 2, 3, 4, 6, 9, 20 photos with the software STRATA 3D

III.2. Shape from stereo

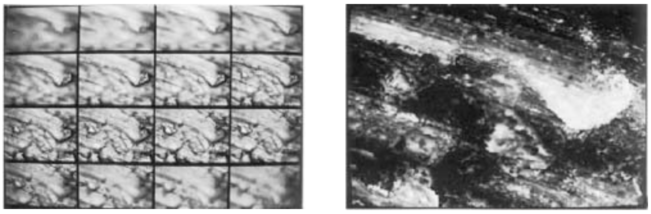
The basic principle of stereo vision is very easy to understand. Assume the simplified configuration of two parallel looking 1D cameras with identical internal parameters. Furthermore, the basis, i.e., the straight line connecting the two optical centers of the two cameras, is assumed to coincide with the x-axis of the first camera.
The way in which stereo determines the position in space of a pair of image points is triangulation, and many techniques could be considered a shape from stereo technique and they could be classified in two groups the first one makes use of Stereo 3D vision as Z-Map software with StereoPro system, and the second group with mono vision as PhotoModeler and ImageModeler.
Stereo vision refers to the ability to acquire information on the 3D structure and distance of a scene from two or more images taken from different viewpoints.
Some automated stereo systems determine which point in one image corresponds to a point in another image (Correspondence Problem).A problem is that some parts of the scene are visible in a subset of the images only. Therefore, a stereo system must also be able to decide the image parts that should not be matched.
Correspondence algorithms in the automated systems could be classified into correlation-based and feature-based algorithms. In correlation-based algorithms, the elements to match are image windows of fixed size, and the similarity criterion is a measure of the correlation between the windows in the two images. These algorithms typically give dense measurements of depth.
On the other hand, feature-based methods use a set of features to find correspondence in two images. The distance between feature descriptors is measured with the numerical and symbolical properties of the features. Corresponding elements are given by the most similar feature pair. The feature-based approaches typically give 3D depth only sparsely at the corresponding feature points.[1]



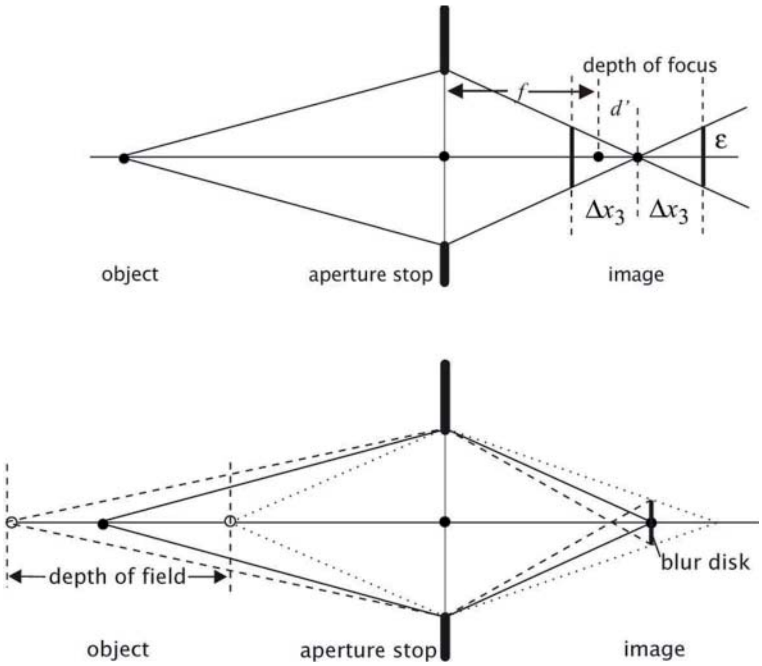
4/ Stereo photogrammerty triangulation

III.3. shape from focus

Shape From Focus (SFF) is another technique for depth estimation. An object is only imaged without blurring if it is within the depth of field. At first glance, this does not look like a depth from triangulation technique. However, it has exactly the same geometry as the triangulation technique. The only difference is that instead of two, multiple rays are involved and the radius of the blurred disk replaces the disparity. The triangulation base corresponds to the diameter of the optics. Thus depth from focus techniques shares all the basic properties of a triangulation technique. For given optics, the resolution decreases with the square of the distance. The shape from focus method presented here uses different focus levels to obtain a sequence of object images. Algorithms as the sum-modified-Laplacian (SML) operator is developed to provide local measures of the quality of image focus. The operator is applied to the image sequence to determine a set of focus measures at each image point. A depth estimation algorithm interpolates a small number of focus measure values to obtain accurate depth estimates. A fully automated shape from focus system has been implemented using an optical microscope and tested on a variety of industrial samples.[2]



5/ Focus series with 16 images of a metallic surface taken with depth distances of 2 µm; the focal plane becomes deeper from left to right and from top to bottom. b Depth map computed from the focus series. Depth is coded by intensity. Objects closer to the observer are shown brighter.
by J. Steurer, H. Giebel, and W. Altner 1986



6/ Illustration of the depth of focus and the depth of field with an on-axis point object.

III.4. Shape from shading

The shape of surfaces can also be determined from the local orientation of the surface elements. This is expressed mathematically by the surface normal. Then, of course, the absolute depth of surface is lost, but the depth profile can be computed by integrating the surface inclination. The surface normal can be inferred from the shading because the radiance of a surface depends on the angle of incidence of the illumination source.[3]

The first shape-from-shading technique was developed by Horn in the early 1970s.

The first mention of 3D reconstruction using shape from shading is due to the Dutch astronomer Van Diggelen. The first resolution was suggested by Rindeisch, who demonstrated that, if the photometric behaviour of a surface follows certain properties, then the shape can be expressed as an integral, along a set of convergent straight lines. He implemented this computation on images of the Moon, claiming that its surface verifies the necessary photometric properties reasonably well.

Later, Horn suggested calling this problem «shape from shading», and showed that the resolution proposed by Rindeisch in a particular case could be generalized, while still using the characteristic strips expansion.

The gray level at a pixel in the image depends on the light source location, and the surface normal. In SFS is given a gray level image, the aim is to recover the light source and a surface normal at each pixel in the image. The illuminations from different directions are required to solve the shape from shading problem in a unique way. This technique is known as photometric stereo. It could be considered a passive technique if the light is natural and an active one if the light is projected by the operator.

The main disadvantages of this method are:

- The Shadow areas of the object cannot be recovered reliably because of poor intensity information;
- The method cannot be applied to general objects because it assumes that the entire surface of an object has the same reflectance (Lambertian reflectance surface) which doesn't depend on the viewing angle;
- The method is very sensitive to noise.

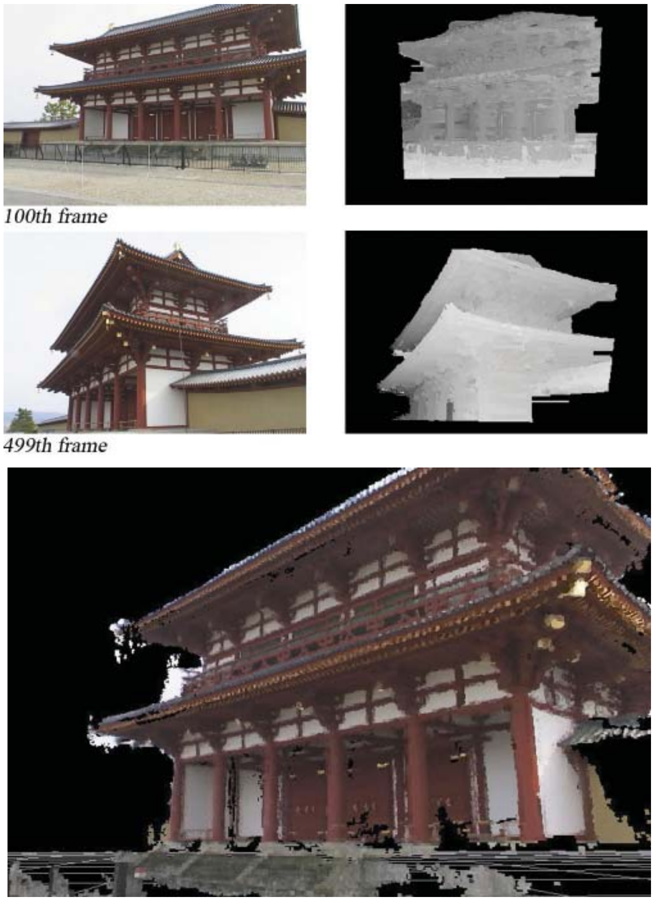
7/ Displacement map obtained from different directions illumination by shape from shading. Machine vision lab, Swiss Federal institute of technology

III.5. Shape from motion

In this section we are interested in extracting the shape of a scene from the spatial and temporal changes occurring in an image sequence. This technique exploits the relative motion between camera and scene. Similar to the stereo technique, the process can be divided into the sub processes finding of correspondence from consecutive frames and reconstruction of the scene. Although, there are some important differences, the differences between consecutive frames are, on average, much smaller than those of typical stereo pairs, because images sequences are sampled at high rates. Unlike stereo, in motion the relative 3D displacement between the viewing camera and the scene is not necessarily caused by a single 3D transformation.

Regarding correspondence, the fact that motion sequences provide many closely sampled frames for analysis is an advantage. Firstly, tracking techniques, which exploit the past history of the motion to predict disparities in the next frame, can be used. Secondly, the correspondence problem can also be cast as the problem of estimating the apparent motion of the image brightness pattern (optical flow). Two kinds of methods are commonly used to compute the correspondence. Differential methods use estimates of time derivatives and require therefore image sequences sampled closely. This method is computed at each image pixel and leads to dense measurements. Matching methods use Kalman filtering to match and track efficiently sparse image features over time. This method is computed only at a subset of image points and produces sparse measurements.

Unlike correspondence, reconstruction is more difficult in motion than in stereo. Frame-by-frame recovery of motion and structure turns out to be more sensitive to noise. The reason that the baseline between consecutive frames is very small. For reconstruction we can use the motion field of the image sequence. The motion field is the projection of the 3D velocity field on the image plane. One way to acquire the 3D data is to determine the direction of translation through approximate motion parallax. Afterwards, a least-squares approximation of the rotational component of the optical flow could be determined and use it in the motion field equations to compute depth.

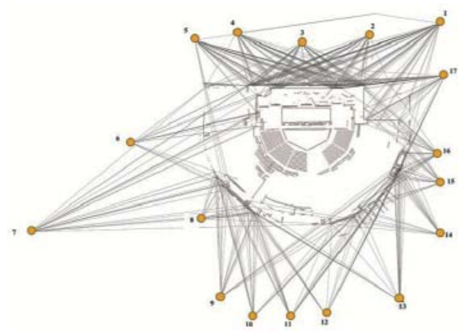


8/ Point cloud of an Outdoor Scene by Multi-baseline Stereo using a Long Sequence of Images by Tomokazu Sato, Masayuki Kanbara, Naokazu Yokoya and Haruo Takemura, Nara Institute of Science and Technology in Japan

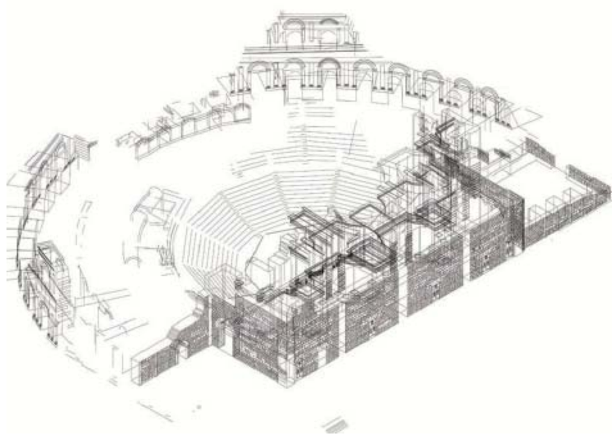
III.6. Spherical Photogrammetry

Is a proposed technique been developed in the Polytechnic University of Marche by Prof. Eng. Gabriele Fangi.
This technique is based on the multi-image spherical panoramas. The spherical panorama can be considered as the analogical recording of the angular observations of a Theodolite that having its centre in the centre of panorama.
The virtual Theodolite triangulation is used to find the position of the points and lines in the virtual space, then the CAD software integration required to complete the plot.
This technique, according to Fangi, is a solution when the laser scanner is not practical to use and it could function as the integration of laser scanning, but not as alternative; it is a low- cost, low weight and very fast method. As a demonstrative test these two architectural projects are presented here. A geometrical survey can even be done with simple and low-cost instruments in a quick manner. They have been performed with Spherical Photogrammetry».[4]

The benefits of this technique are:
- High resolution
- Low cost
- Field of view up to 360°
- Ideal field booklet which records all possible angular directions from a point
- Quick method
- No distortions
- The possibility of using a normal topographic software
- The possibility of combining with Theodolite data



9/ Panorama stations for a photogrammetric survey of a Roman theater Sabratha, Libya by Prof. Fangi, Polytechnic University of Marche



10/ The wire-frame of the plotting by C. Pisa

Notes
1. Banks, M. Bennamoun, K. Kubik, and P. Corke, 1999
2. S K Nayar, Y Nakagawa
3. Bernd Jaehne, Digital Image Processing, 2005
4. Gabriele Fangi, Spherical Photogrammetry for Cultural Heritage, 2010

Sintesi

Le tecniche cosiddette passive nella fotogrammetria sono diverse e in questo capitolo ne viene proposta una breve analisi e descrizione; almeno di quelle più importanti. Esse sono:
Shape from silhouettes
Shape from stereo
Shape from focus
Shape from shading
Shape from motion
Spherical photogrammetry
Si può osservare che alcune di queste tecniche si basano sul principio della triangolazione, come la tecnica stereo, motion, focus e anche la fotogrammetria sferica, mentre le altre si basano su principi di corrispondenza diversi come nel caso delle tecniche silhouettes e shading.
Shape from silhouettes (visual Hull) è una delle prime tecniche usate per la modellazione 3D. In questa tecnica dopo l'orientamento si crea il volume infinito chiamato dal prof. A. Laurentini (visual hull) creato dal raggio che parte dal centro di presa come generatrice e il contorno apparente dell'oggetto visto da quel centro come percorso e dall'intersezione si ricava il volume dell'oggetto modellato. Una proprietà di questa tecnica è che aumentando le prese fotografiche il volume si stringe per adattarsi meglio alla forma reale dell'oggetto modellato ma il limite di questa tecnica è che non si possono ricavare le superfici convesse perché non possono essere una parte del contorno apparente da alcun punto di vista.
Questa tecnica può essere applicata su oggetti piccoli su cui poter girare intorno ed è conveniente per oggetti con superfici lisce non convesse.
Nella tecnica "Shape from stereo", da una coppia di foto con viste tra loro parallele si può ricavare la profondità tramite la triangolazione e questa tecnica può essere utilizzata nella visione stereoscopica se c'è lo strumento di visualizzazione adatto come StereoPro system della Menci o nella visione monoscopica con un normale schermo di computer alternando la visione da una foto ad un'altra. In quest'ultimo caso si stanno sviluppando algoritmi per il riconoscimento dei punti omologhi anche in automatico.
"Shape from focus" è un'altra tecnica tramite cui si può rilevare la profondità da una seria di foto della stessa vista con un cambiamento studiato della messa a fuoco e con algoritmi specifici si può identificare la parte della superficie messa a fuoco in ogni immagine. La tecnica si basa sulla triangolazione per ricavare la profondità anche se a prima vista potrebbe non sembrare. La base della triangolazione da due foto in questo caso è riferita al raggio della lente usata e invece dello sfalsamento dell'immagine nel caso della triangolazione da due foto (quando la profondità non è esatta) qui c'è la parte sfocata della foto.
La tecnica "shape from shading" rileva l'andamento della superficie tramite il cambiamento del chiaroscuro della luce riflessa da una sorgente ed è una delle tecniche che non si basano sulla triangolazione e per questo, usando questa tecnica non si può ricavare la profondità assoluta dell'oggetto, ma solo l'orientamento relativo della normale della superficie rilevata. Le prime prove sono state fatte per costruire un modello della superficie della luna. Questa tecnica è limitata agli oggetti con riflettanza omogenea su tutta la superficie e non dipende dall'angolazione della luce. Le zone di ombra non danno nessuna informazione e questo metodo è troppo sensibile al rumore nell'immagine.
"Shape from motion" sfrutta il piccolo cambiamento tra una fotogramma e il successivo dentro un filmato per riconoscere facilmente lo spostamento di ogni punto dentro l'immagine e applicare una triangolazione automatica indicando un percorso di traslazione approssimativo all'inizio. Poi con il metodo dei minimi quadrati si può determinare la traslazione esatta per produrre una nuvola di punti. Anche questa tecnica è molto sensibile al rumore nella diaframma del video e ha una precisione relativamente bassa limitata alla risoluzione del filmato.
Nella fotogrammetria sferica la restituzione avviene per intersezione di due o più rette proiettive. I panorami vengono orientati come si orienta una stazione di teodolite (Fangi, 2007), cioè usando la condizione di complanarità per orientare un panorama rispetto ad un altro. In questo caso si stimano le coordinate modello di una serie di punti e si effettua la rototraslazione nel sistema di riferimento.

I modelli attigui possono essere concatenati.
Ove si accetti una precisione ridotta si può usare il normale software topografico, ovvero effettuare compensazioni combinate teodolite-panorami.
I vantaggi di questa tecnica consistono nel fatto che si ha a disposizione una specie di (pseudo) fotocamera ideale:
- Risoluzione molto elevata (es. 30000x15000 pixel)
- Costi molto bassi
- Angolo di campo fino a 360°
- Libretto di campagna ideale in cui sono registrate tutte le possibili direzioni angolari provenienti da un punto.
- Estrema velocità di esecuzione
- Nessuna distorsione
- Possibilità di usare normale software topografico
- Possibilità di effettuare compensazioni combinate teodolite-panorama.

IV. Camera Calibration

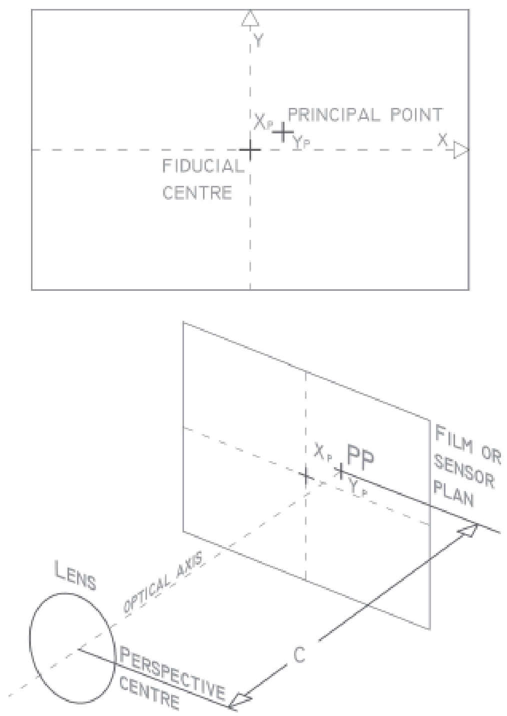
IV.1. Why to calibrate the camera

In order to satisfy the metric requirements of photogrammetric measurement, calibrated cameras are needed. Basically, a calibrated camera is one of which the values of principal distance, principal point offset, and lens distortion as a function of image point location are known.
The determination of calibration parameters in close-range photogrammetry could be said to have dramatically evolved in the early 1970s when laboratory camera calibration gave way to the concept of self calibration using multi-station photogrammetric bundle adjustment (Brown, 1971 and 1974; Kenefick et al., 1972).[1]
Camera calibration may have several objectives:[2]

- evaluation of the performance of the lens;
- evaluation of the stability of lens;
- determination of the optical and geometric parameters of lens;
- determination of the optical and geometric parameters of lens-camera system; or
- determination of the optical and geometric parameters of an imaging data acquisition system.

With a perfect lens system, light rays will pass from object space to image space and from a sharp image on the plane of focus according to the fundamental physical laws of optics. The reality of the imperfectly constructed lenses or complex system as wide angle and zoom lenses means that elementary formulae provide only a good first approximation. Aberration, or deviation from theoretically exact models, must be understood and considered by photogrammetrists, even though they may be ignored for applications requiring only a low accuracy.
Correcting distortions using the calibration parameters to produce a distortion-free photo is one of the Digital image specificities, by the invention of the digital camera we can produce with an acceptable approximation an ideal perspective from a photo using a generic camera and lens.

- The Parameters which are required to calibrate a camera are:
- The Radial distortion (lens distortion Parameter)
- Decentring distortion (lens distortion Parameter)
- Principal distance (Interior orientation Parameter)
- The principal distance of autocollimation (PPA) (Interior orientation Parameter) and,
- The offsets (xp, yp) from PPA to the centre of the fiducial axes (Interior orientation Parameter).



1/ Geometry of the image plan and interior orientation

IV.2. Calibration parameters

IV.2.1 The radial distortions

An image of a target is displaced radically either closer to or farther from the principal point then it has been radically distorted. The point of symmetry for radial distortion may not be exactly at the principal point, but it is usually so close that the principal point is adopted.

Gaussian radial distortion describes the magnitude of the radial distortion when the nominal principal distance is used as a basis for calculations, so the magnitude of these distortions varies with radial distance and may change with focusing (the various image scales)

Balanced radial distortion is the term used where the Gaussian curve has been mathematically transformed by shifting the principal distance by an amount Δc which has been chosen such that:

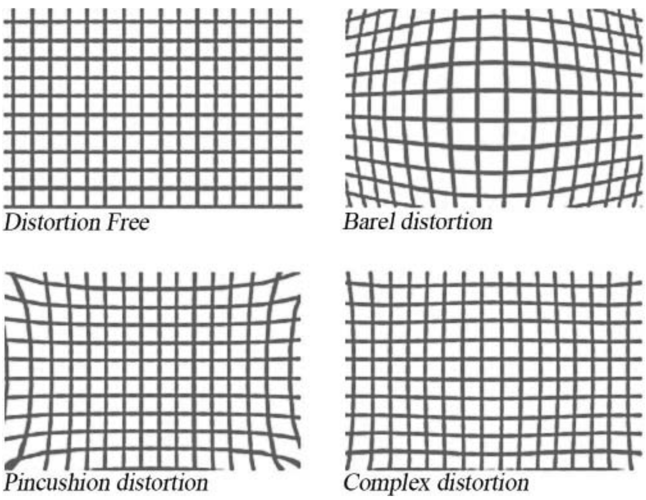
-the main value of the transformed distortion curve out to certain radial distance is zero

-the main square value of the distortion out to certain radial distance is minimum, or

-the minimum and the maximum value of distortion out to certain radial distance are equal.[3]

It is usually expressed as a polynomial function of the radial distance from the point of symmetry (usually coinciding with the PP):

$$\delta r = K_1 r^3 + K_2 r^5 + K_3 r^7, r^2 = (x - x_0)^2 + (y - y_0)^2$$



2/ Lens radial distortions

IV.2.2. Decentring distortion

All elements in a lens system ideally aligned at the time of manufacture, to be collinear to the optical axis of the entire lens system. Any vertical displacement or rotation of a lens element from a perfect alignment will cause the geometric displacement of images known as decentring distortion.

IV.2.3. Principal Distance

The perpendicular distance from the perspective centre of the lens system to the image plane is termed the principal distance. In aerial photogrammetry where the camera lens is fixed to infinity focus, the terms focal length and principal distance may be used synonymously.

In non topographic photogrammetry, especially in close range, the cameras used are often focusable and it is the principal distance which must be determined.

IV.2.4. Principal Point of autocollimation

The location of an image on the image plane formed by the direct axial ray passing through the centre of the lens system is known as the principal point of autocollimation.

IV.2.5. Fiducial origin

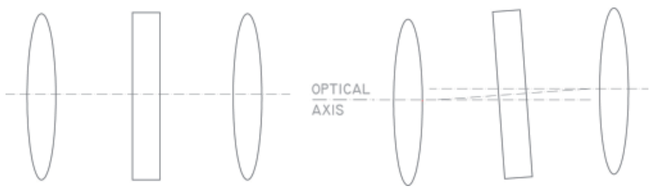
The intersection of imaginary lines drawn from opposite pairs of fiducial marks in the sides or corners of the image plane defines a point known as the fiducial centre or origin.

In an ideal camera, this point, sometimes known as indicate principal point, would coincide with the physically important principal point of autocollimation.

Other optical aberrations can affect the photos and can be grouped into two categories:

- those which reduce image quality, and
- those which alter the location of the image

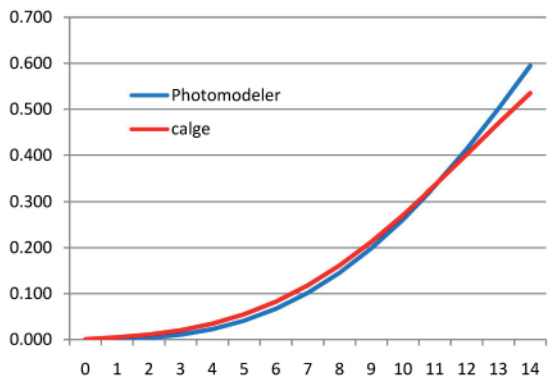
The former are well understood by the good photographers and as general rule they try to use a small aperture so as to maintain a larger depth of field and minimize coma, spherical aberration and, to a lesser extent, astigmatism.



3/ Misalignment of lens elements: perfect alignment (Left), decentred lens (right)

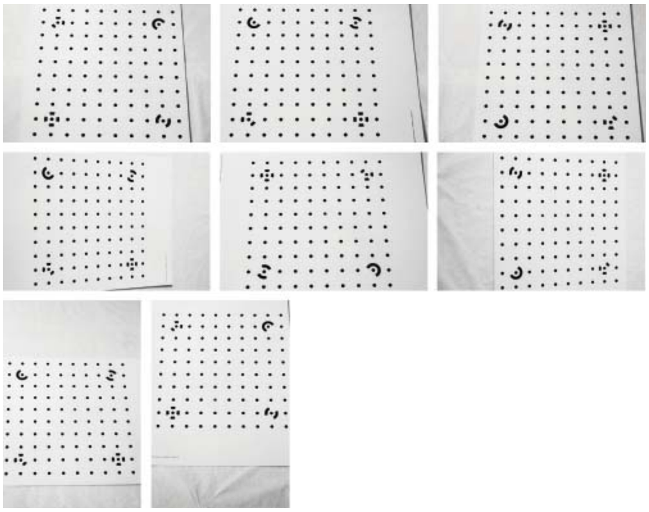
IV.3. Calibration Method

The methods used for the calibration of the close range cameras, have been evolved over the last few decades from an initial mimicking of those used for aerial cameras, where the application was essentially parallel axis stereoscopic photography, the techniques which use the favourable geometric conditions of convergent camera axis to extract the interior orientation and lens distortion parameters.
For the analogue cameras it used to use the «On-the-job calibration» which determine the parameters of lens and camera calibration in situ at the same time as the photography for the actual measurement of the object. Or the Self calibration which is an extension of the concept embodied in on-the-job calibration. Thus the observations of discrete targeted points in the project are used as the data required for both the object point determination and the determination of the parameters of camera calibration.
plumb-line calibration in laboratory is analytical technique which is a convenient method to determine the radial distortion at two different focus settings. This technique was champion by Brown and was very popular in the 1970s.[4]
Currently, for the digital image we have many commercial photos modelling software with calibration function



4/ Lens distortion curves by photomodeler and Calge for a 18 mm lens in the a research of the D.I.T.S. department in the faculty of engineering, Rome university «La Sapienza»

In our case the calibration done by using the photomodeler calibration function in its calibration sheet, Photomodeler has reliable calibrations results (based on a research of the D.I.T.S. department in the faculty of engineering, Rome University «La Sapienza» by C. Nardinocchi)
As a consequence, it was compared with the scientific software «Calge» and very similar results were obtained.
PhotoModeler includes a Camera Calibration function that determines information about the camera. It calculates the camera's focal length, lens distortion, format aspect ratio, and principal point.
The Calibration sheet for use with PhotoModeler's Camera Calibrator Program was printed on 90cm X 90cm rigid support. The calibration sheet is used with PhotoModeler's Camera Calibrator program to produce camera calibration parameters.
After calibration the parameters were used to correct the photos by Menci Z-Map software.

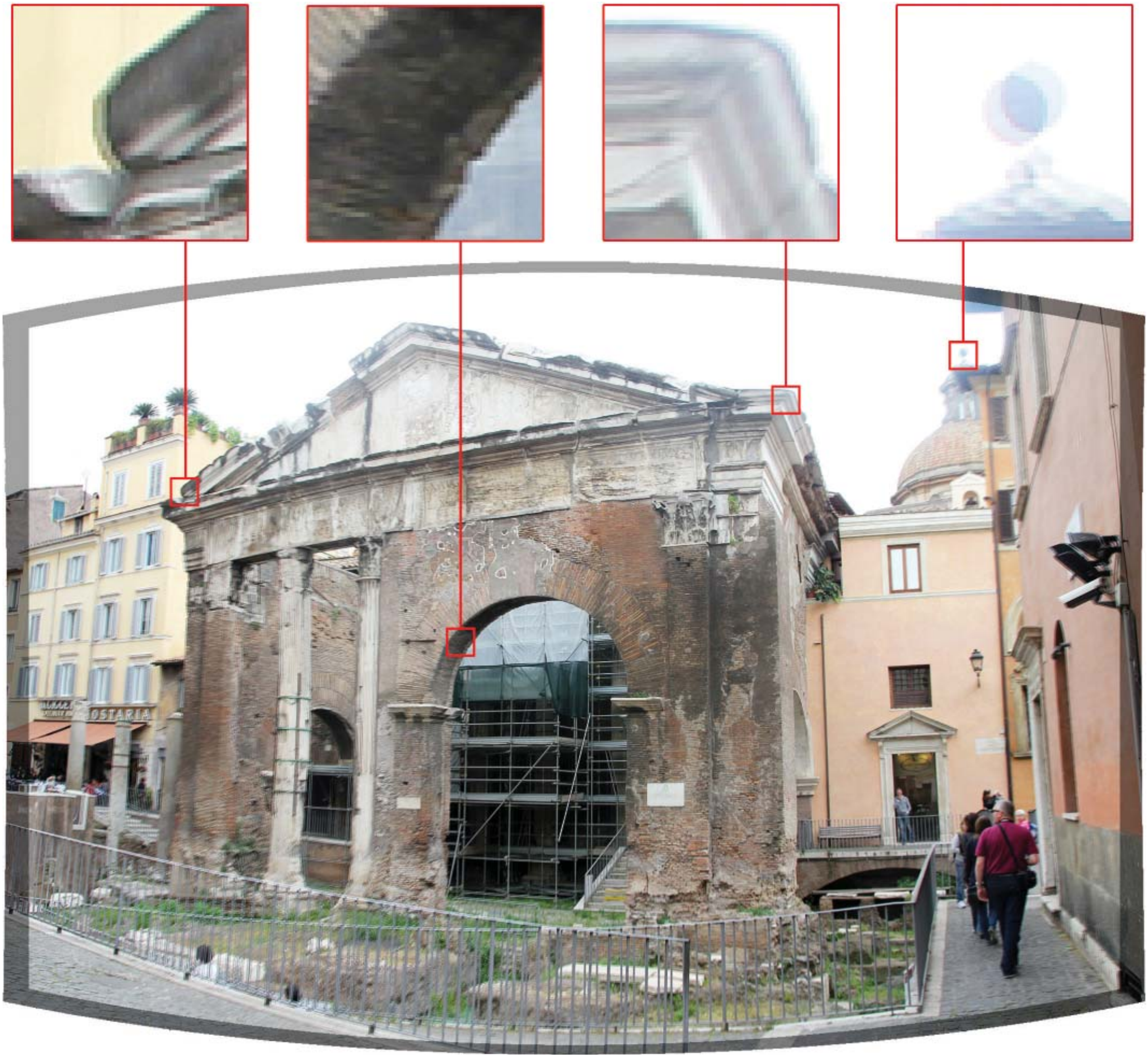


5/ The photos used in the calibration

The original photo

The corrected photo

6/ Superimposition image of the original 17 mm lens photo and the corrected photo by using the calibration parameters



7/ Superimposition of two equirectangular images, the first corrected and projected by PTGui directly and the other corrected using the calibration parameters with other software then just projected with PTGui. The gray frame around is the crop applied to the correct image to have the original image dimensions.

Calibrating the camera for a multi-image panoramic photograph

One of the steps in the panoramic image combining is the Calibration of the Camera-Lens system which is usually an automatic step in the stitching software.

The software can use the EXEF meta data saved in the Image file to calibrate and correct images to be used in the panorama composition or it could be inserted if we have it from a previous calibration.

IV.4. The necessity of calibration in case of Multi-Image panorama

Panoramas photographs usually do not required any correction, because the stitching software is able to calculate the distortions during stitching process and it correct the images. but, in case of single-image spherical photo, where is no control points in the project, it is important to have the calibration parameters from a previous stitching project of a 360° panorama or to correct the photo in other system, then to project it without calculating or giving any deformation parameters to the stitching software. That was an experiment to try, to view the difference between those two ways and getting a correct equirectangular projected photos. PTGui results were very good.

A good correspondence was obtained between the two equirectangular images the maximum error was about 4 pixels in a 2000 pixel width image, the greatest differences were in the extreme points in the image where the distortion is maximum usually.

Notes

1. C.S. Fraser and S. Al-Ajlouni, 2006
2. Ziemann and El-Hakim, 1982
3. Brown, 1968
4. J.G.Fryer

Sintesi

La calibrazione della macchina fotografica si rende necessaria per correggere le aberrazioni dell'immagine generate dall'obiettivo. Essa consiste nel determinare i parametri della geometria del sistema ottico (lente e macchina fotografica).

La calibrazione può avere diversi scopi:

- *valutare la performance della lente*
- *valutare la stabilità della lente*
- *determinare i parametri della geometria e dell'ottica della lente*
- *determinare i parametri del sistema lente-macchina fotografica o del sistema di acquisizione dell'immagine*

I parametri che servono per calibrare una macchina fotografica fanno riferimento alla distorsione radiale e alla distorsione decentrata.

La distorsione radiale si ha quando un punto nell'immagine viene spostato radialmente più lontano o più vicino al centro in relazione con la distanza tra il punto e il centro. Il centro di simmetria della distorsione centrale può non essere nel punto principale ma molto vicino anche se spesso si considerano sovrapposti. In questo tipo di distorsione si possono avere la "barrel distortion" e la " Pincushion distortion", o anche una distorsione mista tra le due.

La distorsione decentrata avviene quando le lenti non sono allineate perfettamente nel momento di fabbricazione cioè gli assi di tutte le lenti dentro l'obbiettivo non sono coincidenti.

Uno dei parametri fondamentali della calibrazione è la distanza principale, cioè la distanza tra il centro della lente (obbiettivo) e il piano dell'immagine.

Il punto principale di autocollimazione che è la proiezione perpendicolare del centro della sistema delle lenti al piano dell'immagine è diverso dal punto principale nel caso in cui il piano dell'immagine (il sensore) non è perfettamente perpendicolare sull'asse ottico.

Una verifica sulla procedura di calibrazione è stata fatta nelle applicazioni qui proposte, usando la stessa macchina fotografica e lo stesso obbiettivo, basandosi prima su foto singole per determinarne la precisione e confrontando poi i risultati ottenuti sulle stesse foto usando i parametri di correzione determinati da un montaggio di un panorama multi immagine.

La prima calibrazione è stata eseguita usando la funzione integrata con il programma Photomodeler che da risultati di buona qualità secondo gli studi del laboratorio nel dipartimento D.I.T.S. della Facoltà di Ingegneria Sapienza.

Dopo aver ricavato i parametri di calibrazione la correzione dell'immagine e stata fatta usando "Z-map" della Menci Software.

La seconda calibrazione è stata fatta direttamente con il programma di stitching "PTGui" che ottiene i parametri di calibrazione dopo aver fatto un stitching di un panorama chiuso di 360°.

La stessa immagine di prima è stata corretta e proiettata usando la proiezione rettilineare

Le due foto corrette in teoria devono risultare identiche perciò sono state sovrapposte per verificare la corrispondenza. I risultati delle due correzioni sono molto simili con una piccola differenza nelle parti estreme della foto; differenze di circa 4 pixel su una larghezza di 2000 pixel (Fig.7).

Sapendo che nella foto panoramica multi immagine le parti più lontane dal centro del panorama non si usano e vengono sostituite con parti di altre foto sovrapposte, si comprende che non c'è bisogno di calibrare la macchina fotografica per un rilievo basato sui panorami sferici multi immagine.

V. Taking Photos

Taking photos is the first step of photogrammetry, Photos have to be taken under a programmed plan, we also can use photos that have been taken for other purposes, but in this case the quality of the resulting model programming can be affected.

Handling a good Photographing work it helps to avoid many problems in the Modelling Phases:

- A good photographing project can reduce uncovered surfaces areas by the photos;
- It will be possible to model something in a high precision;
- A good quality photos can turn into a good model texture.

Before photographing few factors to put into consideration:

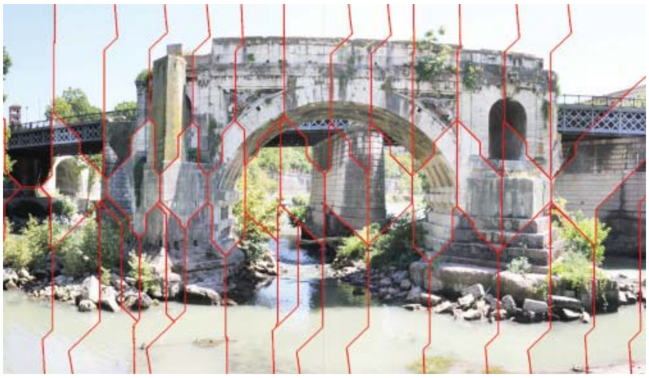
It is very important to know the purpose of modelling the photographed architectural object, and the final aimed product.

Taking as many photos as possible is useful in the photogrammetry to provide more data. Some photos might not be required during the survey period while it might be useful to verify the quality of the survey through the additional photos, as well as it will work as documentation data in case of more models required afterwards.

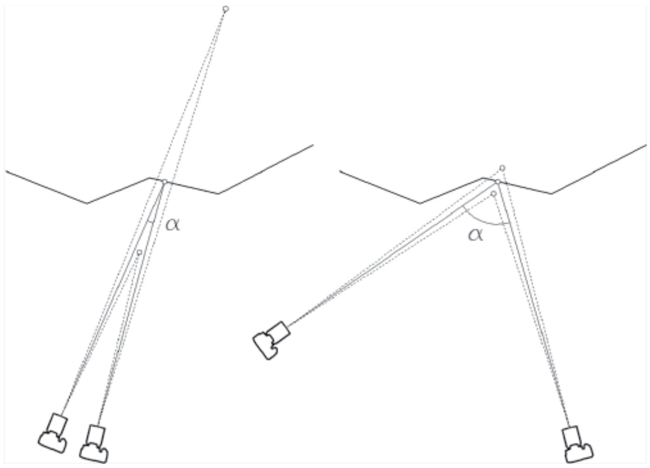
V.1. Photographing Stations

In the next graphics we can see that in the case (A) the difference of the angle between the field of view of two panoramas, which cover a lateral surface is normal, but, when the distance between the centre of the panorama and the surveyed surface is less (B), the difference between those two angles is greater, and since the surveying precision is linked to the lower precision of the used panoramas, it is much lower if one of those angles are so small. In this case it is better to make another panoramic station between those two (C).

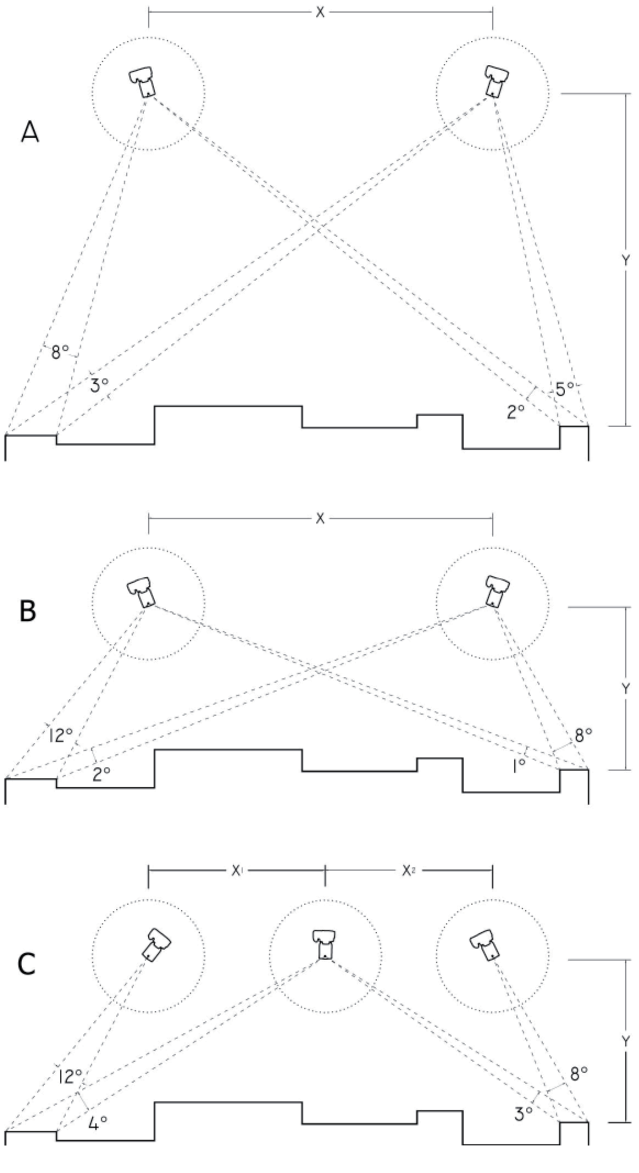
In general the distance between the two panorama stations (X) must be more or less equal to the distance from the surveyed surface (Y) for best results.



1/ Example for panorama creation and stitch line visualisation

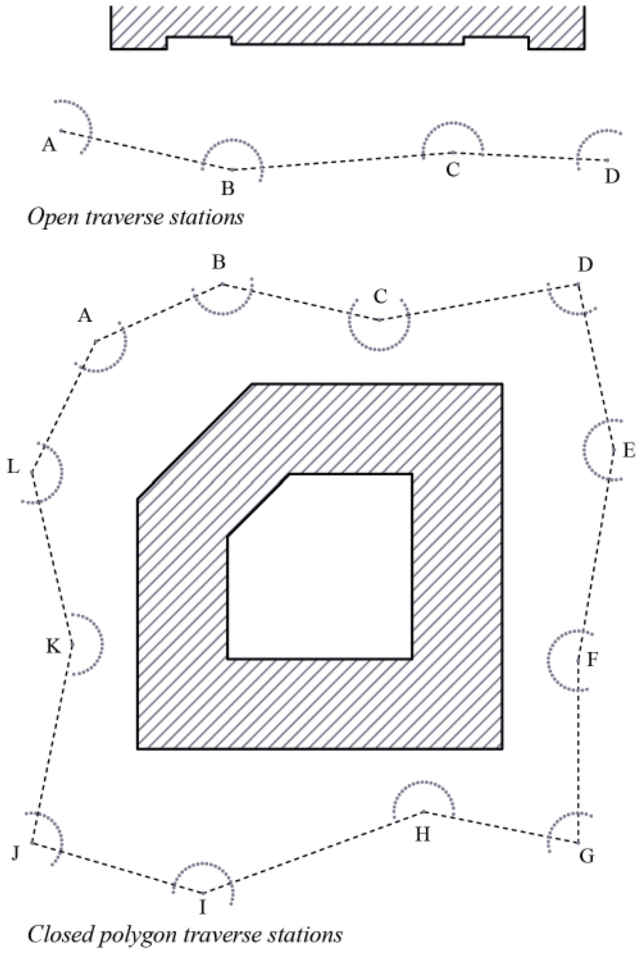


2/ Taking photo from too close positions increase the error so much



3/ In (A) case (when X ≈ Y) the difference between angles covering far sides of a facade from two different panoramic stations are not extremely high 8/3 and 5/2
In (B) case, stations closer to the facade (X > Y) those differences are extremely high 12/2 and 8/1
In (C) case (when X1 ≈ X2 ≈ Y) with the new panorama station differences returned to be normal 12/4 and 8/3

The positions of Photographing stations are very important. If the survey has many panoramic stations it is recommended, if it is possible, to situate them to create closed polygon traverse. In this case, the last panorama will have common observations with the first one. A closed traverse enables a check by computation, with a gap called the linear misclosure. When it is within an acceptable tolerance, the misclosure can be distributed by adjusting the bearings and the distances of the traverse lines using a systematic mathematical method (Fig.4).



4/ Depending on the surveyed architecture form, Stations could be distributed as open traverse or closed polygon traverse.

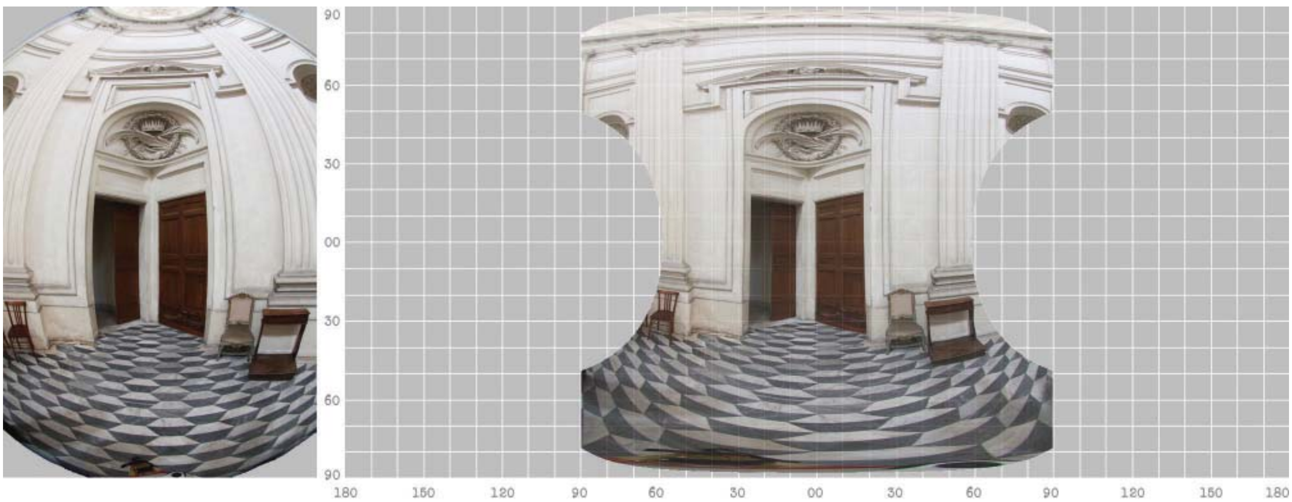
V.2. Single-Image spherical Photos

If the entire surveyed object could be photographed in just one photo and if the maximum resolution of the camera sensor is enough for the requested survey quality, it is possible to use a single image for every station. In such case no need to use the tripod and the panoramic head which are needed for a multi-image panorama.
It could be photographed using a wide angle lens, as fisheye lenses while the size of the digital image might not be sufficient. The maximum size of the recent commercial digital cameras sensors is about 20 mp then the size in pixels of the image will be limited to this number. Consequently, no way to increase the resolution for the details if needed, in the other hand in the multi-image panoramas it is possible using a small angle lenses, thus more photos and better sampling.
To project a single image as a spherical photo, it is necessary to use the calibration parameters of the camera-lens system obtained by using a calibration software or some stitching software, which have the ability to define calibration parameters from a closed 360° multi-image panorama photograph composition for the specific focal length, if the used lens is a zoom lens, because the lens deformations cannot be calculated by the software in a high precision if it doesn't have a closed 360° panorama.

V.3. Multi-Image spherical panoramas

In using an ordinary camera to make panorama photographs, there is a special "no-parallax point" around which the camera must be rotated in order to keep foreground and background points lined up perfectly in overlapping frames.
Arguments about the «no-parallax point» location are frequent and confusing . In large number of publications devoted to photographic technique, it is stated that the «no-parallax» point for multiple-image panoramic photography is "the front nodal point" of the lens.
In the last few years, studies shows that the «no-parallax» point is not the front nodal point but, it must be in the aperture, or more precisely, at the "entrance pupil", which is the virtual image of the aperture stop looking into the lens from the front.[1]
In our case, we'll avoid the confusion discussion of the technical definition of the «no-parallax» point and we will identify this point in practical visual tests. As we will see next
The following rules for the acquisition of the separate images should be considered:

- The images must overlap each other.
- The overlapping area of the images must be textured in order to allow the automatic matching process to identify identical points in the images. The lack of



5/ Equirectangular projection of a fisheye 8mm lens photo texture in some overlapping areas may be overcome by an appropriate definition of the image pairs if the whole object shows little texture, the overlapping areas should be chosen larger.

- The images should be at the same size in pixel.
- The images are mapped onto a common image plane using a projective transformation. Therefore, to generate a geometrically accurate image the separate images must be acquired from approximately the same point of view, i.e., the camera can only be rotated around its optical centre (no-parallax point).

So, it needs a tripod and a panoramic head to rotate the camera around the lens’s "no-parallax" point.

The required number of photos can be determined as per the horizontal field of view and can be calculated as follow:

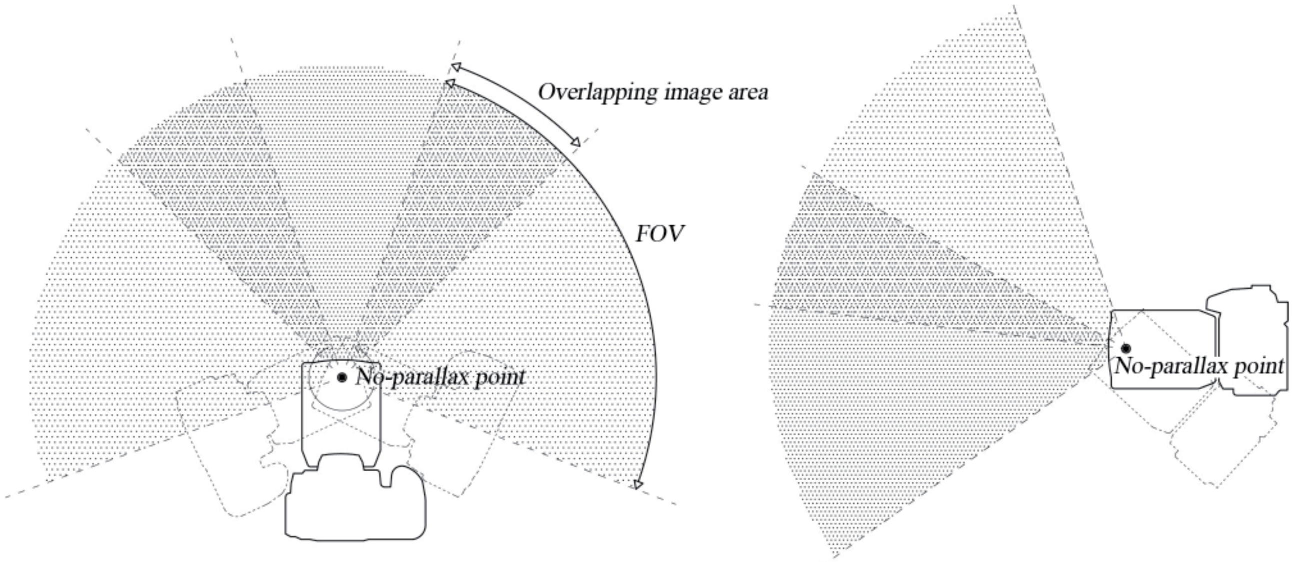
$$\text{Number of photos to be taken} = \frac{100 \,.\, A}{(100-B) \,.\, HFOV}$$

A: Final panoramic field of view
B: Overlapping percentage
HFOV: Horizontal field of view

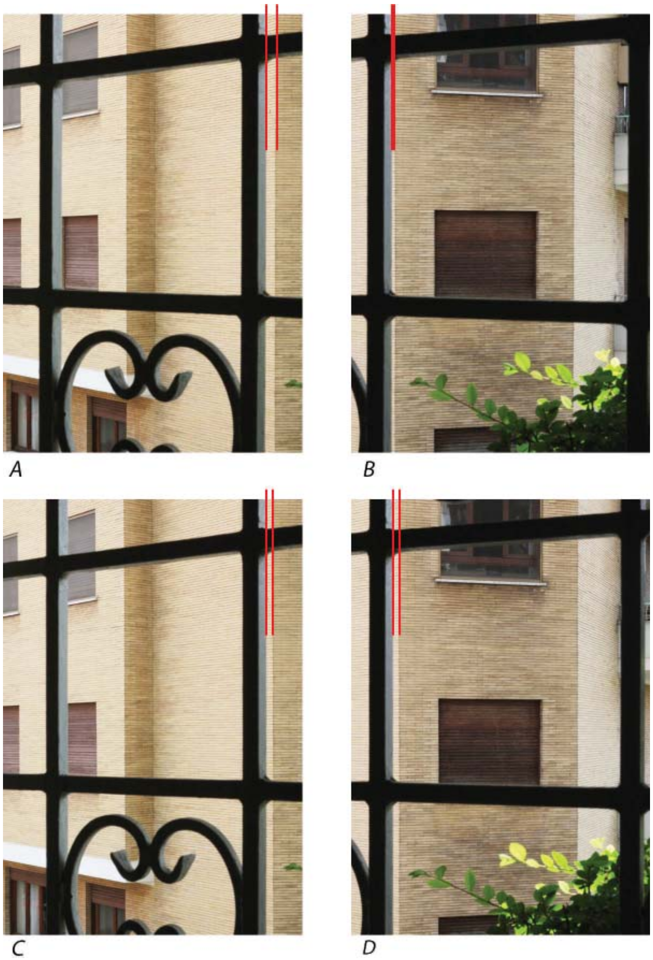
Calculating the number of pictures to be taken is necessary to avoid missing some photos in order to cover the entire panorama with overlapped photos. It can be done by calculating both the horizontal and the vertical angles between one photo and the other, then rotating the panoramic head by this specific angle for the specific used lens.

Determining the "no-parallax" point of a lens is quite easy to do visually. Two vertical features are needed to use them as reference (e.g. a vertical doorway, vertical light pole, etc...). One must be very close to the camera, the other, far away. An adjustable tripod panorama head is needed too. Accuracy will be in the order of 1mm for a circular fisheye lens. Accuracy will be greater when the distance between these two features is greater.
The diagram in (Fig 8,9) show what happens if the rotation wasn’t around the «no parallax point» of the lens. Note that the relative positions of the objects on each side of the gap are determined from the nodal point of the lens, not the rotation axe.

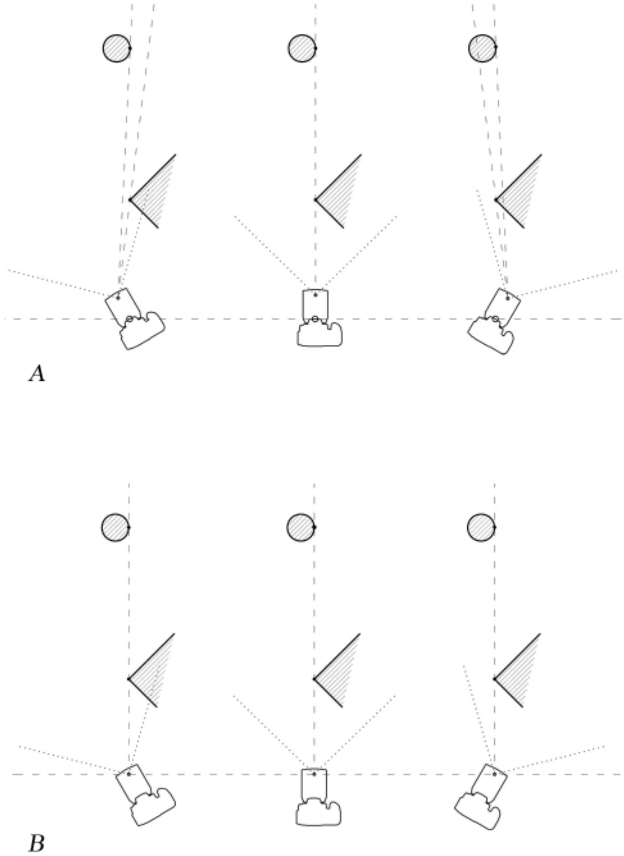
6/ Panoramic Head for Cylindrical and spherical panoramas



7/ Camera rotation around the "No-parallax" point for a multi-image panoramic photo



8/ (A) and (B) photos are taken from a camera rotated around a point different from the «no parallax» point, and it is noticeable from the change of the reference distance indicated in red. But in(C) and (D) it was rotated around the right "no parallax" point so the reference distance did not change.



9/ (B) rotation around the "no-parallax" point, (A) rotation around a different point.

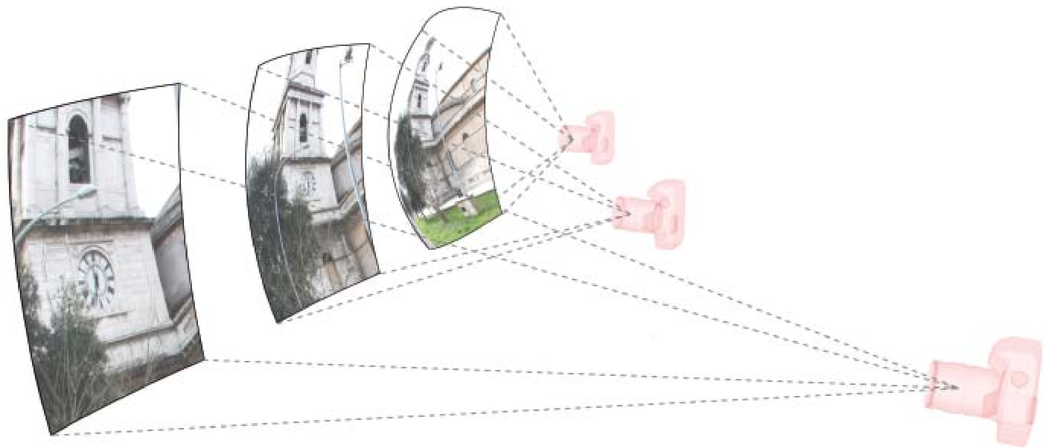
V.4. Photos Quality

Being a good photographer is very important aspect to get a good results in photogrammetry. Many problems could be avoided like having panoramas with some «out of focus» objects, or much contrasted photos as very bright or very dark zones. Subsequently, taking good photos in the right settings under the place conditions, is important to obtain the maximum information required from a photo.
The use of the flash is not recommended as it makes a great contrast between surfaces lighting in relation to the inclination or/and the distance from the flash.
In general using the Auto focus affects small changes to the calibration parameters for every image, so it is better option to use the manual focus to fix it for all images in the same panorama. The solution to have all objects in the photo focused is to enlarge the depth of field by using a small lens aperture. However, this will be difficult in the internal spaces. Consequently, the shutter speed will be lower to obtain enough light then taking photos time will be much greater. A high ISO speed can help in such case except it can affect too the quality of the image when it is so high.
There is a great difference between indoor and outdoor surveys. In indoor survey generally, we face lighting problem, while in outdoor photographing it is possible to use a fixed focus with a small aperture in the daylight.
The most important factor is to have a clear sharp photos, thus if necessary to use the Auto focus it is useful to do so. Tests show that out of focus parts of photos will damage seriously the modelling more than one time.

- It will be difficult to find the features to create control point in the combining panorama phase.
- It is complicated to indicate the right position points in the orientation phase so it could affect the orientation.
- It will be unhelpful in the modelling phase having a bad texture to use by modelling.
- The Model will get a bad texture that will affect the representation.

Some post-production work will be useful to have clear photos, and the use of RAW format images is recommended if it is difficult to take photos afterwards in case of bad exposure or much contrasted photos. RAW format images have much more data that can be recovered in the post-production software.

To have nice photos means better texture for the model then a beautiful representation of textured model. The ideal conditions in making photos is to be in a diffused light like a cloudy day in an outdoor survey, in this case the texture will be less contrasted avoiding the strong shadows caused by the sunlight. In the render phase, it is possible to add the virtual sunlight direction in a various day times not only the taking photos time. Additionally, shadows changes between panorama station and the other, so the change of the light direction will be visible in the textured model where two panoramas are projected.



10/ The use of wider angle lens means greater field of view for the single photo (less photos and lower sampling).

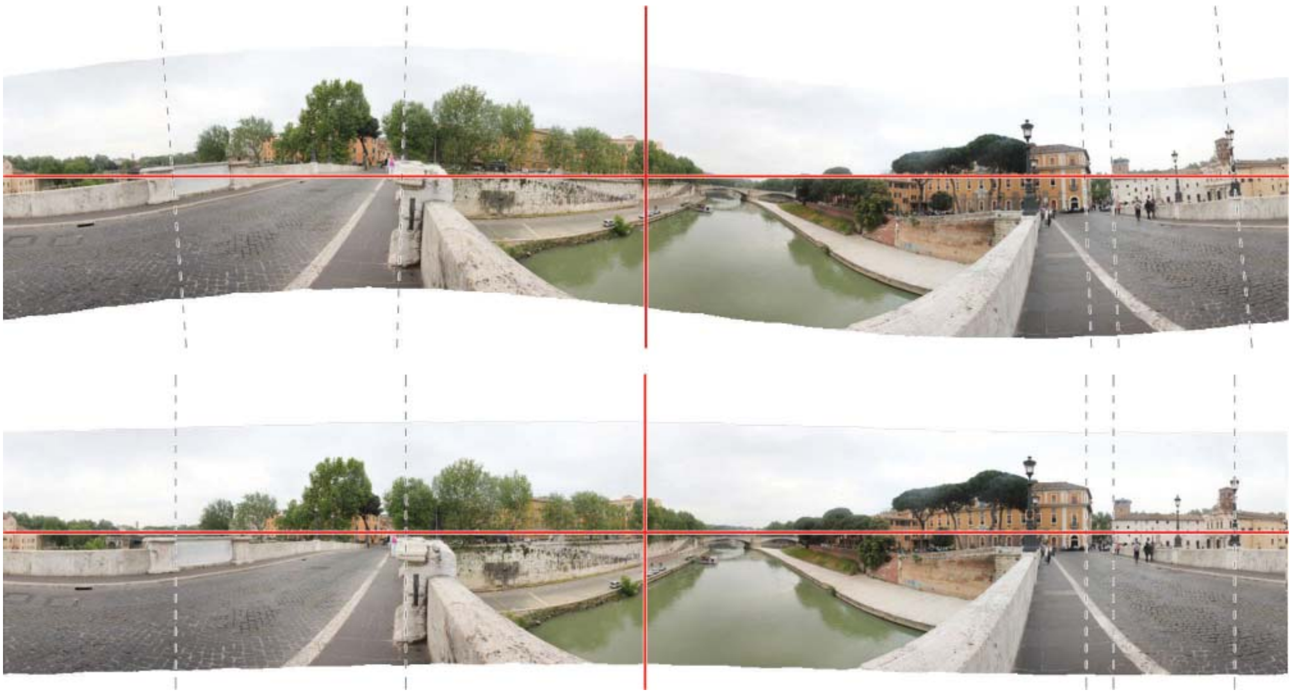
V.5. Preparing panoramas

Using one of the common generic stitching software like Autostitch, Hugin, Ptgui, Panorama Tools, Microsoft Research Image Composite Editor, CleVR Stitcher and Photoshop, which includes a tool known as Photomerge and Auto-Blend, It is possible to prepare panoramas in a very fast operation. Generally, the software steps to create panoramas are:

- photos input, lens specification
- control points selection
- images deformation and composition
- stitching
- color enhancement, blending
- cutting, export to output format

New feature detecting algorithms is so robust and much better than manual control points detecting. However , a fast check is useful to be sure that the software chose the control points on a fix object not a moving one, like what happens often with moving plant leaves.

In the Panorama it is important to indicate some vertical lines in the reality as vertical constraint, in this method the software can adjust the position of the panorama photograph to be oriented. Adding vertical constraints helps to adjust the panorama photograph's horizon, because the verticality of the photograph cannot be accurate even if we try to take photos with a levelled camera.
Afterwards and before creating the panoramic photograph, it is important to gather some information for proceeding with the following steps.
Usually, it is not necessary to use the 360°x180° panorama photographs, or rather, it is better if it covers only the requirements because we can have a smaller image then a smaller file size. The sky can be cropped and the unnecessary pavement near the station centre. But, cropping the panoramic photograph has to be calculated, and we have to know after cropping the dimensions of the 360°x180° panorama of this Image.



11/ Indicating some vertical edges in the photo will adjust the horizon in the Panorama photograph

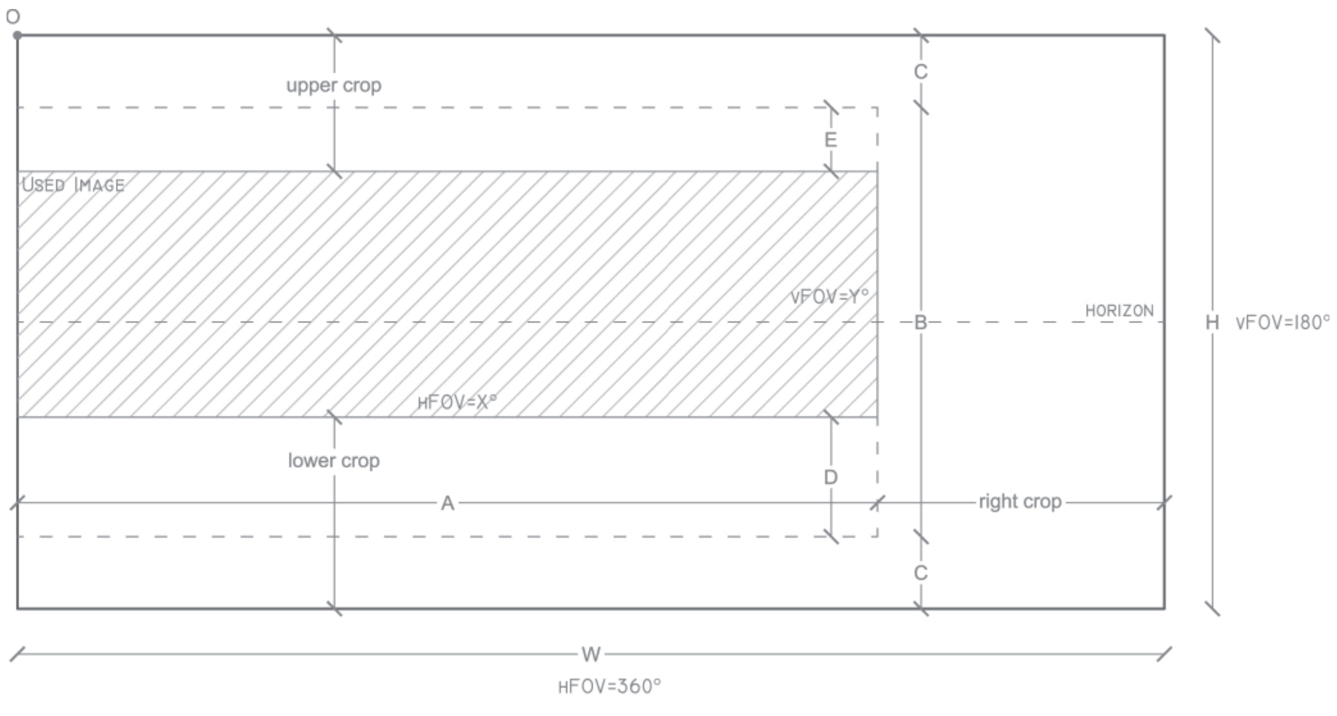
The Dimensions of the panorama Image is affected by the focal length and the sensor image quality. It can not be fixed for two different panorama stitching (even if those two parameters and the aperture are fixed). Other than they are approximately of the same size.
For example, using a 17mm lens with a resolution of 5184 x 3456 pixel (18 mp) we'll get a panoramic Image width from 24600 to 26300 pixels. For the same image size with a 50mm lens we get a panoramic Image width from 66000 to 71000 pixels, That is because of the calibration of the stitching software. Every time we make a panorama Image and some other factors, it can be set to fixed values for calibration parameters but in this research the software is making the automatic calculation of those parameters whenever we make a panoramic composition.
Since we have to know the position of the used panorama photograph in the entire 360°x180° equirectangular panorama photograph, we have to calculate the right, upper and lower crops (left one is not exist because the origin "O" is aligned to the left board to the image).

The stitching software gives us the possibility to know the maximum size of the Image in a certain horizontal and vertical field of view (even if the FOV is not photographed entirely).

From the next scheme (Fig 12):
the right crop = *W - A*
the upper crop = *(H/2)-(B/2)+E*
the lower crop = *(H/2)-(B/2)+D*

when: A and B are the dimensions of the symmetric crop
E and D are asymmetric added crops
The horizon shifts from the centre of the used image in a proportion of the Image high, it is calculated as follow:
(upper crop/2 - lower crop/2) / used image high

Those information could be presented using the following table , it will be very important in the orientation and texture projection steps.



12/ Parameters to be calculated when the panorama is smaller than 360° x 180°.

Those data could be organized using the table in (fig 13), it shows the other important calculations we made, for example: The image size in pixel and the image aspect ratio. Those data will be important to map the photo as texture in the model space.

Since the orientation software is limited to accept images smaller than 100 mp, all big images are to be reduced. Another table was created to insert the calculated parameters after reduction, because all parameters as crops have to be reduced in the same proportion.

In the Table (Fig 14) new parameters were inserted after reducing all the images that are originally bigger than 90 mp to 90 mp while, images smaller than 90 mp was left in their original size.

The first column shows the reduction factor of every panorama and the crops calculated before (in the previous table), are multiplied by the reduction factor in this one.

Since the maximum size in pixel is fixed, the «pixel/angle» resolution of the image is vary according to the field of view of the photo. This resolution is shown in the last column which is very important information to know (how many pixels correspond to an angle).

In the example tables, it is noticeable that the original panoramas have almost the same resolution as they were composed from photos of the same lens (50mm), the resolution variant from 188 to 202 pixel/angle. On the contrary, in the second table the difference between small FOV panorama and big FOV become higher after the size reduction for an example, Panorama 13 has relatively big FOV in comparison with the rest of the panoramas. It is a big size image (about 594 mp) however, to reduce the size to 90mp the width was multiplied by 0.49 maintaining the image ratio. Consequently, the resolution became 97 instead of 197 pixel/angle.

Pano.	Lens's Focal Length mm	Initial Field of View (FOV)		Dimensions of the panorama for the Initial FOV			Dimensions of the panorama for the 360°X180° FOV		Pixel / Angle	Lower Added Crop	Upper Added Crop	Dimension of the Image			New Image Ratio	The New FOV after cropping	
		W	H	W	H	W x H	W	H		H	H	W	H	WxH	H/W	W	H
01PR	50	82	44	15436	8283	127,856,388	67780	33890	188.24	1128	0	15436	7155	110,444,580	0.463527	82	38.01
02PR	50	93	49	17418	9177	159,844,986	67430	33715	187.29	755	0	17418	8422	146,694,396	0.483523	93	44.97
03PR	50	30	22	5819	4267	24,829,673	69836	34918	193.97	1450	0	5819	2817	16,392,123	0.484104	30	14.52
04PR	50	45	22	9108	4453	40,557,924	72893	36446.5	202.40	479	0	9108	3974	36,195,192	0.43632	45	19.63
05PR	50	64	30	12265	5749	70,511,485	68996	34498	191.64	0	0	12265	5749	70,511,485	0.468732	64	30.00
06PR	50	41	35	7878	6725	52,979,550	69188	34594	192.15	0	0	7878	6725	52,979,550	0.853643	41	35.00
07PR	50	48	38	9129	7227	65,975,283	68464	34232	190.19	0	511	9129	6716	61,310,364	0.735678	48	35.31
08PR	50	40	40	7778	7778	60,497,284	70010	35005	194.45	0	1451	7778	6327	49,211,406	0.813448	40	32.54
09PR	50	41	32	7972	6222	49,601,784	69996	34998	194.44	0	1002	7972	5220	41,613,840	0.654792	41	26.85
10PR	50	45	55	8519	10412	88,699,828	68164	34082	189.31	0	3628	8519	6784	57,792,896	0.796338	45	35.84
11PR	50	86	88	15933	16304	259,771,632	66695	33347.5	185.27	0	5905	15933	10399	165,687,267	0.652671	86	56.13
12PR	50	88	85	17218	16631	286,352,558	70435	35217.5	195.66	0	6137	17218	10494	180,685,692	0.609478	88	53.63
13PR	50	127	120	25076	23694	594,150,744	71084	35542	197.45	0	8906	25076	14788	370,823,888	0.589727	127	74.90
14PR	50	113	128	22211	25159	558,806,549	70762	35381	196.56	0	9560	22211	15599	346,469,389	0.70231	113	79.36
15PR	50	67	99	12577	18584	233,730,968	67580	33790	187.72	0	6858	12577	11726	147,477,902	0.932337	67	62.47
16PR	50	41	36	7847	6890	54,065,830	68903	34451.5	191.39	0	2325	7847	4565	35,821,555	0.581751	41	23.85
17PR	50	45	28	8981	5588	50,185,828	71848	35924	199.58	0	1138	8981	4450	39,965,450	0.49549	45	22.30
18PR	50	70	40	13052	7458	97,341,816	67130	33565	186.46	327	0	13052	7131	93,073,812	0.546353	70	38.24
19PR	50	73	42	14037	8076	113,362,812	69228	34614	192.29	0	0	14037	8076	113,362,812	0.575337	73	42.00

13 / Example of a table contains information about 19 panorama images for an architectural survey created using Microsoft Excel. "In gray are the inputs".

	Used Image Parameteres									
	Reduction factor	*Dimensions of the panorama for the specific FOV*			***Dimensions of the panorama for the 360°X180° FOV***		**Final Image crop**			*Pixel / Angle Resolution*
Pano.		*W*	*H*	*W x H*	*W*	*H*	*Upper H*	*Lower H*	*Right W*	
01PR	0.902695	**13934**	**6459**	89,999,706	**61185**	30592	**11558**	13085	47251	169.93
02PR	0.7832702	**13643**	**6597**	90,002,871	**52816**	26408	**9610**	10497	39173	146.70
03PR	1	**5819**	**2817**	16,392,123	**69836**	34918	**15326**	17501	64017	193.97
04PR	1	**9108**	**3974**	36,195,192	**72893**	36447	**15997**	16715	63785	202.40
05PR	1	**12265**	**5749**	70,511,485	**68996**	34498	**14375**	14375	56731	191.64
06PR	1	**7878**	**6725**	52,979,550	**69188**	34594	**13935**	13935	61310	192.15
07PR	1	**9129**	**6717**	61,319,493	**68464**	34232	**14014**	13758	59335	190.19
08PR	1	**7778**	**6327**	49,211,406	**70010**	35005	**15065**	14339	62232	194.45
09PR	1	**7972**	**5221**	41,621,812	**69996**	34998	**15390**	14889	62024	194.44
10PR	1	**8519**	**6784**	57,792,896	**68164**	34082	**15463**	13649	59645	189.31
11PR	0.7370238	**11743**	**7665**	90,010,095	**49156**	24578	**10633**	8457	37413	136.55
12PR	0.705773	**12152**	**7407**	90,009,864	**49711**	24856	**10890**	8725	37559	138.09
13PR	0.4926623	**12354**	**7286**	90,011,244	**35020**	17510	**7306**	5112	22666	97.28
14PR	0.5096574	**11320**	**7950**	89,994,000	**36064**	18032	**7477**	5041	24744	100.18
15PR	0.7811879	**9825**	**9161**	90,006,825	**52793**	26396	**11297**	8618	42968	146.64
16PR	1	**7847**	**4565**	35,821,555	**68903**	34452	**16106**	14943	61056	191.39
17PR	1	**8981**	**4450**	39,965,450	**71848**	35924	**16306**	15737	62867	199.58
18PR	0.9833742	**12835**	**7012**	89,999,020	**66014**	33007	**12836**	13319	53179	183.36
19PR	0.8910024	**12507**	**7196**	90,000,372	**61682**	30841	**11823**	11823	49175	171.33

14 / Table contains information about previous 19 panorama images after reduction.

Notes
1. Douglas A.Kerr «The Proper Pivot Point for panoramic Photography», R.Littelfield «THeory of the «No-Parallax» Point in Panorama Photography»

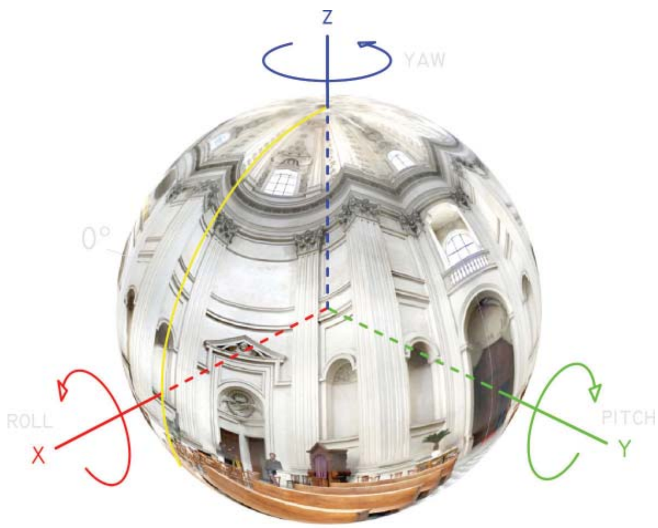
Sintesi

La presa fotografica è una parte importante del rilievo e deve essere progettata e studiata bene prima del sevizio fotografico per evitare i problemi di imprecisione che possono abbassare la qualità del modello.
Quando le coordinate spaziali di un punto vengono ricavate per triangolazione da due proiezioni il problema principale è l'angolo tra le due rette che passano in questi due centri e si intersecano nel punto rilevato. Quando questo angolo è troppo piccolo la precisione sarà molto bassa. Per questo il poligono dei centri delle stazioni deve essere ben studiato. Prima di tutto è importante che la parte da rilevare sia coperta da almeno due panorami e che questi, comunque, non abbiano un angolo troppo piccolo tra di loro. Si può verificare anche il caso in cui un determinato prospetto possa essere modellato tramite un unico panorama sfruttando un vincolo geometrico nell'architettura di questo stesso prospetto.
Nel caso di un prospetto di modeste dimensioni sono sufficienti anche due panorami a condizione che ci sia una distanza sufficiente tra i centri dei panorami e la superficie principale della facciata. Nel caso in cui non vi siano queste condizioni per impedimenti esterni, come per esempio la ristrettezza della strada, c'è la necessità di aumentare i panorami poiché l'angolo tra le proiezioni diventa troppo piccolo nei punti laterali (fig.3). In generale per ottenere una migliore precisione in fase di restituzione, nel caso per esempio di una facciata prevalentemente piana, è opportuno avere la distanza tra i due centri di proiezione più o meno uguale alla distanza dalla facciata.
Nella modellazione da foto singole, come è stato già anticipato nel capitolo della calibrazione, le foto devono essere corrette in funzione dei parametri di calibrazione prima di essere proiettate come immagine sferica. Per le foto panoramiche multi immagine occorre scattare tante foto per ogni panorama dallo stesso punto di proiezione; il punto di proiezione corrisponde al punto chiamato il punto del "no parallasse" ed è quel particolare punto in cui non sussistono problemi di parallasse nella fase di stitching. Fino a qualche anno fa era definito come il punto nodale anteriore poi alcuni studi recenti hanno mostrato che questo punto è diverso dal punto nodale anteriore dell'obbiettivo ed è collegato con l'otturatore e dipende dalla sua apertura.
In questo lavoro il punto del "no parallasse" è stato indicato applicando delle semplici procedure pratiche senza entrare nel dettaglio della definizione. E' stato determinato tramite lo spostamento della macchina fotografica per trovare una posizione orizzontale nella testa panoramica. Ciò è possibile individuando in una inquadratura due elementi verticali fotografati in modo da considerarli appartenenti ad un medesimo piano verticale proiettante e, muovendosi intorno ad un determinato asse verticale, il distacco tra questi due elementi deve rimanere costante. L'intersezione tra l'asse ottico e l'asse di rotazione è un punto dentro l'obbiettivo che è il punto cercato (Fig. 7, 8).
Il panorama sferico deve avere l'immagine di tutti gli elementi verticali come linee verticali nella proiezione equirettangolare e dato che la macchina fotografica non può essere precisamente in una posizione orizzontale o verticale, nel programma di stitching queste linee vanno indicate come linee verticali da raddrizzare e rispettare.
Per preparare i panorami per l'orientamento e la modellazione dobbiamo calcolare la posizione di questo panorama (se non è di 360° x 180°) dentro un panorama immaginario di riferimento che copre tutto il FOV, cioè di 360° x 180°. Avendo l'origine dell'immagine sferica in alto a sinistra la porzione di panorama che abbiamo si allinea a sinistra e si calcolano i tagli in alto, in basso e a destra. Queste informazioni vanno trascritte in modo da poterle utilizzare nella fase di orientamento e di proiezione delle mappe nella modellazione.

VI. Photo Orientation

VI.1. Fondamentals

The determination of the position and orientation of one camera relative to the other is the classic photogrammetric problem of relative orientation. After that, the coordinates of corresponding points in two images can be used to determine the positions of points in the environment, provided that the position and orientation of one of the cameras with respect to the other is known. Rays can be constructed by connecting the points in the images to their corresponding projection centres. These rays, when extended, intersect at the point in the scene that gives the spatial position of that image points. This is how binocular stereo data is used to determine the positions of points in the environment after the correspondence problem has been solved.[1]
Therefore, it is necessary to first determine the relative orientation of one Panorama with respect to the other. The relative orientation can be found if a sufficiently large set of pairs of corresponding rays have been identified.
In order to determine the length of the baseline that connecting the two centres, an accurate information about the length between any two points in the scene is required. If the absolute coordinates of those two points are provided, the model will be scaled and linked as well to the absolute coordinate system, this operation called the «absolute orientation». Since the ray relative directions are unchanged, if we scale all of the distances in the scene and the baseline by the same positive scale-factor, it means that the absolute orientation can be done in any moment even at the end of the modelling process.
To orient the sphere in the space, six parameters are required, three coordinates of the centre and three rotation angles (Fig.1).
For the orientation in this research the spherical panoramic orientation technique was used. Such technique is the digital development of the analogical theodolite developed by Prof. eng. G. Fangi from DARDUS dep. in the Polytechnical University of Marche.
Generally, relative orientation between two or more spherical (equirectangular) Images, are to be calculated using a group of programs by indicating the homologous points in the different spherical images. Those programs use collinearity equations and the coplanarity to calculate the required parameters.
Subsequently, the absolute orientation in the virtual space is linked to reference points coordinates. To solve the normal "surveyor" observation errors in calculation will be based on the least squares method.



1 / Three coordinates of the centre and three angles are necessary to orient the panorama in the space.

According to Prof. Fangi, the spherical panorama can be regarded as the analogical recording of the angular observations of a theodolite, having its centre in the centre of panorama. The greatest difference consists in the fact that while the theodolite is set with its principal axis vertical, in the case of the spherical photo, it is not possible to sufficiently make the principal axis vertical. Therefore, principally, two are the differences between theodolite and the spherical photos : The first one is the achievable precision; in fact maximum width is around the 20.000 pixels (in the case of a complete 360°x180° panorama with current software and hardware capability) then, every pixel corresponds to 0.02 gon, it is very inferior to the one of a theodolite. The second difference is the sphere; contrarily to what happens in the theodolite, the axis cannot be set vertical with sufficient accuracy.
The sphere mapped on the cartographic plane with the so-called latitude - longitude representation or equirectangular representation where

$x = r.\ \theta$

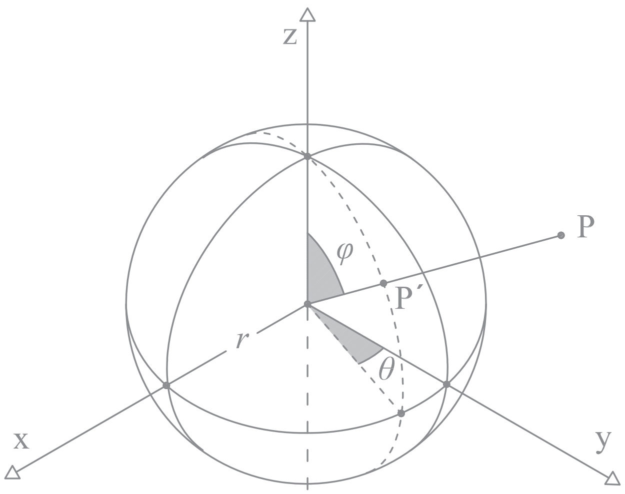
$y = r.\ \varphi.$

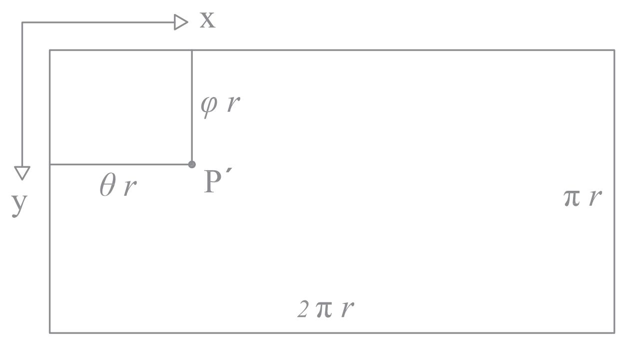
Being the angles expressed in radians. Such representation is not conform, nor equivalent. The poles of the sphere are represented by two segments of equal length, equal to the circumference length of the sphere. The height of the map is equal to the development of a meridian. From such representation the angles of direction θ and φ of the projective line OP can be drawn from the image coordinates x and y.
It is to consider that the panoramic photo is a sphere with two coordinates systems. The first is parallel to the terrain system with the vertical Z axis and origin in the centre O of the sphere «Sphere system». The second has the same centre O of the sphere and parallel to the panorama borders, with Z axis parallel to the lateral borders, so it is almost but not exactly vertical «Panorama system» (Fig.3).
Then, every point has spherical coordinates in the spherical system and the panorama system

$X = d.\sin\varphi.\sin\theta$

$Y = d.\sin\varphi.\cos\theta$

$Z = d.\cos\varphi$

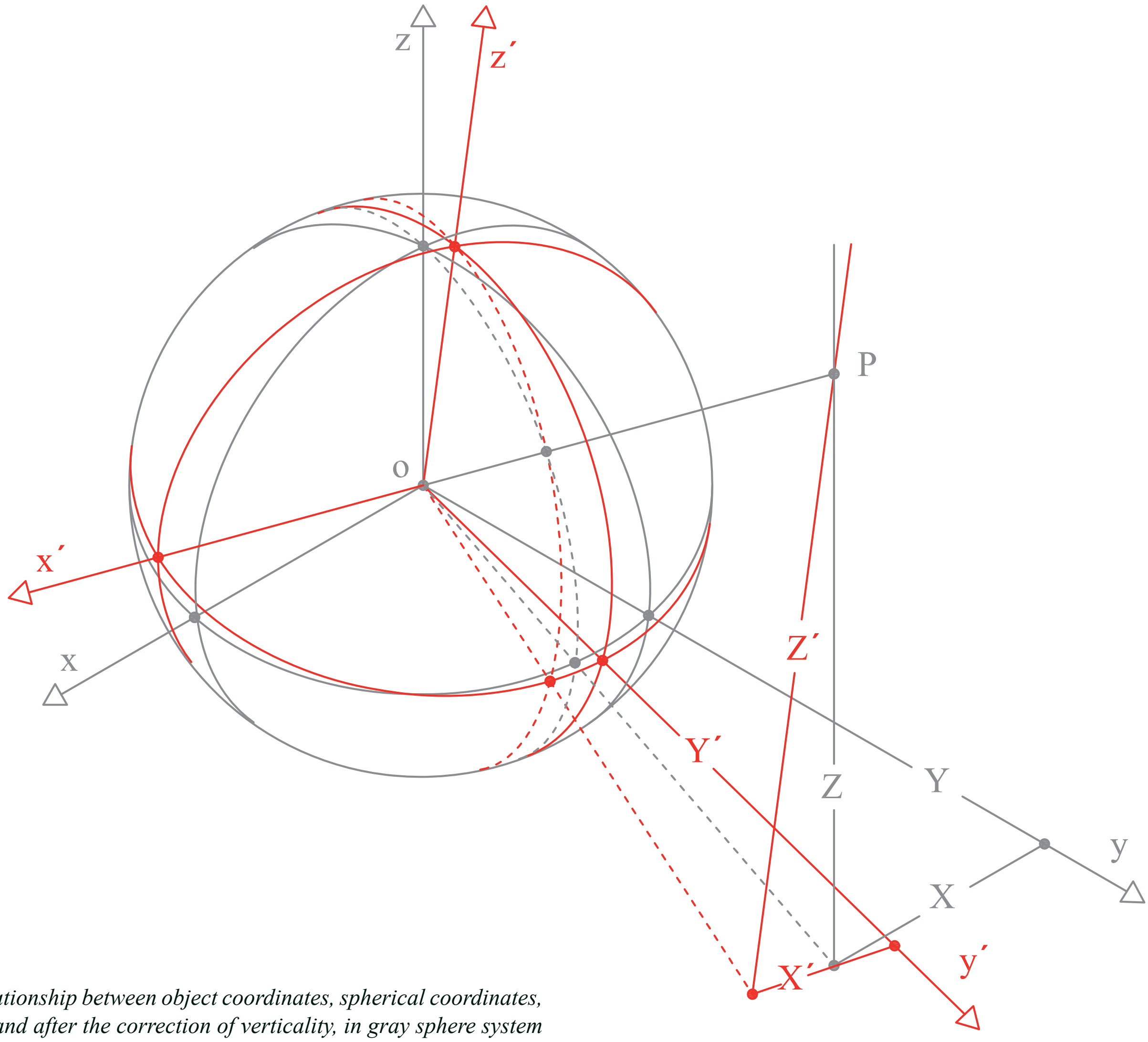




2 / The latitude-longitude projection. Relationship between spherical coordinates and the image coordinate of a spherical image.

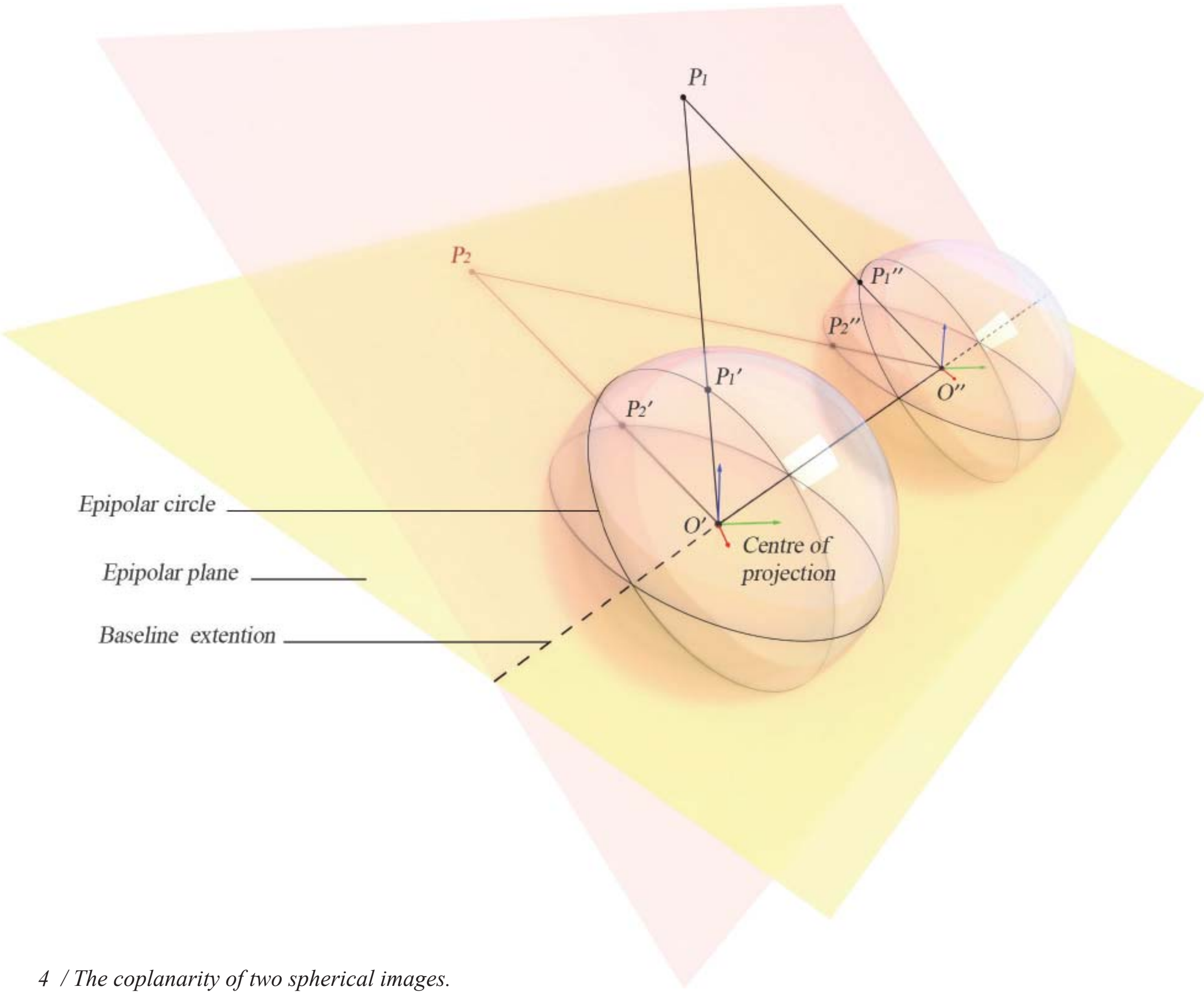
In the panorama composition step, some apparent vertical elements of the photographed architecture defined as vertical constraint, as explained in the «Taking photo» chapter, through this process (Z) axis of the panorama system became almost identical to the sphere «real» vertical (Z) axis, but no guarantee for the perfect alignment. Consequently, a small angular error is considered. It is relatively small error, by then it is considered α = sin α . In the rotation matrix the angle α is used instead of sin α.

By using the rotation Matrix it is obtained equations of collinearity for the spherical panoramas which take into account the missed verticality of (Z) axis of the panorama system. Such equations must be linearized around approximate values of the parameters and coordinates. Those values are supplied by a classical procedure where the initial values of the correction angles are set to zero or by means of the relative orientation between two spherical panoramas using the epipolar geometry (Fig.4).



3 / Relationship between object coordinates, spherical coordinates, before and after the correction of verticality, in gray sphere system and in red panorama system.

This procedure is similar to the one set up for the theodolite stations that was called «blind traverse» [Fangi, 1998]. Apart from the two differences; First, the unknown parameters increase from four to six. Second, the relative orientation is performed with five independent parameters among the eight possible, as the traditional photogrammetry.



4 / The coplanarity of two spherical images.

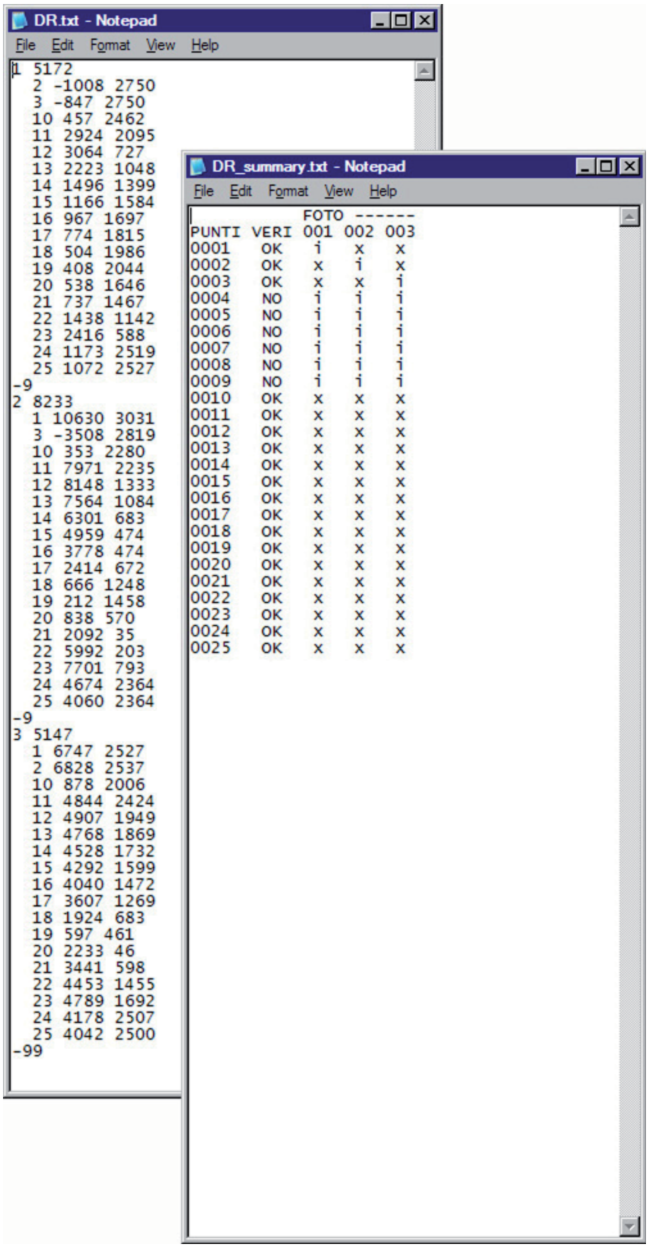
VI.2. Orienting process

Every photogrammetric survey starts with orientation to know the relative position between one photo and the other. Since we don't know where we did capture the photos from (the projection centre).

Most of photo modelling software unified the orientation and calibration steps in one, but in this research I had to face the orientation and calibration as a separate step. As explained in the calibration chapter the calibration of a multi-image panorama is integrated in the composition of the stitched image, and for a single image the correction has to be done before the equirectangular projection.

«Create Points» program is used to indicate the homologous point in different panoramas. Subsequently, it creates series of text files with the planar coordinates of the points in pixel in every panorama. In order to have the maximum accuracy in the orientation, the selections of points have to be distributed to cover the maximum of the field of view. No matter if the indicated points are not perfect, as the least squares method used by the orientation software will resolve this imprecision.

Then this program generates two files in which is written the coordinates U and V of the selected points in pixels in every image and the table of points to signify in which of those images the certain point is indicated.


DR.txt - Notepad
File Edit Format View Help

```
1  5172
  2 -1008 2750
  3 -847 2750
  10 457 2462
  11 2924 2095
  12 3064 727
  13 2223 1048
  14 1496 1399
  15 1166 1584
  16 967 1697
  17 774 1815
  18 504 1986
  19 408 2044
  20 538 1646
  21 737 1467
  22 1438 1142
  23 2416 588
  24 1173 2519
  25 1072 2527
-9
2 8233
  1 10630 3031
  3 -3508 2819
  10 353 2280
  11 7971 2235
  12 8148 1333
  13 7564 1084
  14 6301 683
  15 4959 474
  16 3778 474
  17 2414 672
  18 666 1248
  19 212 1458
  20 838 570
  21 2092 35
  22 5992 203
  23 7701 793
  24 4674 2364
  25 4060 2364
-9
3 5147
  1 6747 2527
  2 6828 2537
  10 878 2006
  11 4844 2424
  12 4907 1949
  13 4768 1869
  14 4528 1732
  15 4292 1599
  16 4040 1472
  17 3607 1269
  18 1924 683
  19 597 461
  20 2233 46
  21 3441 598
  22 4453 1455
  23 4789 1692
  24 4178 2507
  25 4042 2500
-99
```

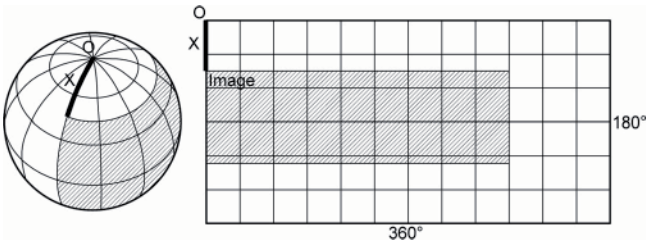
DR_summary.txt - Notepad
File Edit Format View Help

```
                  FOTO ------
PUNTI  VERI  001  002  003
0001    OK    i    x    x
0002    OK    x    i    x
0003    OK    x    x    i
0004    NO    i    i    i
0005    NO    i    i    i
0006    NO    i    i    i
0007    NO    i    i    i
0008    NO    i    i    i
0009    NO    i    i    i
0010    OK    x    x    x
0011    OK    x    x    x
0012    OK    x    x    x
0013    OK    x    x    x
0014    OK    x    x    x
0015    OK    x    x    x
0016    OK    x    x    x
0017    OK    x    x    x
0018    OK    x    x    x
0019    OK    x    x    x
0020    OK    x    x    x
0021    OK    x    x    x
0022    OK    x    x    x
0023    OK    x    x    x
0024    OK    x    x    x
0025    OK    x    x    x
```

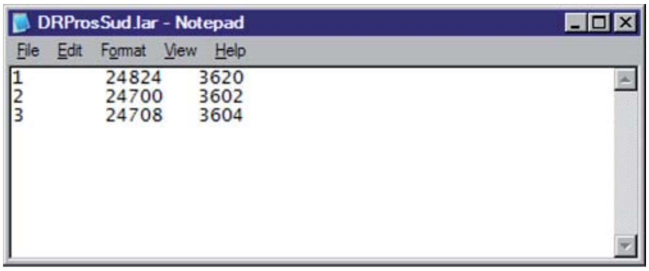
5 / Two text files one indicates the coordinates of every point in every image in pixel and the other shows which are the control points indicated in every panorama by the surveyor.

Subsequently those files are used to orient images using "sphera" software. Previous to this step, the reference coordinates system has to be defined by writing a text file indicating the coordination of two points of the control points available in the two images. Those points will be used as reference points by saveing the text file with a specific extension ".res" in the same folder. The software will use this data to align the axes of the coordinate system in the virtual model and gives the coordinates of the centre and rotation of the panoramas referred to that coordinates system. Another file required is the one which specify the quantity in pixel of the shift of the image origin in vertical, because as said before if the vertical field of view of the panoramic image doesn't start from the upper pole then it is necessary (as explained in "taking photos" Chapter) to know how much the image is shifted down (or the origin shifted up) then the software will add this quantity to bring it again to the upper pole.

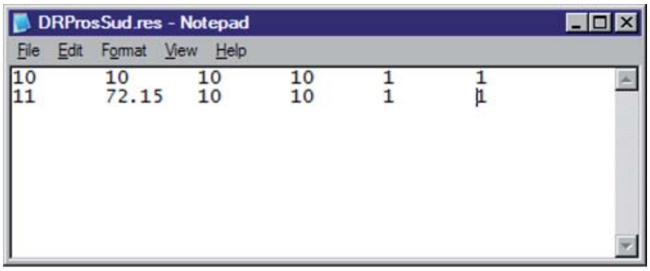
The orientation software "Sphera" generates many useful files. The orientation file in which we can read the coordinates of the position of every spherical image with the rotation angles in Gradian which is a common unit in topographic surveys.
The file contains the precision results that confirm the accuracy of the orientation by assessing errors value, it can identify the mistakes in one or more images or points.
The orientation file is used to start modelling in the virtual space, using generic modelling software as 3ds Max by projecting the panoramic photos from the projecting centre in the right direction indicated in this orientation file as explained in the Image-based interactive modelling chapter.



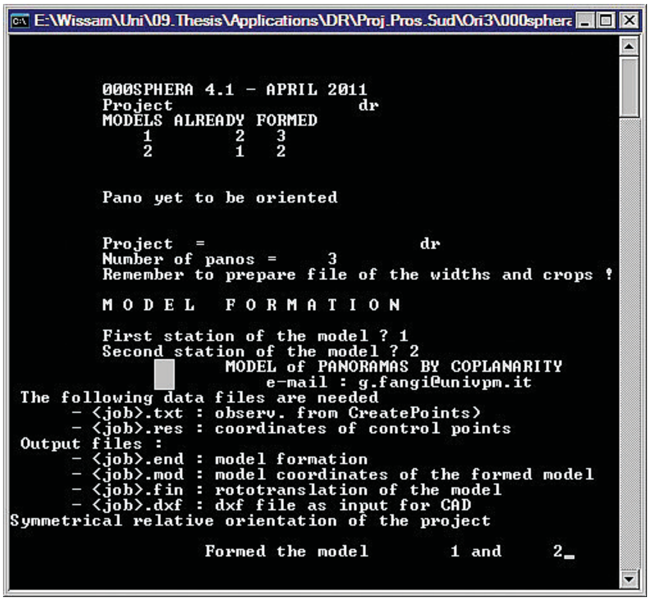
6 / *image shifted down X pixels*



7 / *text file contains from left to right Image number, image width, upper crop height*



8 / *Text file contains the coordinates of the reference points*



9 / *Sphera Program*

Nstaz	X	Y	Z	hstr.	teta0-rad	alfax-rad	alfay-rad Larg	Punto	teta0(g)	alfax(g)	alfay(g)	
1	16.50138	-4.96172	-10.46581	1.500	3.206222982	-.048584776	.002764661	16594	1	204.1145	-3.0930	.1760
2	21.78275	10.57375	13.55201	1.500	6.038706081	-.055105719	.016604777	17643	2	384.4360	-3.5081	1.0571
3	-2.18364	.70256	18.05929	1.500	5.699342964	-.055400652	.012229573	18060	3	362.8314	-3.5269	.7786
4	40.93266	-4.23458	9.77638	1.500	.685487827	-.048580547	.012782522	17669	4	43.6395	-3.0927	.8138
5	-.84123	14.42910	-10.62776	1.500	.629667825	-.057223592	-.000896236	15073	5	40.0859	-3.6430	-.0571
6	-9.15156	23.00109	-10.98427	1.500	.731793146	-.066376671	.000970160	14902	6	46.5874	-4.2257	.0618
7	-26.21172	41.12631	-12.34079	1.500	5.510106319	-.066442567	-.007162229	20826	7	350.7843	-4.2299	-.4560
8	-18.44021	44.46121	-12.65524	1.500	.462881316	-.065961284	-.004870862	24540	8	29.4679	-4.1992	-.3101
9	2.24025	39.89796	-11.88923	1.500	.120681016	-.060357499	-.007626027	18162	9	7.6828	-3.8425	-.4855
10	15.50382	38.08893	-11.56348	1.500	.043587395	-.065380336	.001855833	18506	10	2.7749	-4.1622	.1181
11	38.50701	37.92836	-11.39594	1.500	.158972255	-.056935020	.010259820	17994	11	10.1205	-3.6246	.6532
12	61.63251	41.04334	-11.59338	1.500	2.969364781	-.058050765	.032161620	26256	12	189.0356	-3.6956	2.0475
13	60.48297	19.01147	-10.03480	1.500	1.536289193	-.045763745	.011499278	21940	13	97.8032	-2.9134	.7321
14	61.65846	-16.62971	-7.80396	1.500	2.626302907	-.039222698	.009028896	25768	14	167.1956	-2.4970	.5748
15	58.68582	-57.95432	-5.67226	1.500	4.903682457	-.031493310	.017837715	24692	15	312.1781	-2.0049	1.1356
16	30.07311	-57.58090	-5.39292	1.500	3.193886749	-.047490662	.008749982	24748	16	203.3291	-3.0233	.5570
17	-3.69016	-56.63827	-5.11429	1.500	3.189185026	-.046237536	.004496723	24752	17	203.0298	-2.9436	.2863
18	-26.10384	-54.12817	-4.78819	1.500	6.010029658	-.046887080	.019877625	24692	18	382.6104	-2.9849	1.2654
19	-25.96039	-19.09578	-7.06962	1.500	4.871972895	-.051525354	.019309248	18122	19	310.1594	-3.2802	1.2293
20	-25.59679	-6.90849	-8.22685	1.500	4.902727183	-.052657375	.017941862	18227	20	312.1173	-3.3523	1.1422
21	-31.57533	15.65624	-10.50135	1.500	4.541598022	-.052281065	-.011548478	20648	21	289.1271	-3.3283	-.7352
22	-29.38119	27.35045	-11.16855	1.500	4.977684830	-.069855634	-.009890996	20929	22	316.8893	-4.4471	-.6297

10 / The orientation file contains the coordinates of every panoramic station with the rotations around x, y and z

Notes

1. *B. K. P. Horn "relative orientation" 1978*

2. G. Fangi, "The multi-image spherical panoramas as a tool for architectural survey", 2007

Sintesi

L'orientamento è una procedura per conoscere la posizione e le rotazioni delle foto in un modo relativo tra due o più foto, o in modo assoluto legandoli ad un sistema di riferimento assoluto. E' una operazione da eseguire prima in qualsiasi tipo di applicazione fotogrammetrica in modo automatico o manuale.
In questa ricerca è stata utilizzata la tecnica sviluppata dal prof. Fangi che altro non è che la traduzione digitale dell'orientamento che si utilizzava con il teodolite analogico. La principale differenza con questo, a parte ovviamente la precisione, è che l'asse della sfera non può essere disposto verticale con lo stesso grado di precisione del teodolite. E' quindi necessario stimare due angoli di rotazione attorno ai due assi orizzontali x e y. Dalle coordinate immagine del panorama si ricavano gli angoli orizzontale e verticale che si sarebbero misurati con un teodolite il cui centro coincidesse con il centro del panorama. Occorre però stimare due angoli di correzione degli assi orizzontali per rendere l'asse principale della sfera verticale. I parametri di orientamento di un panorama sono dunque sei, le tre coordinate del centro di presa e tre angoli di assetto degli assi di questa.
La fase di orientamento ha previsto l'utilizzo di diversi software; si inizia con il software "Create points" indicando i punti omologhi tra i panorami (le osservazioni) per ottenere il file che contiene le coordinate immagine U e V di tutte le osservazioni in ogni panorama in pixel. Si scrivono poi due file testo ausiliari. Il primo contiene le larghezze dei panorami con una copertura di 360°, quindi , nel caso di una porzione di panorama (non a 360°) si aggiunge alla larghezza effettiva il taglio destro, e subito dopo anche il taglio superiore effettuato (come già detto quando si è parlato della preparazione del panorama nel capitolo della presa fotografica). Il secondo file testo ausiliario contiene le coordinate di almeno due punti per l'orientamento assoluto. Queste coordinate possono essere quelli reali o possono essere anche indicative; in quest'ultimo caso il modello verrà scalato dopo la modellazione per metterlo nella scala reale.
Successivamente si elaborano i dati con il software "Sphera" che applica le equazioni di orientamento con la correzione stimata con il metodo del minimi quadrati per ridurre l'imprecisione nell'intersezione dei raggi dello stesso punto da immagini diversi. I calcoli si ripetono ogni volta per tutte le osservazioni aggiungendo una nuova osservazione per avere la media dell'errore accettabile soprattutto quando si tratta di stazioni panoramiche su di una poligonale chiusa. In questo caso ad esempio l'ultimo panorama contiene punti omologhi con il primo; l'errore diminuisce verificando la posizione relativa di questi due panorami e ricalcolando tutte le posizioni e le rotazioni dei panorami intermedi.
Si producono dopo l'orientamento i file in cui sono scritti i parametri di orientamento di ogni panorama e l'errore ricavato nel operazione di orientamento per ogni punto. Dalla lettura dei dati se si evidenzia qualche valore di errore troppo alto si possono identificare le osservazioni sbagliate. Quando questi errori sono accettabili si può procedere con la modellazione usando i parametri dell'orientamento per utilizzare le foto che diventano mappe da proiettare con il programma di modellazione.

Wissam Wahbeh

VII. Panoramic Interactive image-based modelling

VII.1. Fundamentals

An interactive system for generating photorealistic textured 3D models of architectural structures and urban scenes from oriented panorama photographs. The concept of this Modelling Technique is based on the usage of texturing techniques in a generic modelling software as virtual projector of an image, and thus to be used to model an architectural object. If the projection centre and the direction are fixed in the 3D virtual space, the objects could be created, moved and modified to match the projections. Objects therefore will take the right shape and location in the virtual space of the surveyed elements.

The proposed Interactive Image-based Modelling technique starts from oriented photos to model an architecture by a classic commercial 3D-modelling program. It exploits the geometrical constraints to simplify and speed the modelling. It is based on the recognition of the geometrical elements of the surveyed architecture. Therefore, on the contrary of the point by point survey's techniques the surveyor in this technique has to understand the architecture before start modelling.

Image-Based Modelling produces two types of information:

1. Vector information which represents the architectural signs and features by vertexes, segments and polygons.
2. Raster information (Texture Bitmap) which describe the discontinuity of the surfaces between architectural elements.

It is ideal technique for the architectural representation, because it produce a low-poly model rich of high resolution maps texture, describing the architecture as how the architect read or describe architecture. Therefore, the result model make this architecture easy to read for the architect, restorer and the traveller in the virtual city.

It is an interactive modelling technique because projected texture has a fixed centre while moving or modifying the surfaces for such when it is projected. Hence , it is visible in an interactive way the offset or the correspondence between the model and the projected map, as well, the quality of the model could be verifiable in various interactive ways and in any moment; as we are going to explore more in this chapter.

The Image-based Modelling of an existing architecture has as concept the inversed steps of the classical modelling process for a representation of an architecture starting from 2D drawings to 3D textured model render. Comparing the classical modelling and the Image-Based Interactive modelling process we can present the following steps:

Classical Modelling:

. Design (propose dimensions) or Survey (finding out dimensions)

. Perform the 2D drawings (plans, sections, elevations, etc.), then 3D model

. Applying materials

. Rendering the scene

Image-based Interactive Modelling:

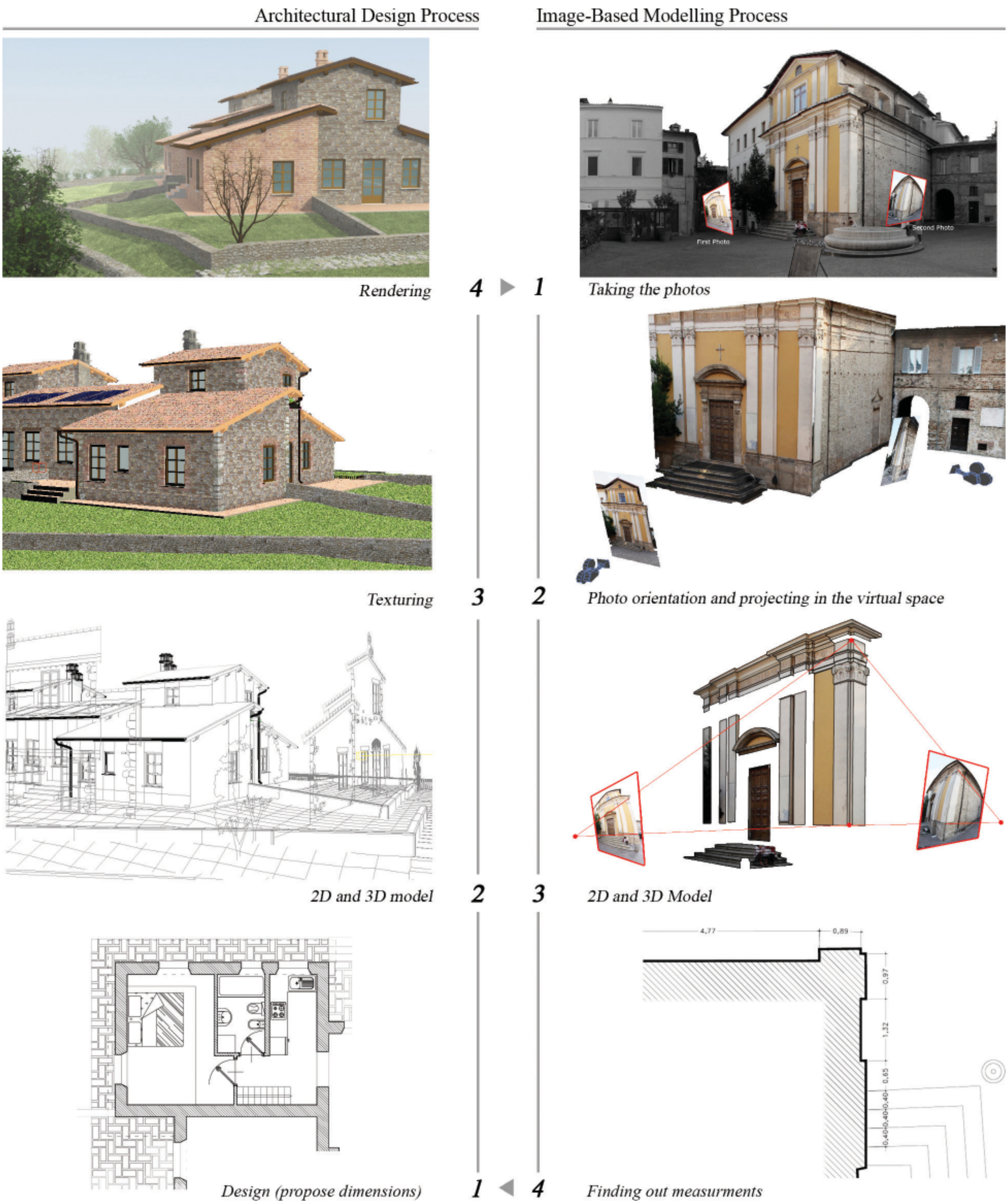
.Taking photos of the architectural element

.Photo orientation and projection in the virtual space (applying materials)

.Modelling volumes, surfaces (already textured) (3D) and curves (2D)

.Finding out measurements

If we consider a photo of an existing building corresponds with a photo-realistic render of a virtual one, as concept, the two operations have inverse process directions. This harmonize with the normal difference between realizing a building from project drawings and realizing drawings of an existing building (namely survey), and this will close a circle between real and virtual architecture (Fig.1).



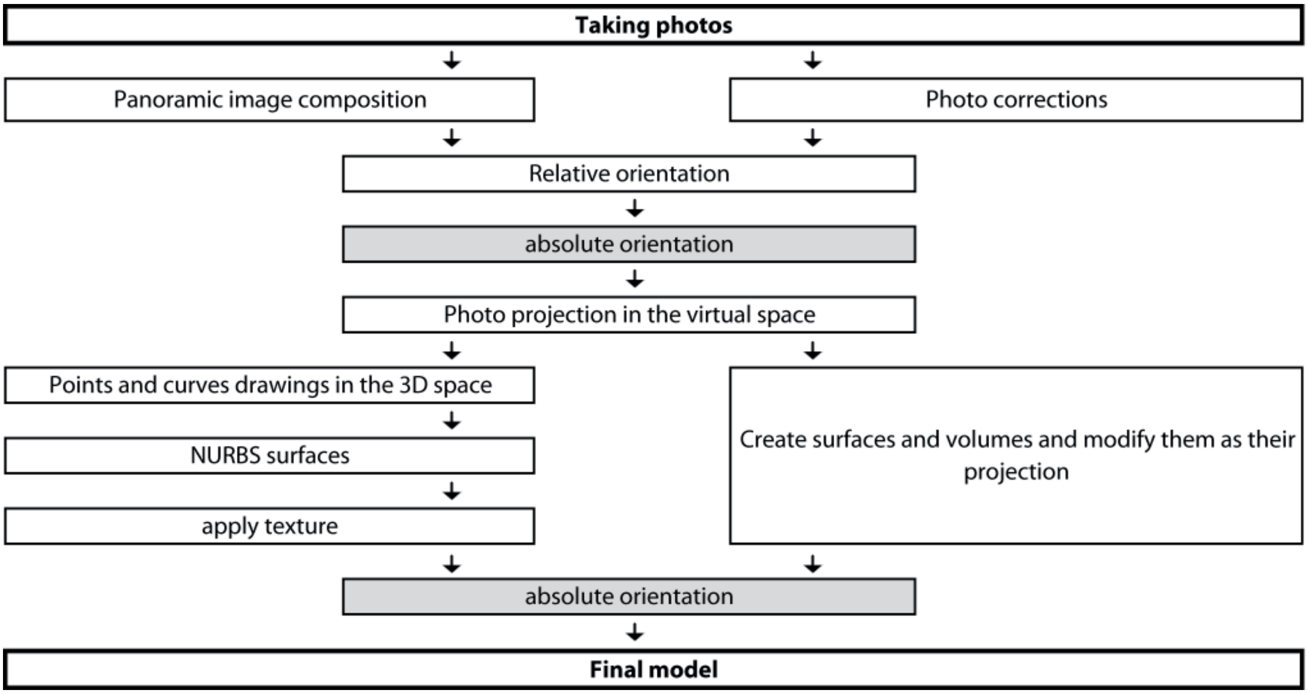
1 / Comparison between architectural design modelling and the image-based modelling process

The Panoramic Image-based Interactive Modelling technique is suitable to be used in many types of surveys, but it has to be studied and programmed before starting the work.
It is necessary to take into consideration the following scheme of the process while using this technique, since it will affect the way to model.
Some steps of the process can be done in different ways, depending on the "type of photos" and the "type of model":

- Type of Photos:
  - Single Photos.
  - Multi-image Panoramas: The panorama has to be composed from single photos.

- Type of model:
  - Polygonal Object: It is possible to create directly the polygonal object or surface which receive the projection.
  - Mathematical Object: To use the projections to draw the surface generators to create a NURBS surfaces.

It is important to notice that the absolute orientation could be done after the relative orientation, or at the end of process, before getting the final model, but, it is always useful to do it before if it is possible, because it could be useful to verify dimensions during the work or to add drawings to the model before the end of the modelling process (scheme 2).



2 / Modelling process scheme. The absolute orientation could be done after the relative orientation, or at the end of process

VII.2. Photo projection in the virtual space

Having the photo orientation parameters from the orientation phase (as explained in the previous chapter) means that we know the exact position and direction of every photo. This is determined by six parameters, three translations and three rotations. Subsequently, it is possible to project the photo in the virtual space using texturing technique in the modelling program called UVW mapping.

UVW mapping is the way in which the image to be spread on the three dimensional surface or (in other way) how to project the image map on the surface.

UVW mapping modifier is to be used as a virtual projector applied on several objects, every object can have several projections, and merely an object has to be created to apply the projection on it.

The spherical UVW mapping has to be used for the central projection by locate the centre, insert the orientation parameters X,Y,Z and give it the right direction by rotating it around the centre the yaw, pitch and roll or X, Y, Z axes angles.

Most material maps are a 2D plane assigned to a 3D surface. Consequently, the coordinate system used to describe the placement and transformation of maps differently from the X, Y, and Z axis coordinates used in 3D space.

Specifically, mapping coordinates use the letters U, V, and W; the three letters preceding X, Y, and Z in the alphabet. The U, V, and W coordinates parallel the relative directions of X, Y, and Z coordinates. In a 2D map image, U is the equivalent of X, and represents the horizontal direction of the map. V is the equivalent of Y, and represents the vertical direction of the map. W is the equivalent of Z and represents a direction perpendicular to the UV plane of the map.

It is important to notice that by default the projected image as spherical mapping, is projected toward the centre of projection as camera capturing light rays to draw a photo. Since it was suppose to be as a projector, projection direction has to be from the centre of the projection toward the object, and then U direction has to be flipped. It has the same difference by photographing our self and looking at our self in the mirror (fig.3).It's essential to employ the right projections for modelling. The good projections for a specific object are:

-Relatively not so far projection centre, because the advantage of maximum density of pixels in the surface could be taken (higher sampling);

-Quite perpendicular to the object's main surface, when just one projection is needed to model, for the same previous reasons;

-When triangulation is to be made, the use of two projections, with an angle between projecting direction in the modelling point as close as possible to 90°, is better for good precision (as explained for the orientation).

3 / Since it was suppose to be as a projector, projection direction has to be from the centre of the projection toward the object, therefore U direction has to be flipped

VII.3. Technical notes

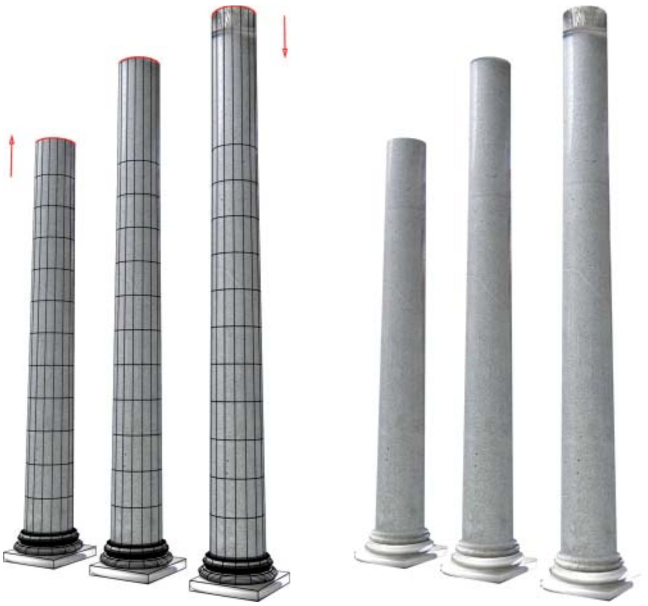
One problem could be the visualisation of the texture on the textured surfaces in the viewport. As the visualization of the map on the surfaces have always limits if the maximum of the hardware potency is used (as to configure the video card driver to make the appearance of the texture in the viewport match the bitmap size as closely as possible).
Other visualization problem could be the affine texture mapping, because affine texture mapping does not take into account the depth information about a polygon's vertices, where the polygon is not perpendicular to the viewer it produces a noticeable defect.
To reduce this effect the solution is subdividing the polygons into smaller polygons.
Other implication is the tiling precision : In 3Ds Max the map tiling and offset are limited to three digits after the comma. This limitation can affect the precision of the model in case of a large dimension model, it was noticeable in the Tiber island model which is in the applications chapter.

4 / In those two images we can notice that in an equirectangular projection image (the first one) if a square of 100x100 pixel projected (the second one) it will have deformation depends on the angle between the surface normal and the projecting ray. In the second image «A» square deformed more than «B» so the resolution in B is higher

5 / The software usually deform the texture map visualisation when a spherical projection used as it is so big image, the solution is to subdivide the big surfaces.

VII.4. Modelling

Modelling is the most important and interesting phase of the process, the automatism here has no role and the result could be verified in any moment during the work in an interactive way.
To model an object, we can use several ways depends on the shape of the object and the best way to create this object. It would be useful to start with a primitive if the object is similar to this primitive form, as to start from cylinder to create a cylindrical column, from a pyramid to create a hip roof, or from a polygon surface to create walls. Another way is to look at a background projection from the centre of the panorama and to draw on a specific work plane.
Here are the techniques to create different objects in the virtual space starting with projected panoramas (a preset UVW map modifier for every panorama):



6 / Identifying the height of the column using an interactive texture projection

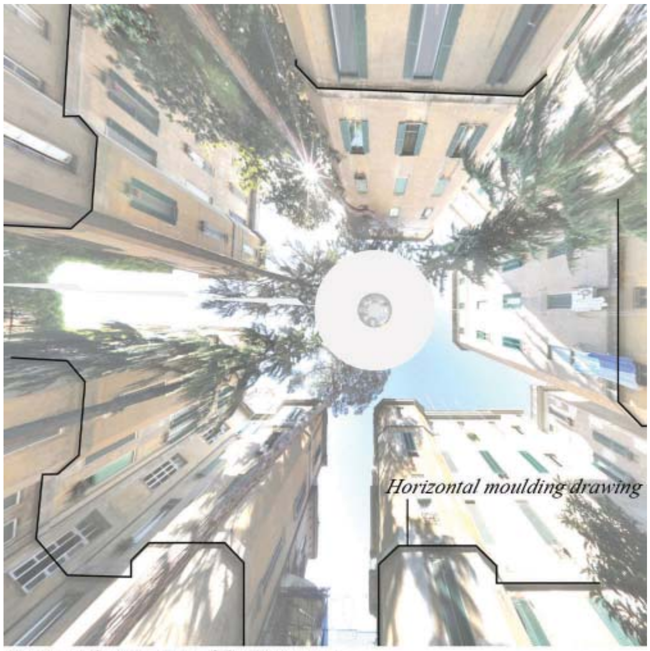
VII.4.1. Locate points

To locate a point in the space a triangulation must be done from two different panoramas:
Two surfaces have to be created and two different projections have to be applied to the those surfaces, then after we move the two surfaces in the space to place the wanted point projection on both in the straight line of their intersection, then the location of the point in the 3d space is located and can be drawn.
This is the only case where the triangulation is needed, but in the next techniques, by exploiting the constraints in the architecture just one projection for modelling is required (mono plotting). Therefore, "Locating Points" is important at the beginning of the modelling as specifying the height of an horizontal plan by locating a point on it, or to locate two points to indicate the orientation of a planar vertical facade. Then, reading and understanding those constraints make it easier to go on modelling.

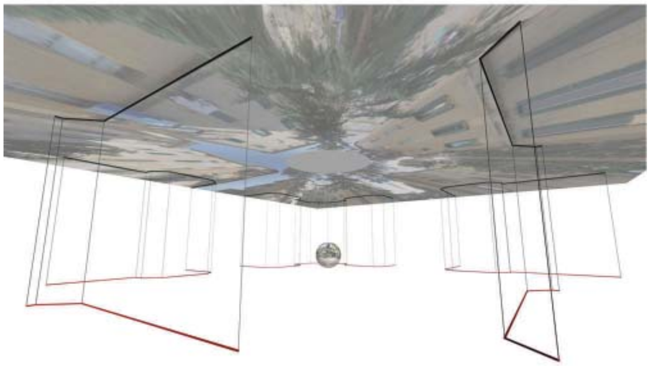
VII.4.2. Tracing planar curves

Knowing that a curve is planar, it is a very important constraint to exploit. At this point no triangulation is needed, but an intersection between straight line and plane required. Therefore, if the plane is identified, just one projection is needed to create curves. Initially, the plane has to be indicated then the active coordinates system has to be aligned to it. The curves could be drawn in two ways. The first way, is to create a plane as a help object and to project the image on it then after to draw on it from any viewport direction moving in the 3D space. The Second way is to project the image on a background object and to draw looking at it from the centre of projection of the panorama.

This is a technique that can be used in many situation in the classical architecture especially, with the mouldings which are usually horizontal or to draw the curves of the facade vertical plan using just one projection



Horizontal projection of the Panorama



7 / Drawing the internal outline using the projection of the central panorama on a horizontal plan has the exact height of a Horizontal planar moulding.

VII.4.3. Modelling by modifying primitives

It starts by a primitive similar to the wanted object model and by projecting the image on it. This could be modified to match two different projections. It is useful when a simple form object is required and that is very common in Architecture (fig.8).

VII.4.4. Modelling by modifying similar shapes

Another common case in Architectural modelling is the repeated objects such as windows, columns and decoration items. If this object is already modelled it could be copied and moved to another location and be modified as and if required (e.g., different dimensions, etc.). In this case some constraints could be exploiting like collinearity as in (figure 9) where a series of columns created from copying one of them and moving it the distance specified by using one projection. And coplanarity, so if two windows are positioned on the same

8 / (up) Modelling the column modifying a cylinder (premetive object), Looking from the centre of projection to the projection on an object behind the column.

9 / (left) Positioning columns in raw using a projection of one photo exploiting the collinearity constraint

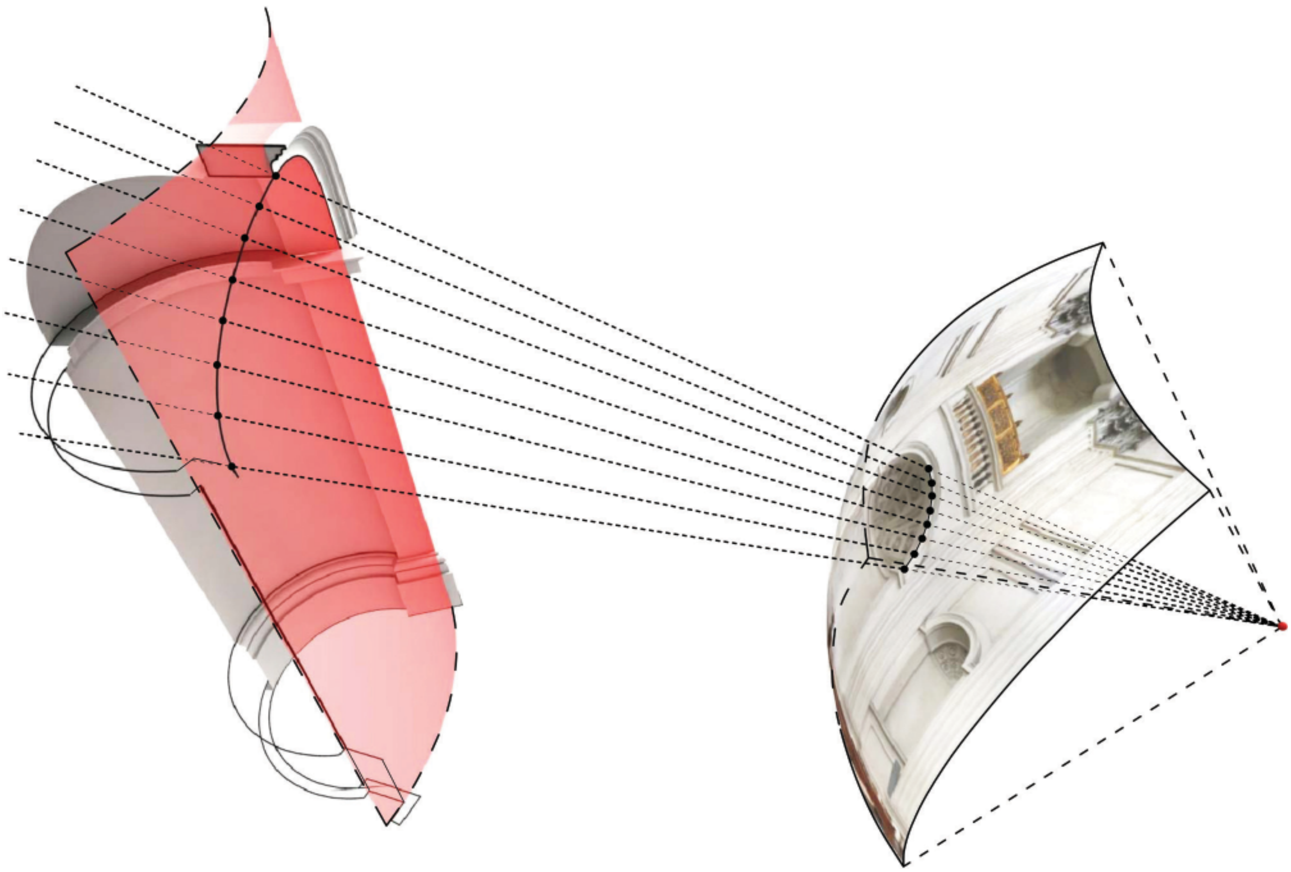
10 / Copying and positioning window polygonal model on the facade surface using a projection of one photo exploiting the coplanarity constraint

planar wall, one projection could be enough to move it to the right place in the 3D space using the wall as a working plane (Fig.9+10).

It is very frequent in Architecture to use the repetitive decoration elements and similar objects, to use symmetry and to use modules in which similar objects are repeated. Consequently, understanding when and where to modify the object to obtain another one is obviously better than creating new one

VII.4.5. Locate points on an identified surface

It is similar to tracing planar curves, no triangulation is needed, but an intersection between straight line and surface is required. If the surface is identified, one projection is enough to create curves, as per the following steps:
First, the surface has to be indicated and created. Second, the active coordinates system has to be tangent in an interactive way to touched surface ("Auto grid" in 3dsMax). In theory it is as drawing on the surface.
The curves could be drawn in two ways. 1) To project the image on this surface then to draw on it from any viewport direction moving in the 3D space 2) To project the image on the background object and obviously make the surface transparent, then to draw on it from the centre of projection of the panorama.
In (Figure 11) an arch in the S Yves church is aligned to the cylindrical surface, then after drawing the section, it was swept along a path which drawn point by point from one projection on the cylindrical surface.



11 / One projection is enough to locate points and to create 3D curves on a specific surface

VII.5. Verifying the correspondence

It is possible to verify the correspondence or the precision of an element position using a new projection. A non-used projection in the modelling of an element can verify if this element is positioned in the right place in its projection from this photograph.

Verifying the model is important thus to the quantity of parameters to orient the projections in the scene so for any error in parameter insertion will cause an imprecision in the model.
In (Figure12) we can verify the correspondence between the plot and the raster image projection in the background, by viewing it from the centre of projection.
In (Figure13) we are looking from a different point than the centre as no correspondence between the plot and the projection in the Background.

12 / viewing it from the centre of projection when the projection is in the background.

13 / looking from a different point than the centre (no correspondence).

Sintesi

La tecnica di modellazione proposta, utilizzando i panorami sferici orientati, è stata studiata per modellare in particolar modo l'architettura sfruttando i vincoli geometrici. Per avere una modellazione veloce e sintetica è fondamentale il riconoscimento e l'identificazione della parte geometrica dell'architettura. Quindi l'operatore deve essere a conoscenza della geometria dell'oggetto rilevato a differenza del rilievo "punto per punto" che viene fatto in altre tecniche di restituzione fotogrammetrica. Un aspetto positivo di questa procedura di modellazione è dato dalla possibilità di modellare tridimensionalmente gli elementi e i segni architettonici con un risultato foto realistico come spesso viene richiesto in un rilievo architettonico. Tutto questo usando un software generico di modellazione non dedicato alla foto-modellazione.

Questa tecnica produce due tipi di informazioni:

1. l'informazione vettoriale relativa ai segni architettonici ed alla sue geometrie (vertici, segmenti, curve...)

2. l'informazione raster che può essere ad alta definizione per descrivere la discontinuità tra i segni architettonici (texture).

Questa tecnica è quindi ideale per rappresentare un'architettura. Produce un modello leggero (low poly) e ben leggibile dall'architetto, dal restauratore o da un visitatore di una città virtuale.

I metodi usati per modellare l'architettura sono:

- *Individuare i punti effettuando una triangolazione tramite l'intersezione di due superfici che ricevono due proiezioni diverse. E' questo l'unico metodo in cui servono due proiezioni. Si utilizza di solito all'inizio della modellazione, prima di ritrovare i primi oggetti, per usare i vincoli;*
- *Disegnare le curve piane, riconoscendo il piano su cui vanno disegnate; si può disegnare su una proiezione o su questo piano direttamente. Si utilizza spesso nei casi delle modanature orizzontali e delle facciate piane;*
- *Modellare modificando le superfici primitive presenti nel programma, come per esempio un cilindro che può diventare una parte della colonna o un cubo per modellare la base di questa colonna;*
- *Modellare modificando oggetti già modellati per ottenere altri simili, come le finestre;*
- *Disegnare curve su superfici identificate; questo metodo è simile a quello delle curve piane ma in questo caso la curva è sghemba.*

Dopo la modellazione degli oggetti si procede alla verifica della corrispondenza usando un'altra proiezione aggiornando progressivamente il modello. Questa fase è importante perché evita di modellare oggetti fidandosi troppo dei vincoli delle geometrie apparentemente ideali ma che in pratica non lo sono.

VIII. Applications

This technique was applied in four different levels of architecture survey. Models were not of high level of details because the priority in this research is to study several cases of surveying using this technique that could face the problems and focus on the differences of the working process in every case.
Those surveys are an Internal space which is the interior of S.Yves church in Rome, an external single facade survey (Porticus Octaviae) using single-Images panorama, Urban Block survey and an urban context survey, for this the Tiber Island was selected as an example of Isolated peace of urban context.

VIII.1. Working process

Phases:
- Taking photos
- Stitching the photos to panoramas
- Panoramas orientation
- Create the virtual space and the projection of the panoramas
- Modelling using the projected panoramas

Equipment:
- Camera;
- Tripod;
- Panoramic head;
- Field note book/sheets.

Main used Programs:
- "PTGui" for stitching panoramas;
- "Create Points" e "Crea" for the orientation;
- 3DsMax for modelling.

To prepare maps for the modelling in 3Ds Mas:
- Create new material by using the panorama as a diffuse map;
- Assign the material to the Object (sphere);
- Apply the modifier UVWmap to the sphere;
- Use the spherical mapping for the UVWmap;
- Flip the U tile if we want the positive normal toward the inside;
- Move the spherical UVWmap gismo and insert the orientation X,Y,Z coordinates;
- Rotate the UVWmap gismo and insert the orientation angles.

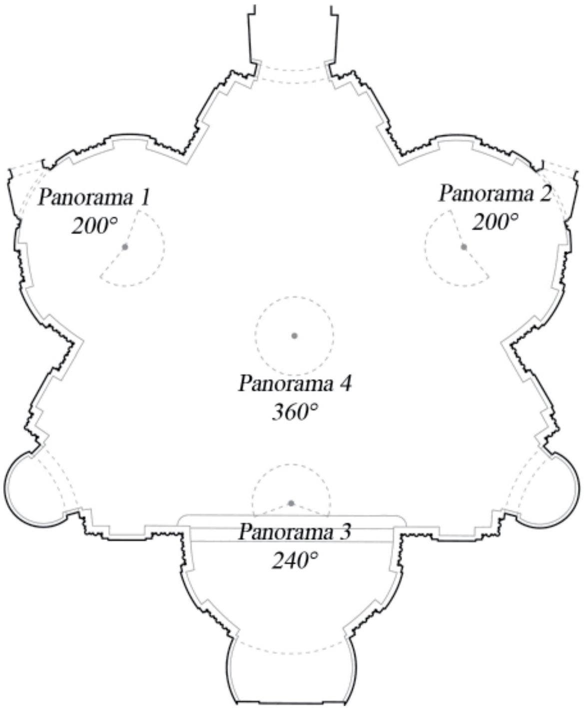
VIII.2. Internal Space Modelling
The Church of Saint Yves at La Sapienza

A masterpiece of the Roman Baroque Church architecture in Rome, Italy, was built in 1642-1660 by the architect Francesco Borromini. Sant'Ivo church is a perfect example of an architectonic complexity of geometry and structure, also of Borromini's the use of symmetry. It is full of Borromini's typical curved surfaces; symbolical meanings weaved into his compositions. Saint Ivo's most prominent feature is its dome.
The church started out as a chapel of the University of Rome palace. The University is called La Sapienza, and the church is devoted to Saint Yves (parton saint of the jurists), giving the church its name. Borromini was forced to adapt his design to the already existing palace. He choose a plan equilateral triangle trimmed by arcs of circles which have the centres in the three angels and the radius 1/6 of the triangle segment. He added to the plan three half circles of the same radius with the centres in the middle of every segment. He created a basis for a hexagonal array of chapels and altar then undulations both concave and convex of the interiors in a centralized church.
He merged the facade of the church with the courtyard of the palace. The dome, with its corkscrew lantern, is remarkable in its novelty. The complex rhythms of the interior have dazzling geometry to them.

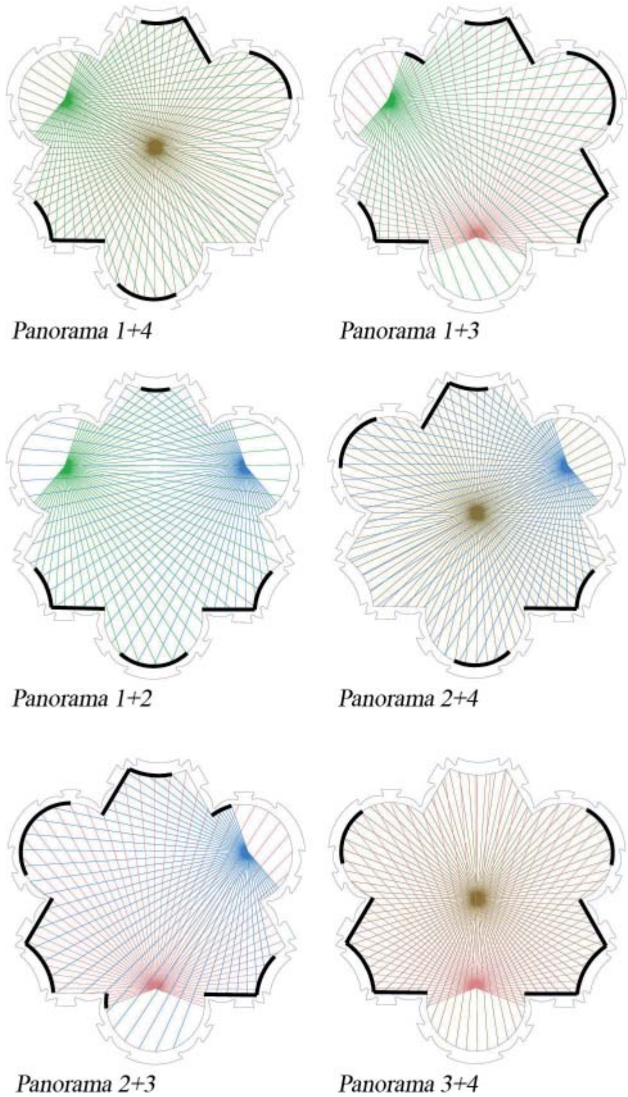
1 / The site plan of S.Yves church Block, scale 1:5000
Global coordinates: Latitude: 41°53'53.53"N Longitude: 12°28'28.40"E

Photographing

The survey started with photographing. 138 photos has been used to create four high resolution panoramas for modelling The position of panoramas is decided to obtain a good coverage of the whole internal space, walls and details.
The following scheme shows the position of all used panoramas in plan, the coverage field and the orientation, afterwards the regions which could be modelled with a good precession using a couple of those panoramas (thick black curves). Those regions are specified based on the angle between two triangulation rays created from the two panoramas centres for those regions. It results, that all walls could be covered by a good triangulation from minimum two panoramas in the specified positions (fig.2).



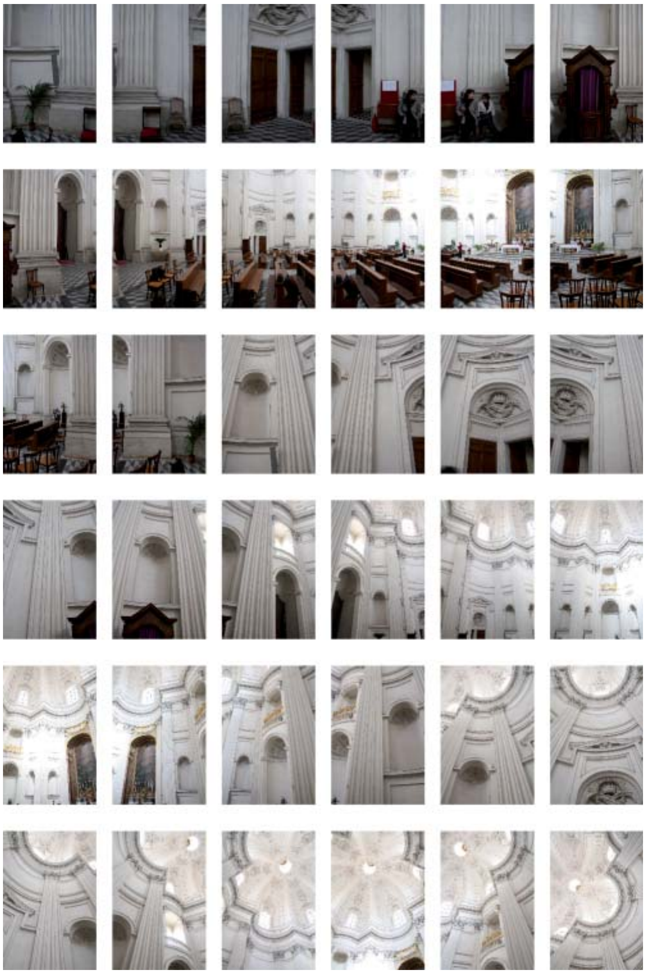
2 / The positions of four panorama stations in the plan



3 / The Parts of the church in plan (Thick black) where the triangulation effected by using the two indicated projection that could has a good precesion.

Panoramas composing and orientation

The multi-image panoramas composed using PTGui software with a particular attention of the verticality constrains in the vertical edges as presented in the photos:



4 / Photos that composed panorama 1

Panorama 1: a 360°panorama formed from 36 photos Captured with 18 mm lens then cropped to FOV 200° X 120° Size in pixel: 11879 x 7100, Size in mb: 14.43

Panorama 2: a 360°panorama formed from 36 photos Captured with 18 mm lens then cropped to FOV 200° X 120° Size in pixel: 11892 x 7135, Size in mb: 14.18

Panorama 3: a 360°panorama formed from 36 photos Captured with 18 mm lens then cropped to FOV 240° X 120° Size in pixel: 14266 x 6923, Size in mb: 13.45

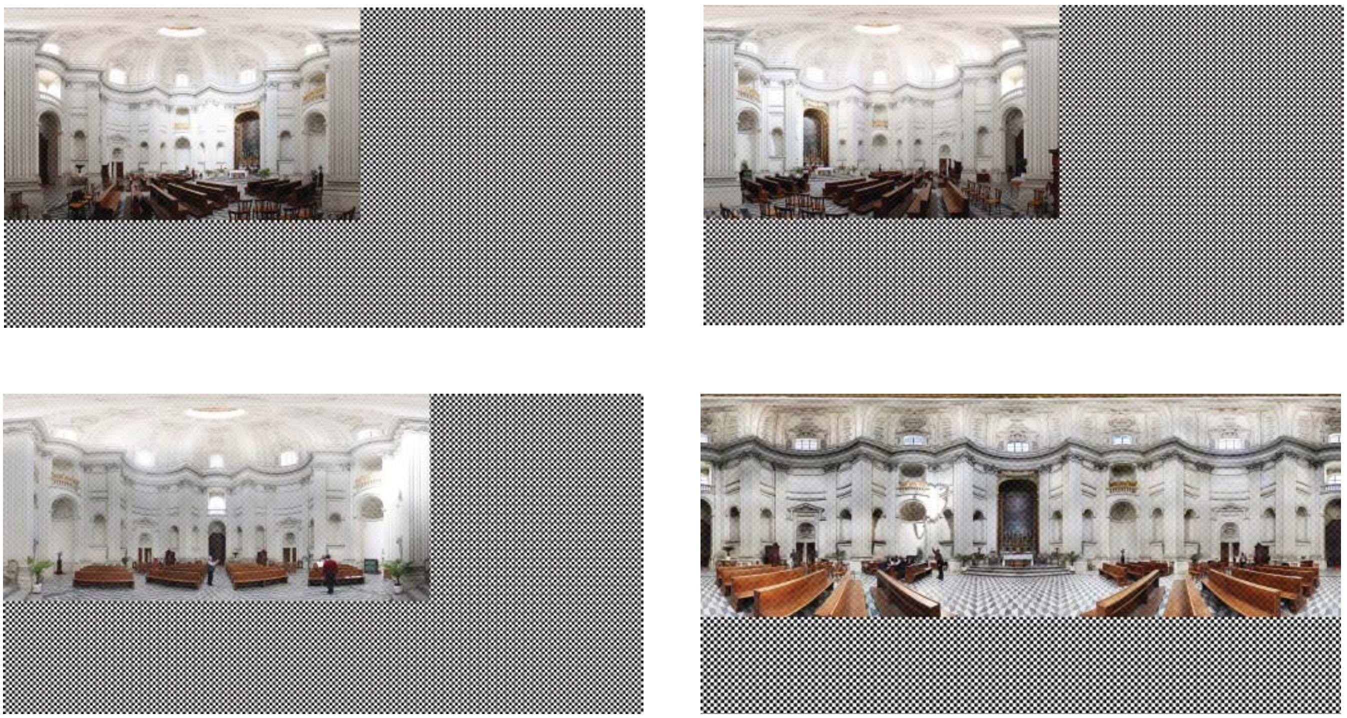
Panorama 4: a 360°panorama formed from 30 photos Captured with 14 mm lens then cropped to FOV 360° X 125° Size in pixel: 18453 x 6424, Size in mb: 13.45

The first three panoramas were cropped to have smaller panoramas which are necessary for the orientation software that support the maximum of 100000 pixels for each one and, it is useful to avoid problems caused by the hardware for a big file size. The ignored zone in those panoramas was the close pavement to the panorama centre where a large quantity of pixels can cover only few details.

Orientation is done using prof. Fangi's series of software "create points", "Crea" and "Pano" as explained in the orientation chapter and the obtained panoramas coordinates are in the table 5.
To apply the panorama in the modelling stage as a complete spherical map, the equirectangular image was completed to cover 360° x 180° using a checked texture with Photoshop (Fig.6).

	Center coordinates			Rotation		
	x	y	z	alfa X	alfa Y	alfa Z
Panorama1	93.94995	83.46109	102.15662	-.0393	.0283	22.4041
Panorama2	106.40111	83.58299	102.13108	.0166	-.0158	155.9153
Panorama3	100.22643	74.24375	102.14938	.0737	.2024	266.4375
Panorama4	100.18713	79.95421	101.83983	-.1037	-.2240	1.9430

5 / Table of the orientation coordinates of the four panoramas



6 / Panoramas position in the complete 360 x 180 spherical projection

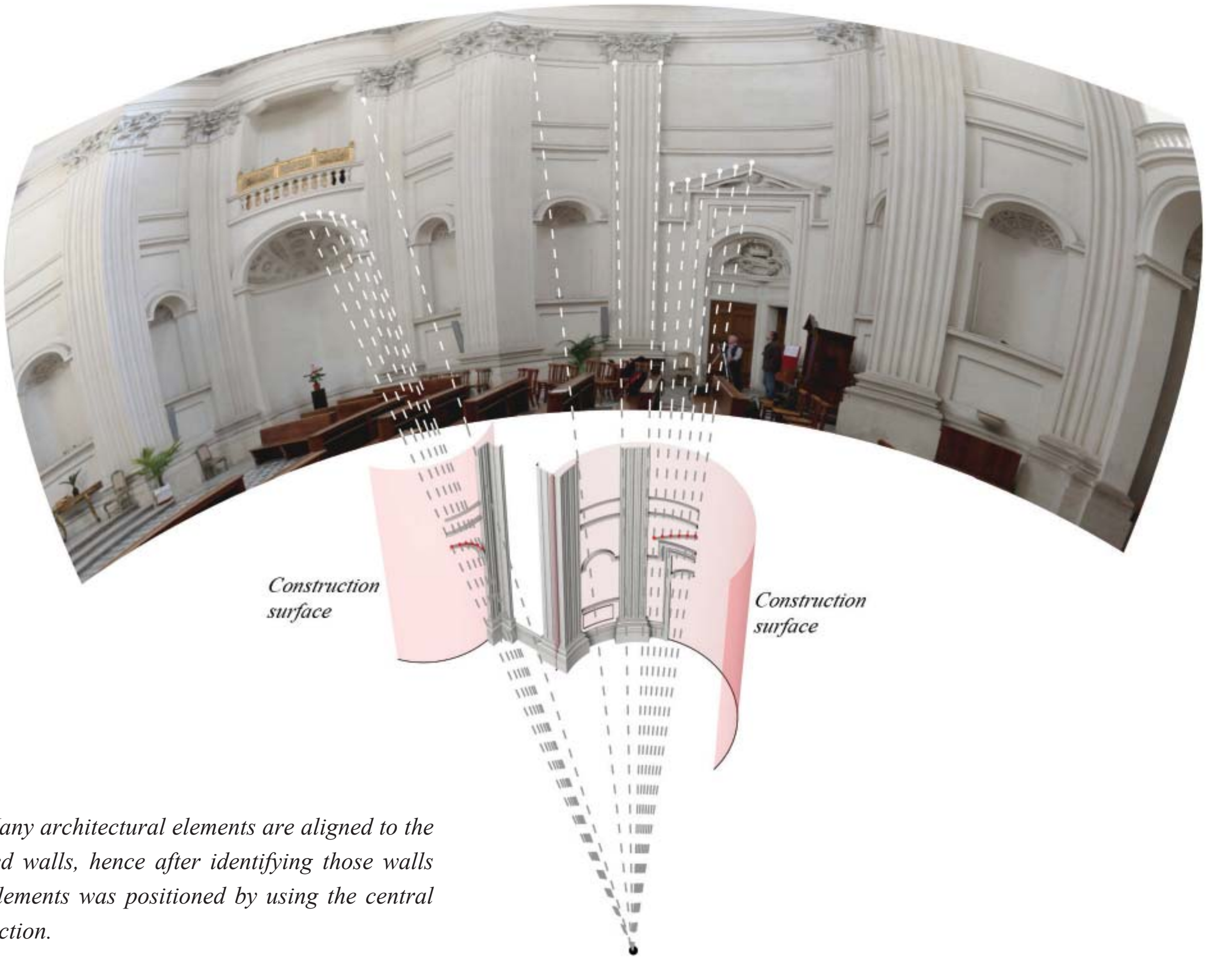
Modelling

In the modelling phase, modelling methods were used as referred to in the Image-based interactive modelling chapter. The requested model in this case is a mathematical one, so in 3ds Max generator curves was created then exported to Rhinoceros that forms the NURBS model.

Here are some methods used to create the Model

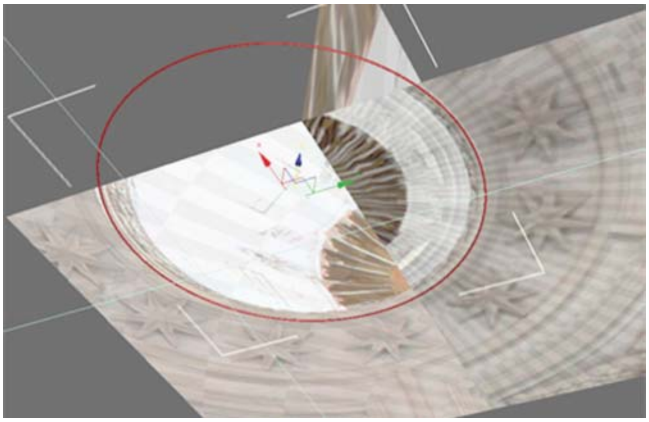
The plan was drew identifying a point corresponds to the height of a horizontal moulding; then a horizontal surface was created on this height; the central panorama was projected on this plan surface; then the path of this moulding was drew in this surface as polyline (which is the same path of the

8 / Positioning the curves in an identified surface

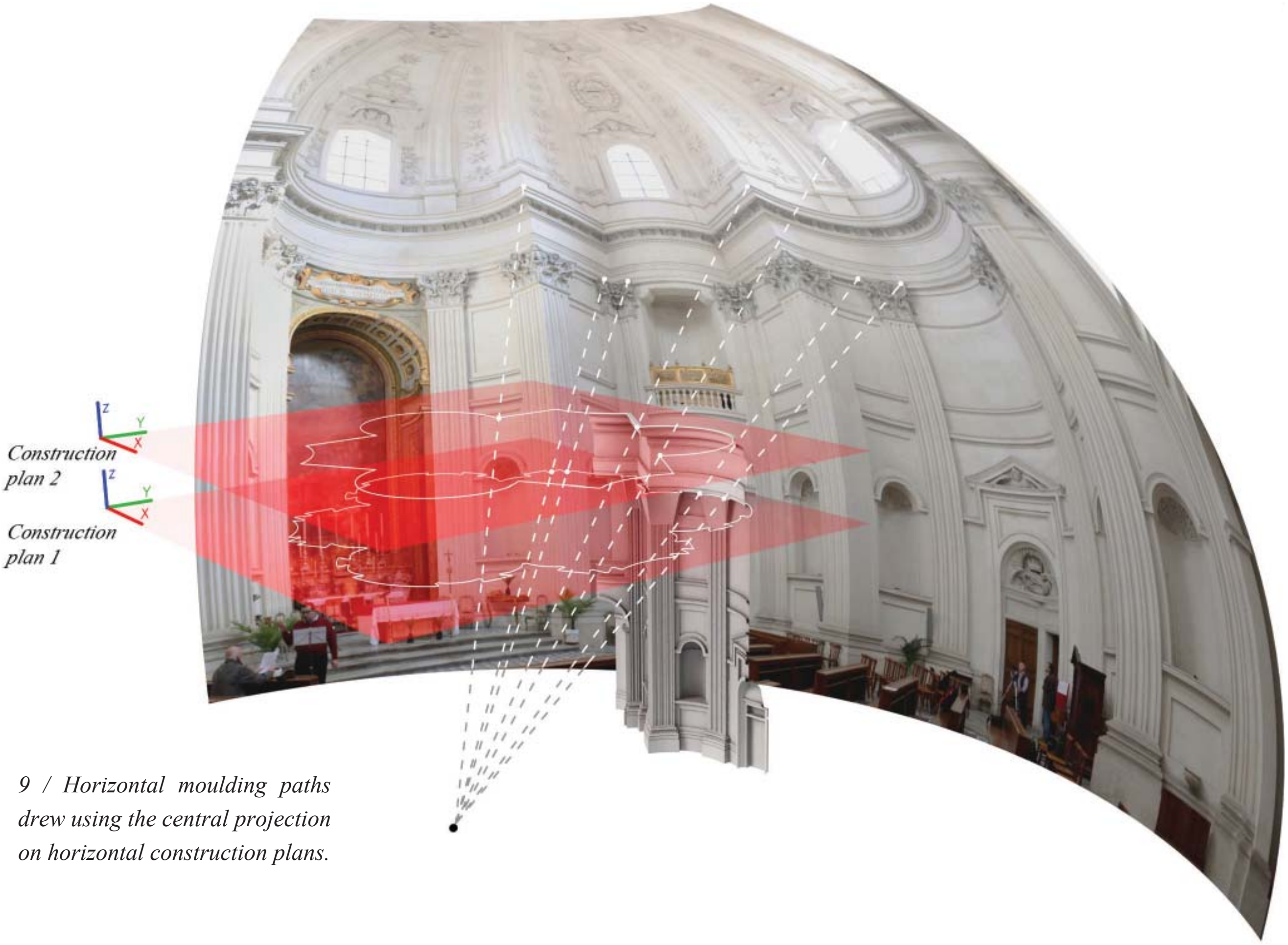


7 / Many architectural elements are aligned to the curved walls, hence after identifying those walls the elements was positioned by using the central projection.

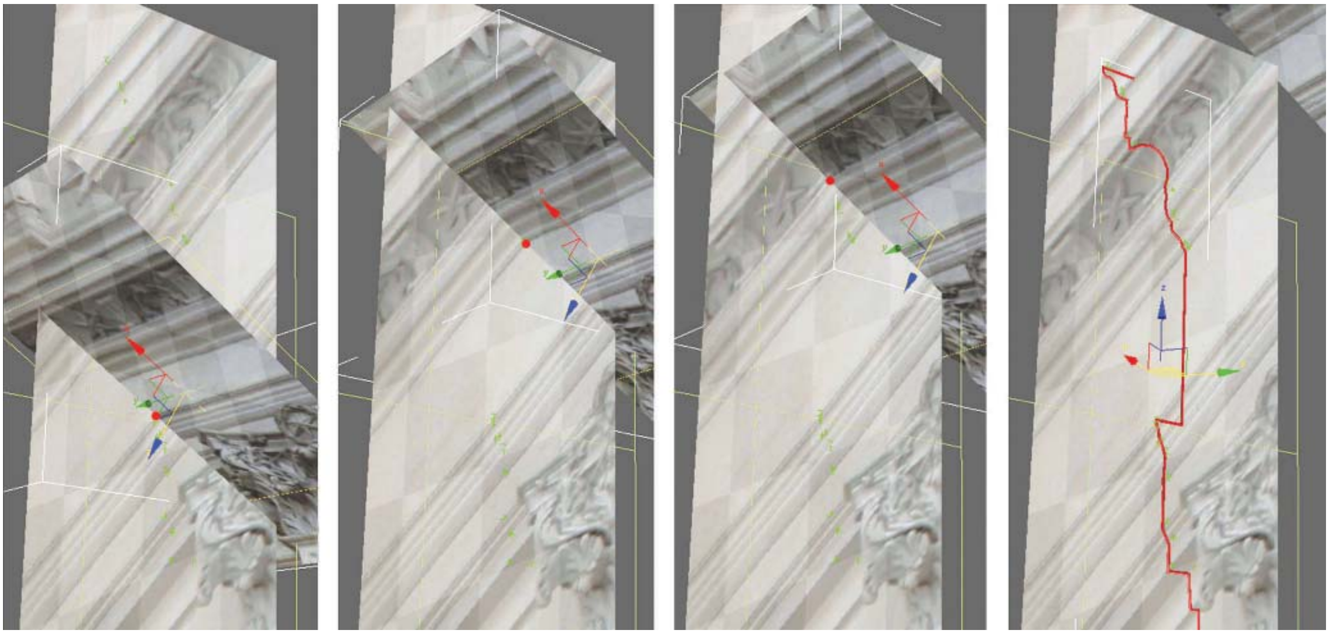
wall), this polyline was extruded in vertical because walls are obviously vertical in such case.To draw the section of moulding, an intersection of two planes is used to locate the points. The first one was perpendicular on the generator curve in an arbitrary point and textured with a panorama, whiles the other plane perpendicular on the first one and textured with a different panorama. By moving the second plane using XForm modifier Gismo, the relative texture position can be changed to find the correspondence points (Fig.11).



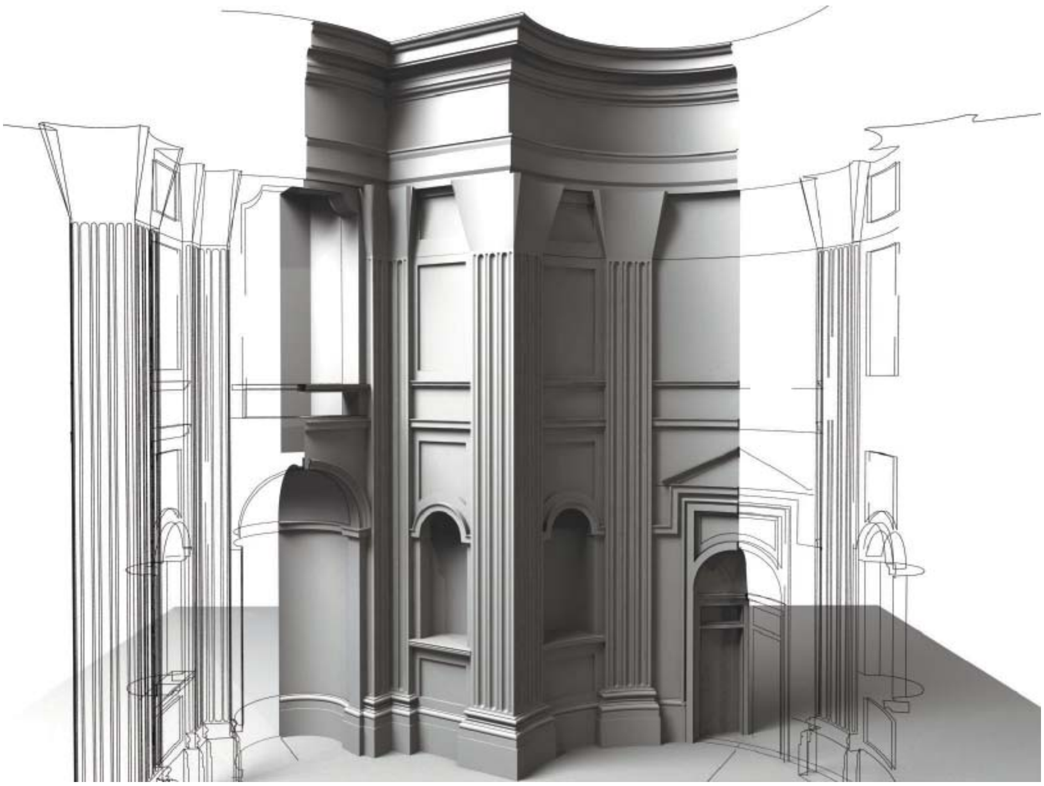
10 / The oculus ring indicated using two different projections on one horizontal surface, by changing the height of this surface. The oculus height is exact when the circle is complete from those two different projections.



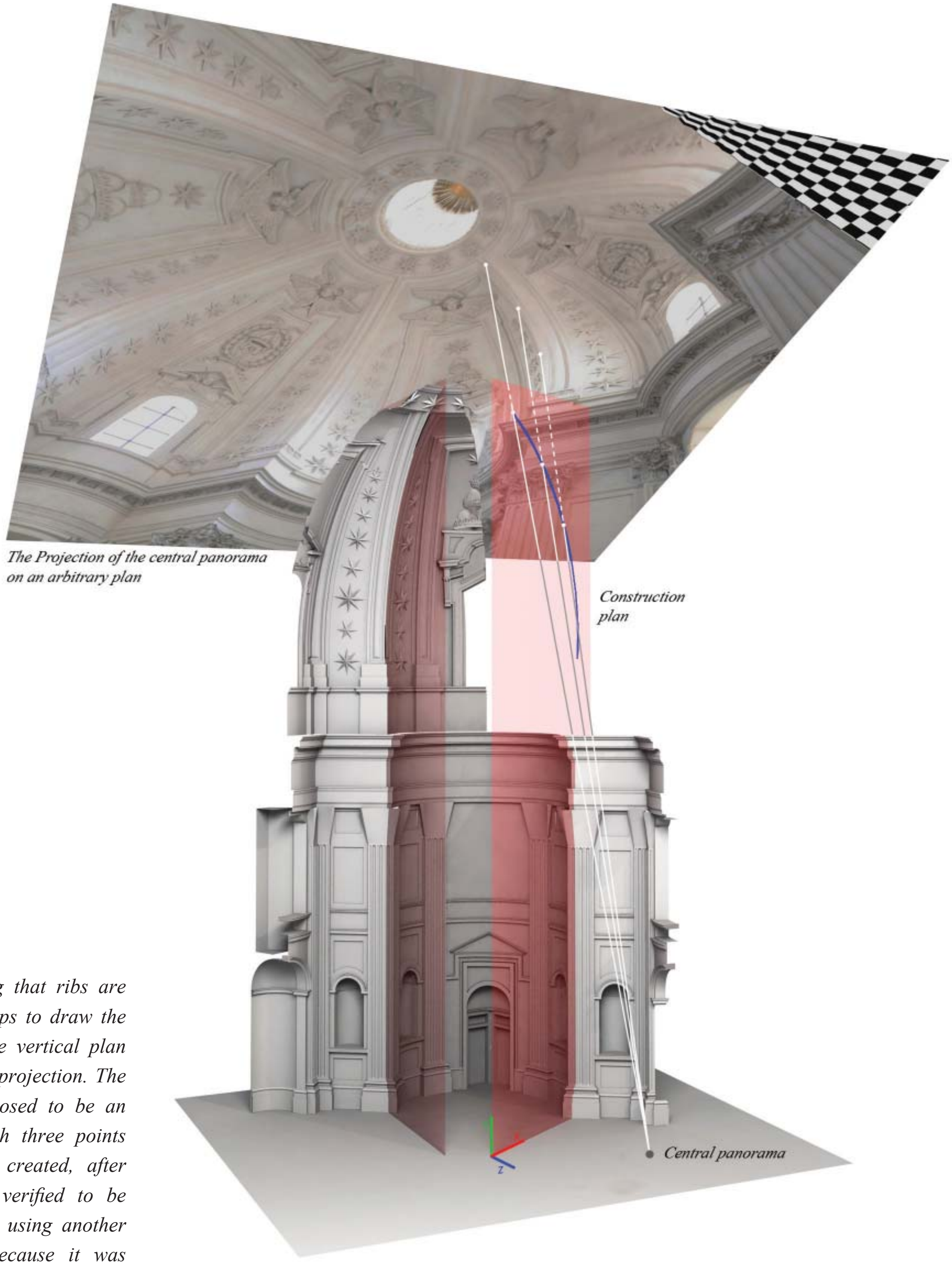
9 / Horizontal moulding paths drew using the central projection on horizontal construction plans.



11 / For some 3D moulding generators courves the "Locate points" technique was used to creat them



12 / To create a NURBS model only a wireframe model was created using 3Ds Max then the model was exported to Rhinoceros to create the surfaces.

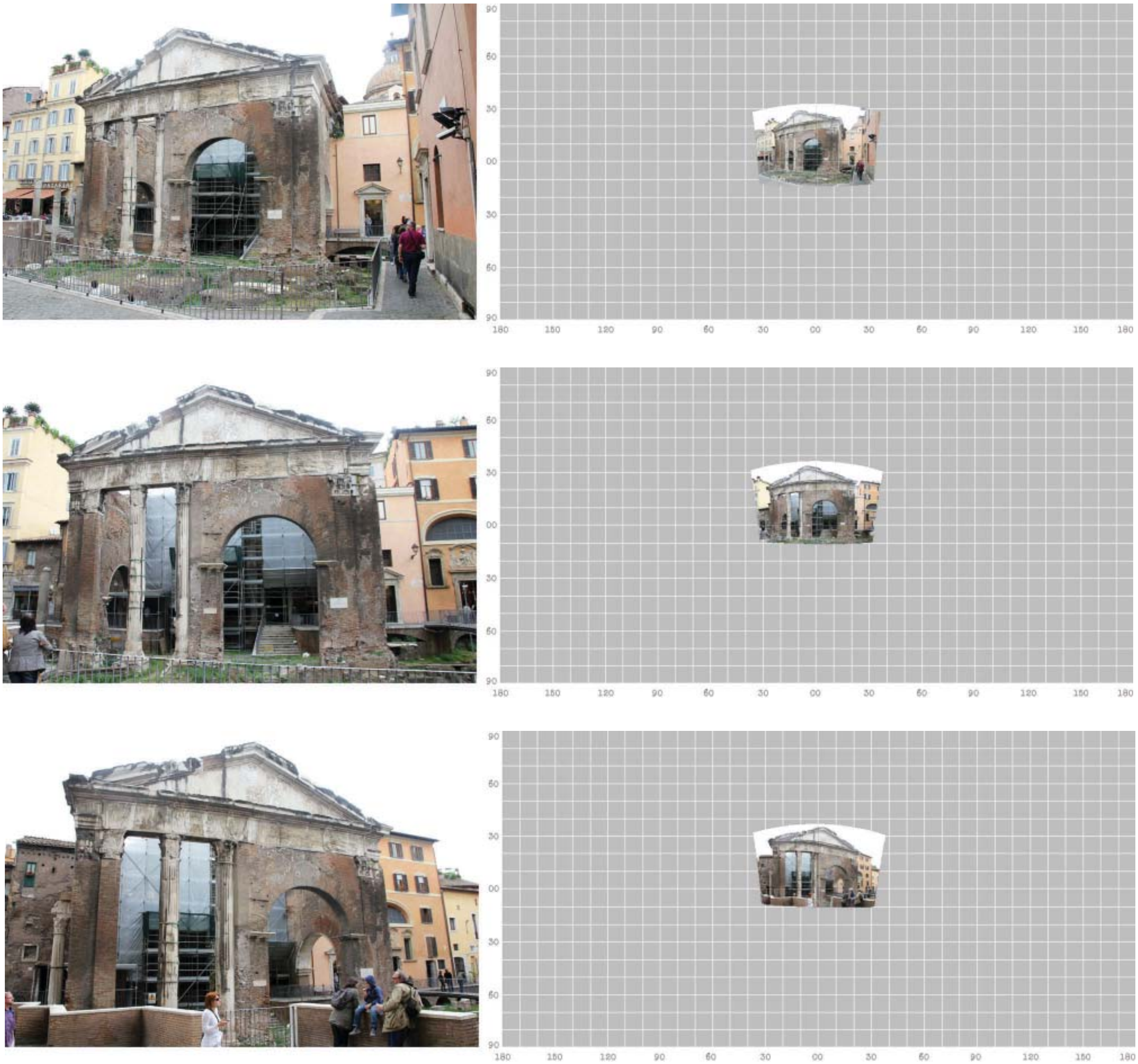


13 / Knowing that ribs are vertical it helps to draw the section on the vertical plan by using one projection. The rib was supposed to be an arc, then with three points the arc was created, after that, it was verified to be really an arc using another projection (because it was correspondent) .

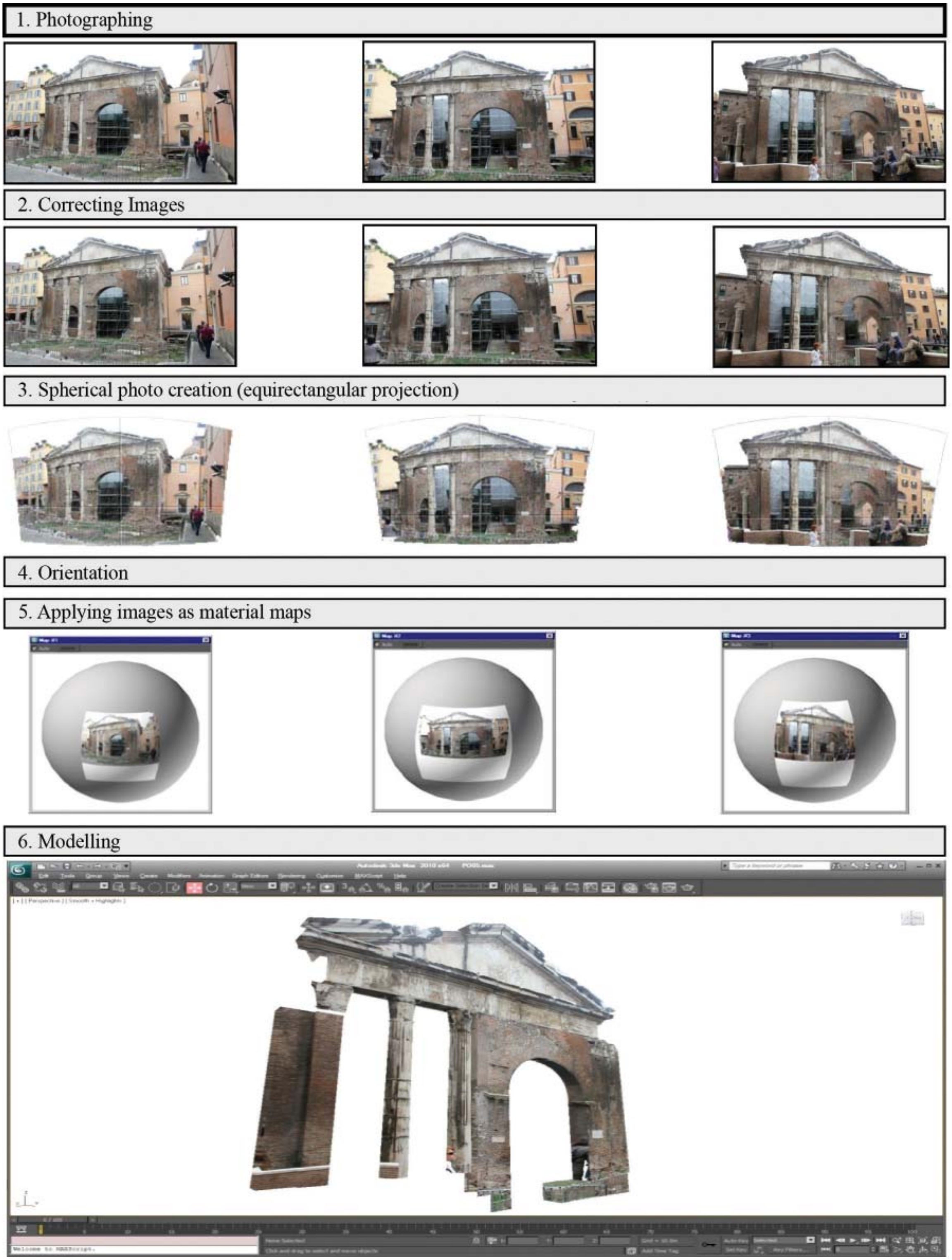
VIII.3. Facade Modelling (From Single-Image Panorama)
Porticus Octaviae

Built by Augustus and dedicated in the name of Octavia this entrance of which some ruins still exist. It had the form of a double pronaos, projecting inward and outward. Across each front of this pronaos, between the side walls, were four Corinthian columns of white marble, supporting an entablature and triangular pediment. The entablature, pediment and two of the columns of the outer front still exist (the other two have been replaced by a brick arch, perhaps after the earthquake of A.D. 442). In the inner front we can see two columns and part of the third with portions of entablature and pediment. The height of the pronaos columns is 8.60 meters.
This monument was selected to be surveyed because it is a small facade with several architectural elements. In this case the survey using single photos could be tried. Using the 17 mm lens the entire facade could be photographed by one shot. That is an example of a small monument to be surveyed simply using three shots without the composing of a multi-image panorama, consequently no need to use the tripod and the panoramic head in this case. But the camera-lens system has to be calibrated to correct images before projecting them as equirectangular images and using them for modelling.
Then, only three photos are used using the maximum of the resolution of the camera sensor which was 18 mp for this modelling. (Figure 15) shows the images and the equirectangular projection of each as a portion of a panorama in the complete 360° x 180° Field of view.
The correction of the photos was done in PTGui by using calibration parameters of the same camera and lens saved from a previous 360° panorama composition as explained in the calibration chapter

14 / The site plan of the surveyed Block, scale 1:2000
Global coordinates: Latitude: 41°53'32.82"N, Longitude: 12°28'42.71"E



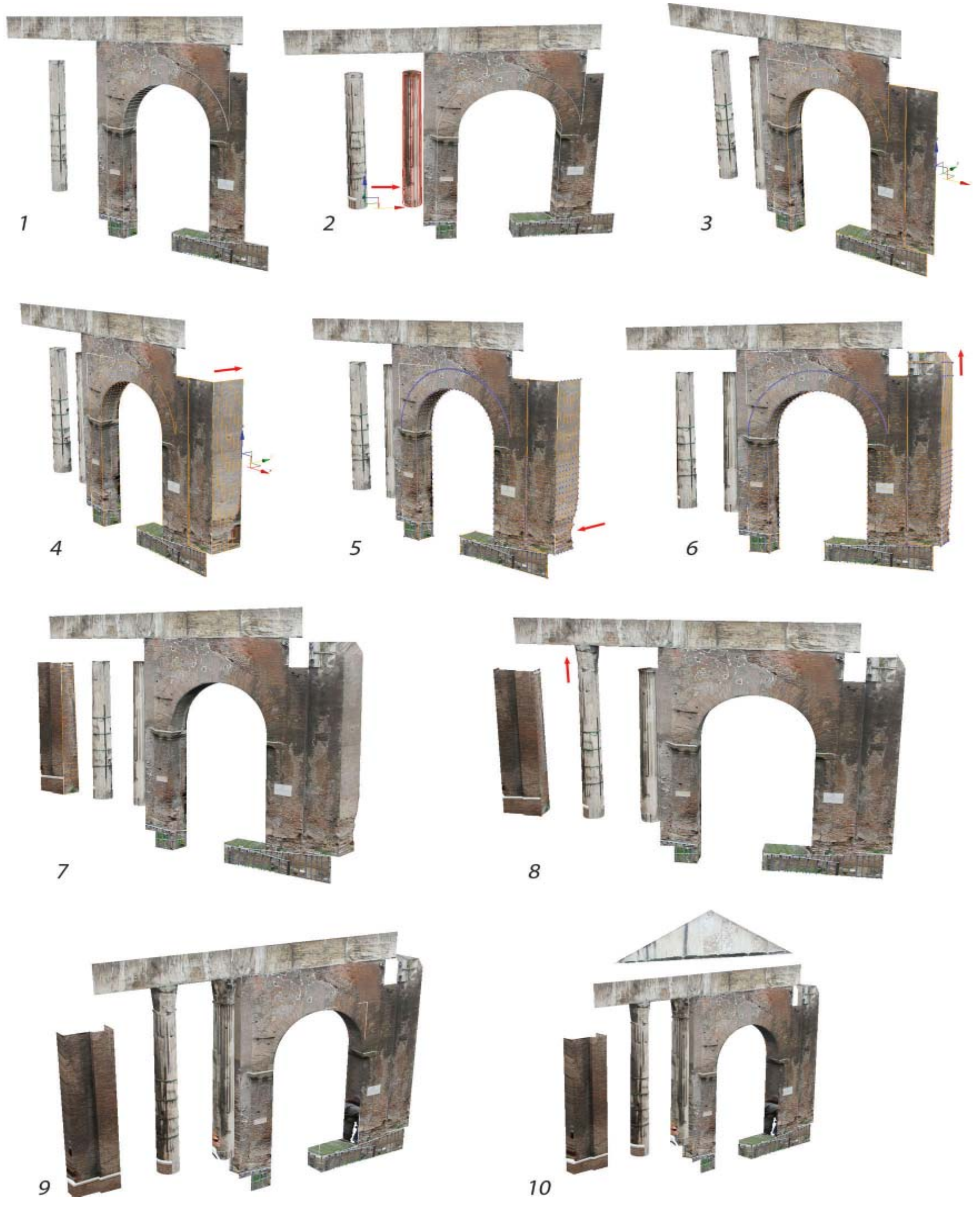
15 / The used photos with their equirectangular projections positioned in a spherical 360° x 180° panorama



16 / Image transformations to arrive to the model.

After the equirectangular projection the single photo is exactly like a panoramic one and the orientation is done in the same way to have the three translations and three rotations. In the modelling phase, modelling was very simple and fast having a simple object and a relatively small size images as projected maps, That mades it possible to avoid hardware and software problems which were present always in the other surveying projects when the maps (photos) were many and so heavy even if the model had always low poly objects. Next is the table of the orientation parameters. Then some steps of the modelling process (Figure 17)

	Center coordinates			Rotation		
	x	y	z	alfa X	alfa Y	alfa Z
Photo 1	23.88847	-3.33019	3.08606	-0.358	-0.1361	340.255
Photo 2	18.01134	-2.73381	3.17688	-0.1824	0.08	357.599
Photo 3	10.75745	-0.95412	3.67111	0.7671	-1.7459	387.111


1
2
3
4
5
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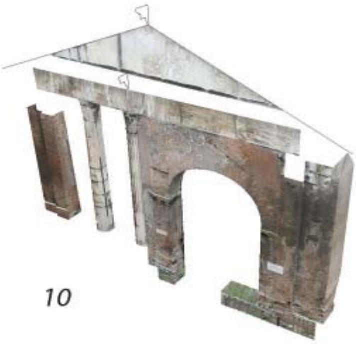
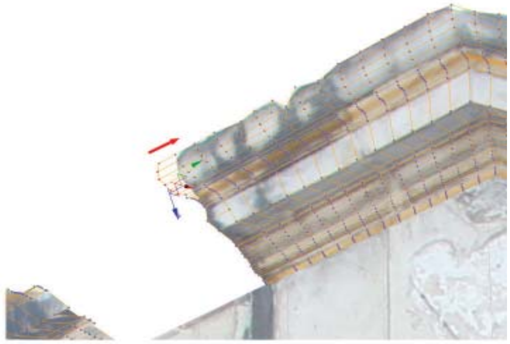
7
8
9
10

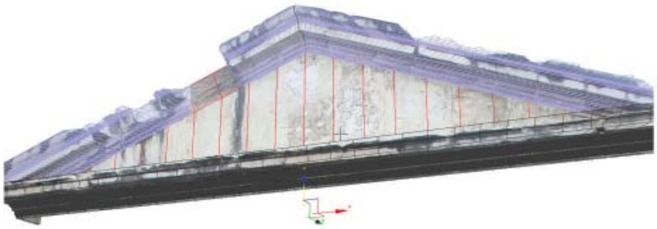

11


10


12


13


14


15


16

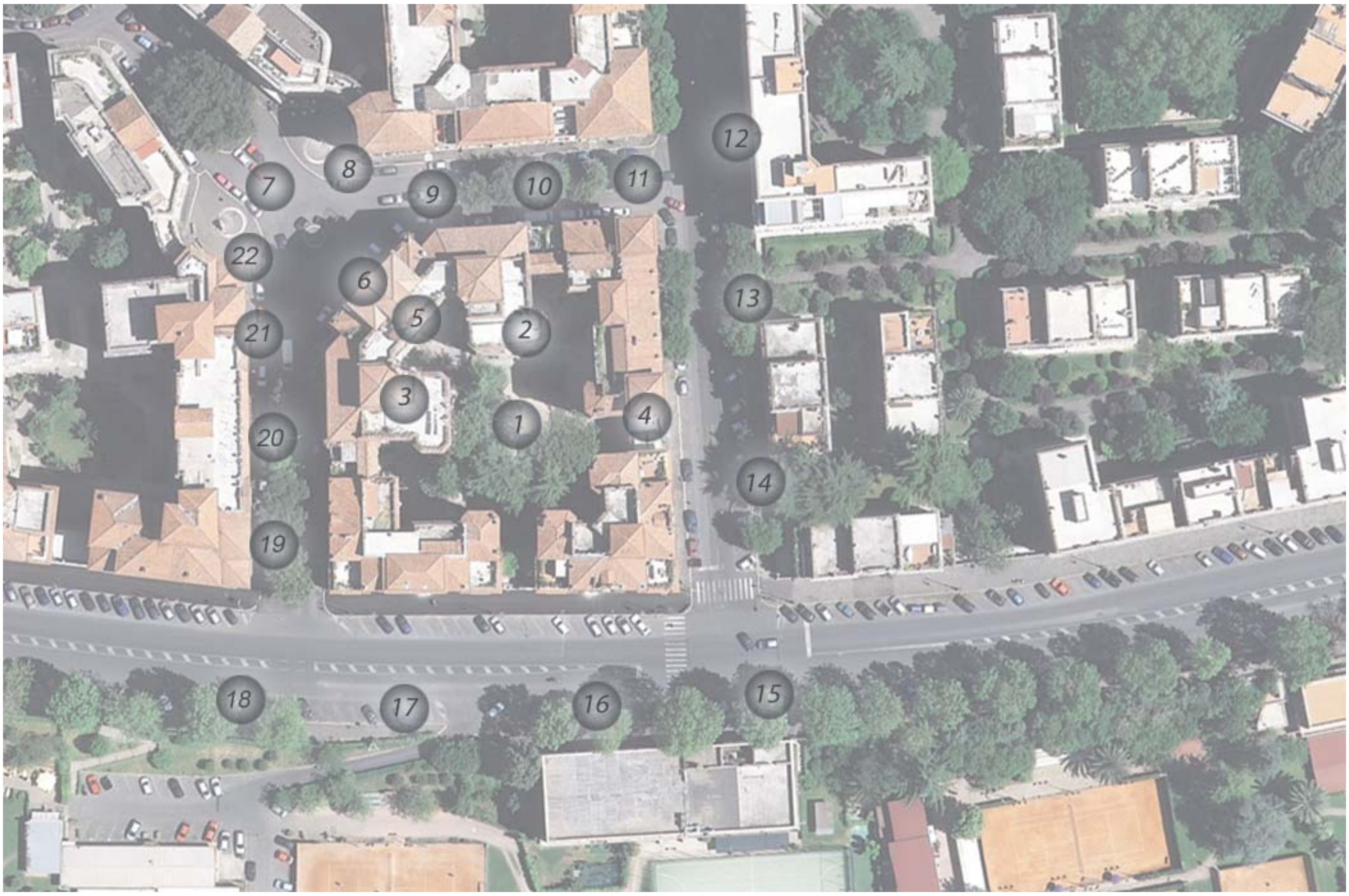

17

17 / Modelling process

VIII.4. Urban Block Modelling

It was completed in 1927 by the Italian architect Mario De Renzi (Roma 1897 -Roma 1967) as his very first project. It occupies about 4200 m^2 of land, the length of the longest facade is about 70 m, contains 4-5 floors and 5 stairwells. The internal courtyard is around 1000 m^2.
This survey is an example of a classical urban block with an internal court. The photos were tacked from all the streets around and some from the roofs but that wasn't enough to cover all the building. The facades of the building had a good precision but the roofs couldn't be photographed entirely therefore, some parts of the building were modelled using the constraints with one projection, but couldn't be verified by other projections. It is clear that in a situation like this it is necessary to make panoramas from a high place around the building as other building roofs even from a far distant using a long focal length lens or a solution could be the use of a geo-referred ortho-rectified aerial photos.

18 / The site plan of the surveyed Block, scale 1:5000
Global coordinates: Latitude: 41°55'26.86"N, Longitude: 12°27'53.97"E

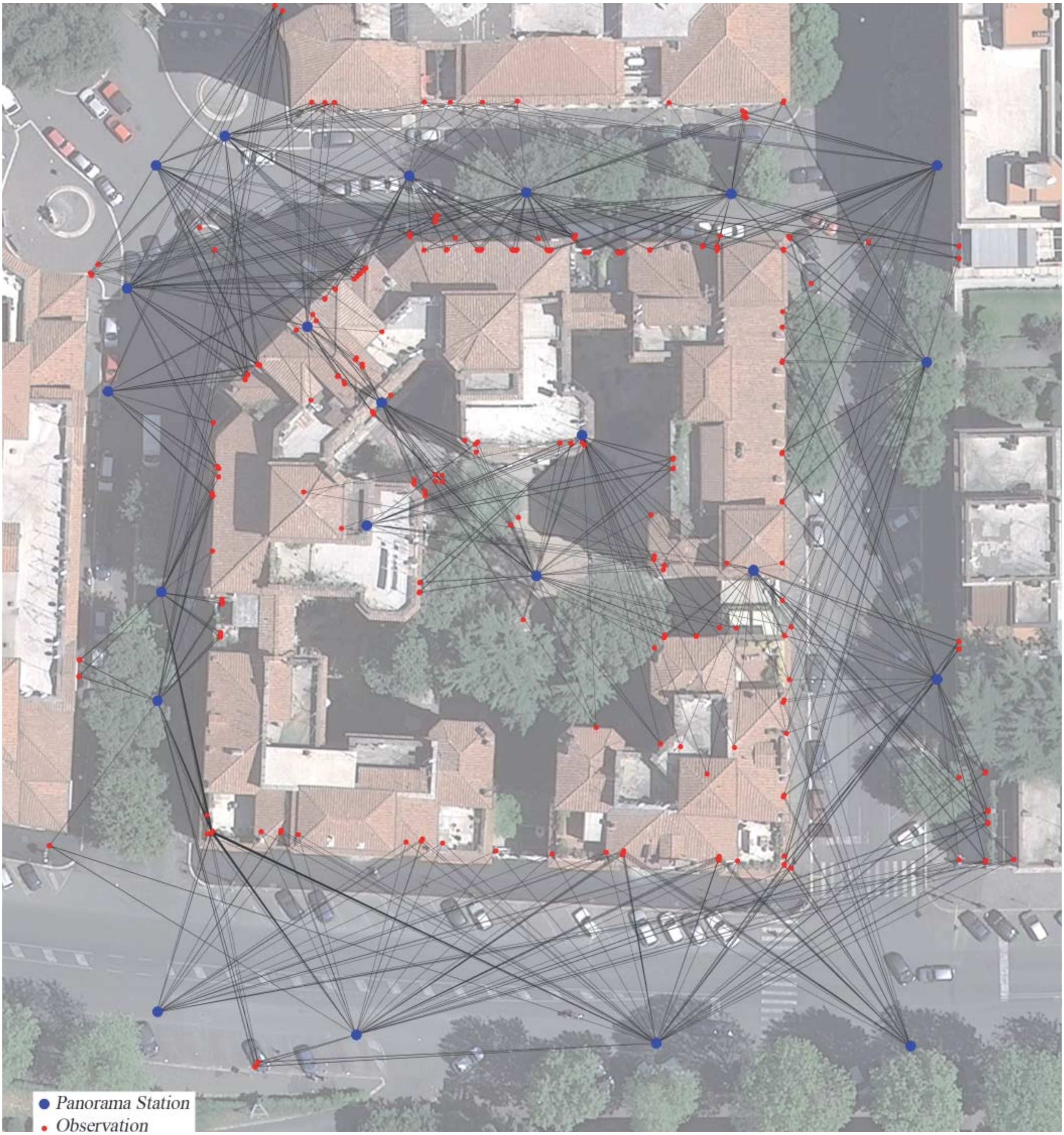


19 / Panorama stations in the survey project In this project 1032 photos with a 17 mm lens was used to create 22 panoramas that could cover the maximum view of the building

Taking the photo in this survey was challenging due to the trees locations that are surrounding the entire building, thus it became difficult to cover all the angles. Furthermore, panorama station was so close to the facade in the narrow streets, then they had to be close to each other. Another challenge was linking the panoramas in the inner courtyard with those outside, therefore two panoramas were taken in the entrance (5 and 6) to connect the internal polygon (panorama 1) with the external (panorama 7), and for more accuracy another panorama (4) was taken from the fourth level balcony were the internal courtyard can be visible and the external eastern street which made it possible to connect the two panoramas (1) and (14).

It was necessary to take panoramas with wide field of view to cover even the buildings around, since the panoramas are very close to the facade, in many observation points collimation rays from two different panorama centres intersect with a very big angle but that creates implications in the orientation that many times orientation software was failed to orient them thus the panoramas was repeated with a bigger field of view to find more collimation points on the surrounding buildings and objects.

20 / The used panoramas



21 / Collimations set to orient the 22 panoramas around and inside the Building

In (figure 21) is the orientation collimation. It was tried to distribute the observations to obtain better orientation, it was quite difficult to obtain a good orientation for this project due to strange angulations in the narrow streets where panoramas where so close to the building then, as we can notice in this figure, some observation where on the other buildings and some fixed objects as road signs.

Next are the tables which contain the parameters of the panoramas as they composed to be oriented. All photographs were taken by using the 17 mm lens with image size of 18 mega pixel. This size of the image with this lens product a spherical 360° panorama of about 315 mega pixel which is a very big file and the software didn't support a file in such dimensions, so after cropping images to the requested field of view every image was reduced to 90 mega pixel if bigger (as described in the taking photos chapter).

In the first table we can see the parameters of the maximum resolution panoramas and in the following one the parameters of the panoramas after reduction and in the two red columns we can observe the two important parameters to be tacked in consideration to the orientation phase which are the top crop and the width of the 360° panorama of every image.

It is clear that the pixel/angle resolution helps to give the priority of the panorama which has the better resolution if we have to choose one of two useful panoramas for the same modelling.

Maximum Resolution Image (17mm Lens) in pixels

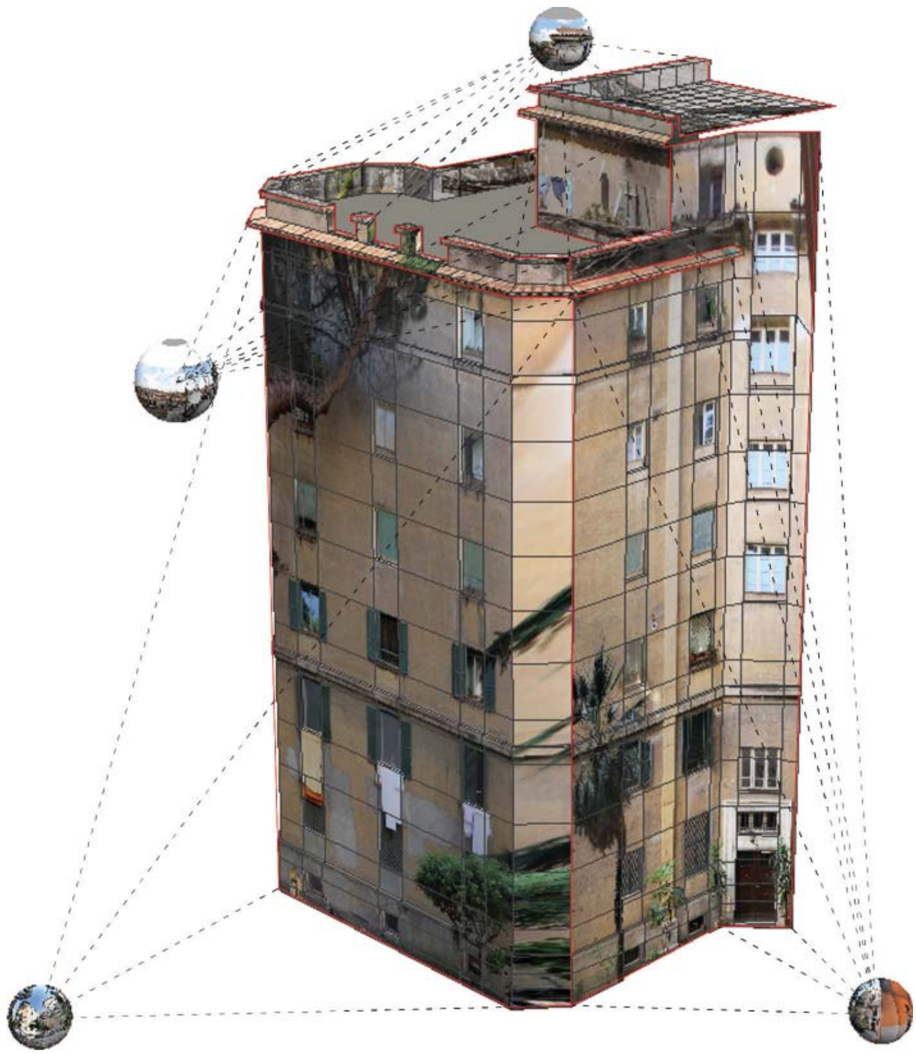
	Lens's Focal Length	Initial Field of View (FOV)		Dimensions of the panorama for the Initial FOV			Dimensions of the panorama for the 360°X180° FOV		Pixel / Angle	Lower Added Crop	Upper Added Crop	Dimension of the Image			New Image Ratio	The New FOV after cropping	
Pano.	mm	W	H	W	H	W x H	W	H		H	H	W	H	WxH	H/W	W	H
01DR	17	360	130	25044	9044	226,497,936	25044	12522	69.57	859	0	25044	8185	204,985,140	0.32682	360	117.66
02DR	17	360	144	26016	10406	270,722,496	26016	13008	72.27	0	2884	26016	7522	195,692,352	0.28913	360	104.09
03DR	17	360	133	25988	9601	249,510,788	25988	12994	72.19	0	2430	25988	7171	186,359,948	0.27594	360	99.34
04DR	17	293	154	20476	10762	220,362,712	25156	12578	69.88	0	1853	20476	8909	182,420,684	0.43509	293	127.48
05DR	17	360	180	25060	12530	314,001,800	25060	12530	69.61	2603	0	25060	9927	248,770,620	0.39613	360	142.61
06DR	17	360	180	25176	12588	316,915,488	25176	12588	69.93	2385	0	25176	10203	256,870,728	0.40527	360	145.90
07DR	17	360	110	25176	7693	193,678,968	25176	12588	69.93	2469	0	25176	5224	131,519,424	0.2075	360	74.70
08DR	17	250	130	17487	9093	159,009,291	25184	12592	69.95	3673	0	17487	5420	94,779,540	0.30994	250	77.49
09DR	17	360	150	24656	10273	253,291,088	24656	12328	68.49	3546	0	24656	6727	165,860,912	0.27283	360	98.22
10DR	17	360	150	24644	10268	253,044,592	24644	12322	68.46	3792	0	24644	6476	159,594,544	0.26278	360	94.60
11DR	17	360	155	24640	10609	261,405,760	24640	12320	68.44	3760	0	24640	6849	168,759,360	0.27796	360	100.07
12DR	17	115	100	8387	7293	61,166,391	26256	13128	72.93	3139	0	8387	4154	34,839,598	0.49529	115	56.96
13DR	17	360	110	24780	7572	187,634,160	24780	12390	68.83	2939	0	24780	4633	114,805,740	0.18697	360	67.31
14DR	17	250	100	17895	7158	128,092,410	25768	12884	71.58	2802	0	17895	4356	77,950,620	0.24342	250	60.85
15DR	17	75	66	5142	4525	23,267,550	24692	12346	68.56	1708	0	5142	2817	14,485,014	0.54784	75	41.09
16DR	17	360	89	24748	6118	151,408,264	24748	12374	68.74	2537	0	24748	3581	88,622,588	0.1447	360	52.09
17DR	17	360	90	24752	6188	153,165,376	24752	12376	68.76	2571	0	24752	3617	89,527,984	0.14613	360	52.61
18DR	17	117	75	8025	5144	41,280,600	24692	12346	68.59	1987	0	8025	3157	25,334,925	0.3934	117	46.03
19DR	17	360	148	24892	10233	254,719,836	24892	12446	69.14	3411	0	24892	6822	169,813,224	0.27406	360	98.66
20DR	17	360	151	24704	10362	255,982,848	24704	12352	68.62	3670	0	24704	6692	165,319,168	0.27089	360	97.52
21DR	17	360	122	24700	8371	206,763,700	24700	12350	68.61	3157	0	24700	5214	128,785,800	0.21109	360	75.99
22DR	17	360	120	24724	8241	203,750,484	24724	12362	68.68	3161	0	24724	5080	125,597,920	0.20547	360	73.97

	Used Image Parameteres									
	Reduction factor	*Dimensions of the panorama for the specific FOV*			***Dimensions of the panorama for the 360°X180° FOV***		**Final Image crop**			*Pixel / Angle Resolution*
Pano.		*W*	*H*	*W x H*	*W*	*H*	*Upper H*	*Lower H*	*Right W*	
01DR	0.6625938	**16594**	**5423**	89,989,262	**16594**	8297	**1152**	1721	0	46.09
02DR	0.6781596	**17643**	**5101**	89,996,943	**17643**	8822	**2838**	882	0	49.01
03DR	0.6949361	**18060**	**4984**	90,011,040	**18060**	9030	**2868**	1179	0	50.17
04DR	0.7023833	**14382**	**6258**	90,002,556	**17669**	8835	**1939**	638	3287	49.09
05DR	0.6014765	**15073**	**5971**	90,000,883	**15073**	7537	**0**	1566	0	41.87
06DR	0.5919129	**14902**	**6039**	89,993,178	**14902**	7451	**0**	1412	0	41.39
07DR	0.8272164	**20826**	**4321**	89,989,146	**20826**	10413	**2025**	4067	0	57.85
08DR	0.9744382	**17040**	**5281**	89,988,240	**24540**	12270	**1705**	5284	7500	68.16
09DR	0.7366158	**18162**	**4955**	89,992,710	**18162**	9081	**757**	3369	0	50.45
10DR	0.7509333	**18506**	**4863**	89,994,678	**18506**	9253	**771**	3619	0	51.41
11DR	0.730276	**17994**	**5001**	89,987,994	**17994**	8997	**625**	3371	0	49.98
12DR	1	**8387**	**4154**	34,839,598	**26256**	13128	**2918**	6057	17869	72.93
13DR	0.8853914	**21940**	**4102**	89,997,880	**21940**	10970	**2133**	4735	0	60.94
14DR	1	**17895**	**4356**	77,950,620	**25768**	12884	**2863**	5665	7873	71.58
15DR	1	**5142**	**2817**	14,485,014	**24692**	12346	**3911**	5619	19550	68.56
16DR	1	**24748**	**3581**	88,622,588	**24748**	12374	**3128**	5665	0	68.74
17DR	1	**24752**	**3617**	89,527,984	**24752**	12376	**3094**	5665	0	68.76
18DR	1	**8025**	**3157**	25,334,925	**24692**	12346	**3601**	5588	16667	68.59
19DR	0.7280251	**18122**	**4967**	90,011,974	**18122**	9061	**806**	3289	0	50.34
20DR	0.7378157	**18227**	**4937**	89,986,699	**18227**	9114	**734**	3442	0	50.63
21DR	0.8359514	**20648**	**4359**	90,004,632	**20648**	10324	**1663**	4302	0	57.36
22DR	0.8465054	**20929**	**4300**	89,994,700	**20929**	10465	**1744**	4420	0	58.14

The next table contains the orientation parameters. The orientation was done in this case fixing the horizontal rotations of the panoramas as we can see in the X and Y rotation columns. It was difficult for the software to calculate the orientation with a good accuracy for the three axes as said before due to the low accuracy triangulations in the narrow streets but, after fixing the horizontal rotations, considering that the vertical axis of panorama coordinates systems are exact and ignoring the correction angles of the verticality which are usually small rotations.
Then we have the texture mapping parameters to be used in 3DsMax for projecting the panoramas. Tiling is to be used to identify the proportion of the image compared with the entire sphere projection in U and V directions.
Offset is to indicate how much the map is to be moved up and down to put the horizon in the right place by changing V offset, and to move it to the left to make it start from the origin. This parameter is different from the zero when u tiling is different from 1 because, 3DsMax scales the image around the centre of the equirectangular projection and as described in the fundamentals chapter the projection has to start from the left as origin. We can see that this parameter is always negative if it is not Zero.

	Orientation Parameters						Texture Parameters			
	Translation			*Rotation*			*Tiling*		*Offset*	
Pano.	*X*	*Y*	*Z*	*X*	*Y*	*Z*	*U*	*V*	*U*	*V*
01DR	0	0	1.5	0	0	183.7728	1.000	1.530	0.000	0.034
02DR	4.908	14.402	26.554	0	0	345.8727	1.000	1.729	0.000	-0.111
03DR	-18.872	4.082	30.118	0	0	326.22444	1.000	1.812	0.000	-0.094
04DR	24.668	-0.377	22.255	0	0	39.71682	1.229	1.412	-0.093	-0.074
05DR	-17.356	19.409	2.342	0	0	35.95941	1.000	1.262	0.000	0.104
06DR	-25.254	27.566	2.486	0	0	42.03144	1.000	1.234	0.000	0.095
07DR	-42.299	45.479	2.441	0	0	315.43182	1.000	2.410	0.000	0.098
08DR	-34.546	48.88	2.254	0	0	26.28693	1.440	2.323	-0.153	0.146
09DR	-13.814	44.223	2.621	0	0	6.14232	1.000	1.833	0.000	0.144
10DR	-0.512	42.523	2.8	0	0	1.9701	1.000	1.903	0.000	0.154
11DR	22.65	42.467	3.083	0	0	8.26515	1.000	1.799	0.000	0.153
12DR	46.409	45.906	2.704	0	0	171.72459	3.131	3.160	-0.340	0.120
13DR	44.747	23.519	3.33	0	0	89.97093	1.000	2.674	0.000	0.119
14DR	45.112	-12.116	4.464	0	0	151.03647	1.440	2.958	-0.153	0.109
15DR	41.91	-53.08	5.225	0	0	281.46906	4.802	4.383	-0.396	0.069
16DR	13.521	-52.295	4.597	0	0	183.56517	1.000	3.455	0.000	0.103
17DR	-20.092	-51.063	4.716	0	0	183.15792	1.000	3.422	0.000	0.104
18DR	-41.798	-48.412	5.356	0	0	343.48473	3.077	3.911	-0.338	0.080
19DR	-41.686	-13.747	4.484	0	0	278.49249	1.000	1.824	0.000	0.137
20DR	-41.088	-1.318	4.049	0	0	279.80136	1.000	1.846	0.000	0.149
21DR	-47.343	19.492	2.928	0	0	259.50798	1.000	2.368	0.000	0.128
22DR	-45.495	31.756	2.914	0	0	284.75874	1.000	2.434	0.000	0.128

During the modelling, in this survey, the maximum imprecision detected is less than 15 cm in zones covered by minimum 2 projections. It was noticeable that those panoramas were less than the requirement, since some of them were quite far from the object to be modelled. Anyway, model precision was not so bad considering that a survey in this dimensions were made by using only 22 panoramic stations, and the average distance between the panorama centre and its projection on the modelled object was around 35 meters.



22 / An internal part of the Building's model shows the textures projected from four different panoramas, the red seams shows the separation between two different projections.

23 / Modelling

24 / South Elevation wireframe, the detailed part of the model

VIII.5. Urban Context Modelling (The Tiber Island)

The Tiber Island (Italian: Isola Tiberina, Latin: Insula Tiberina), is a boat-shaped island which was for long associated with healing. It is an ait, and the only island in the Tiber river which runs through Rome. The island has been linked to the rest of Rome by two bridges since antiquity, and was once called Insula Inter-Duos-Pontes which means “the island between the two bridges”. Tiber Island was once the location of an ancient temple to Aesculapius, the Greek god of medicine and healing. This location may have been chosen for the Aesculapius Temple because it was separate from the rest of the city, which could help protect whoever was there from plague and illnesses. The island eventually became so identified with the temple it supported that it was modeled to resemble a ship as a reminder of how it was.
Travertine facing was added in mid or late first century by the banks to resemble a ship’s prow and stern, and an obelisk was erected in the middle, symbolizing the vessel’s mast. Walls were put around the island, and it came to resemble a Roman ship. Although the Aesculapius temple now lies deep under San Bartolomeo, the island is still considered to be a place of healing because a hospital, founded in 1584, was built on the island and is still operating. It is staffed by the Hospitaller Order of St. John of God or “Fatebenefratelli”.

25 / The site plan of the surveyed site, scale 1:10000
Global coordinates: Latitude: 41°53'26.38"N, Longitude: 12°28'39.00"E

26 / Panorama stations in the survey project

In an open space like this, it was easier to take photos from the survey in the urban block. The photo was taken principally in two levels, the street level and the river level. The vertical difference between them is around 12 meters. Compared to the extensively site, they are almost coplanar because the distance between the panorama centres is most far from each other in about 450 m.

Here there is the problem of the extensive site. Using 50 mm focal length was useful to obtain good resolution panoramas, but the problem was the precision of the modelling program. The modelling program has the limit of precision for the coordinates of the projected map. We can find that in (Figure 30) the map coordinates section of the material editor where we have to insert the parameters calculated to position the map in the complete field of view (360°x180°). The precision of those parameters is limited to three digits after the decimal point.

Then in this model, a problem was noticeable. The quality of the orientation was good and the panoramas where in a high resolution, while they were rather far, as the solution could be more panoramas closer, maybe in the Island but not only around it however, more panoramas create another type of problem.

The other problem were the hardware limits. The used RAM of 4 GB was not enough to support all of the memory for an interactive visualisation during modelling. The model has


01IT.jpg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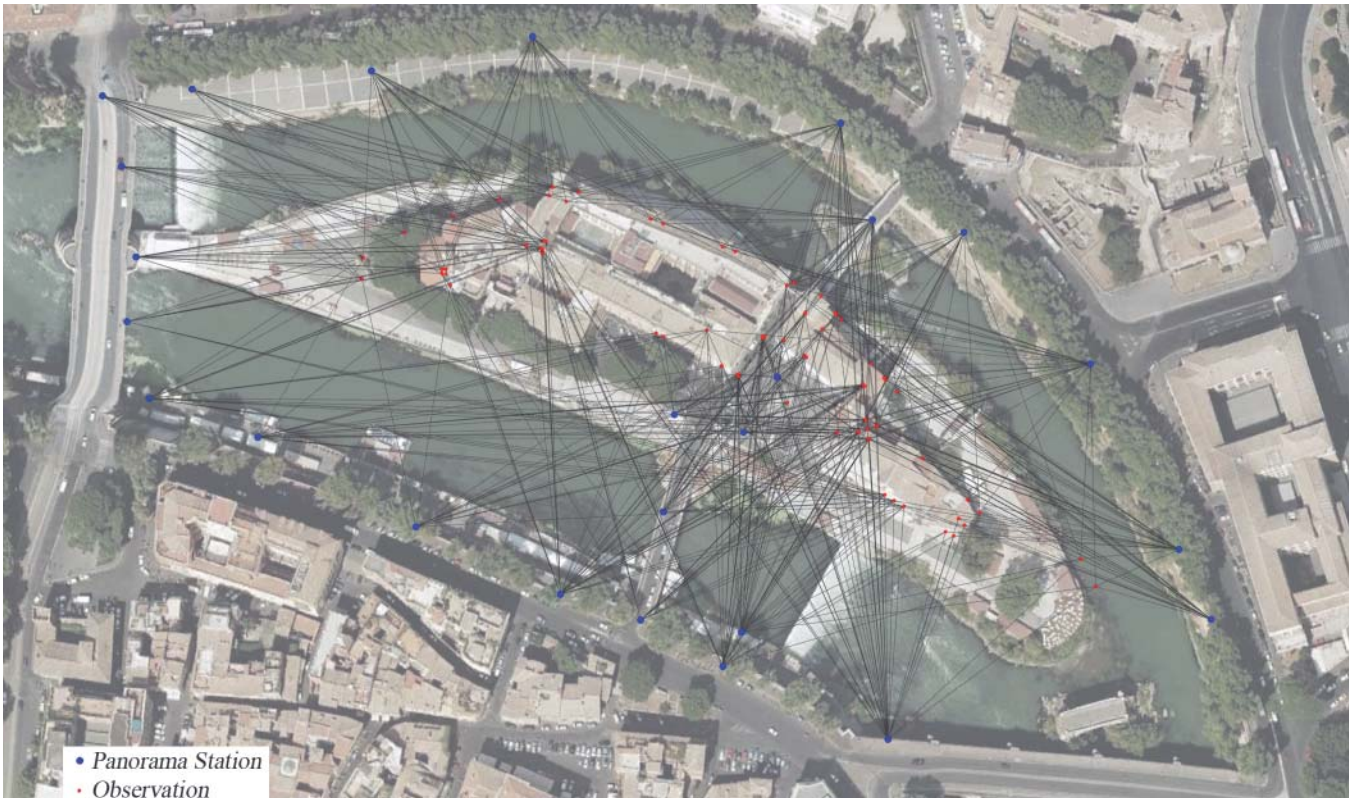
25IT.jpg

27 / The used panoramas



28 / Collimations set to orient the 25 panoramas around and inside the Island

very big resolution maps, which is an important factor for the quality of the model and obviously Image-based modelling cannot be possible in wireframe mode of visualisation. One solution was to reduce the quality of colours to make the file smaller however it wasn't enough. The model had to be divided in parts to continue going on. The solution for this problem is simple: more RAM.
It could be useful in case of an urban context modelling to associate an aerial Image to the model to be a base to start modelling from.

Maximum Resolution Image (50mm Lens) in pixels

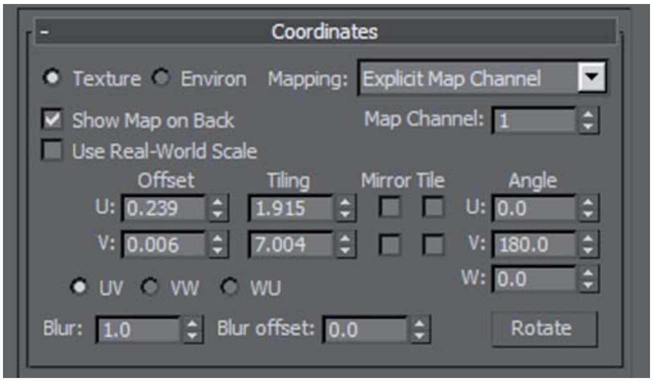
	Lens's Focal Lenght	Initial Field of View (FOV)		Dimensions of the panorama for the Initial FOV			Dimensions of the panorama for the 360°X180° FOV		Pixel / Angle	Lower Added Crop	Upper Added Crop	Dimension of the Image			New Image Ratio	The New FOV after cropping	
Pano.	mm	W	H	W	H	W x H	W	H		H	H	W	H	WxH	H / W	W	H
IT01	50	188	28	36708	5463	200,535,804	70292	35146	195.26	445	0	36708	5018	184,200,744	0.1367	188	25.70
IT02	50	232	44	45069	8548	385,249,812	69936	34968	194.26	0	0	45069	8548	385,249,812	0.18966	232	44.00
IT03	50	228	47	43541	8976	390,824,016	68750	34375	190.97	0	0	43541	8976	390,824,016	0.20615	228	47.00
IT04	50	200	44	39489	8688	343,080,432	71080	35540	197.45	2245	0	39489	6443	254,427,627	0.16316	200	32.63
IT05	50	226	50	42606	9426	401,604,156	67870	33935	188.52	0	0	42606	9426	401,604,156	0.22124	226	50.00
IT06	50	184	52	35150	9934	349,180,100	68772	34386	191.03	0	0	35150	9934	349,180,100	0.28262	184	52.00
IT07	50	168	33	30934	6076	187,954,984	66286	33143	184.13	0	0	30934	6076	187,954,984	0.19642	168	33.00
IT08	50	120	29	21784	5264	114,670,976	65352	32676	181.53	0	0	21784	5264	114,670,976	0.24165	120	29.00
IT09	50	113	27	22188	5302	117,640,776	70688	35344	196.35	0	0	22188	5302	117,640,776	0.23896	113	27.00
IT10	50	124	32	21750	5613	122,082,750	63146	31573	175.40	0	0	21750	5613	122,082,750	0.25807	124	32.00
IT11	50	108	30	19847	5513	109,416,511	66158	33079	183.77	0	0	19847	5513	109,416,511	0.27777	108	30.00
IT12	50	90	35	17729	6895	122,241,455	70916	35458	196.99	0	1514	17729	5381	95,399,749	0.30351	90	27.32
IT13	50	131	30	25877	5926	153,347,102	71112	35556	197.53	748	0	25877	5178	133,991,106	0.2001	131	26.21
IT14	50	162	40	30173	7450	224,788,850	67052	33526	186.25	1340	0	30173	6110	184,357,030	0.2025	162	32.80
IT15	50	170	47	33569	9281	311,553,889	71088	35544	197.46	2504	0	33569	6777	227,497,113	0.20188	170	34.32
IT16	50	177	56	34866	11031	384,606,846	70914	35457	196.98	3299	0	34866	7732	269,583,912	0.22176	177	39.25
IT17	50	200	55	37966	10441	396,403,006	68340	34170	189.83	2886	0	37966	7555	286,833,130	0.19899	200	39.80
IT18	50	177	42	35024	8311	291,084,464	71236	35618	197.88	1931	0	35024	6380	223,453,120	0.18216	177	32.24
IT19	50	140	30	27191	5827	158,441,957	69920	34960	194.22	1026	0	27191	4801	130,543,991	0.17657	140	24.72
IT20	50	82	36	17468	6835	119,393,780	68352	34176	213.02	0	1996	17468	4839	84,527,652	0.27702	82	22.72
IT21	50	137	61	27081	12058	326,542,698	71164	35582	197.67	2890	0	27081	9168	248,278,608	0.33854	137	46.38
IT22	17	360	83	24387	5623	137,128,101	24388	12194	67.74	0	0	24387	5623	137,128,101	0.23057	360	83.01
IT23	17	360	112	24450	7607	185,991,150	24450	12225	67.92	1363	0	24450	6244	152,665,800	0.25538	360	91.94
IT24	17	360	76	24344	5139	125,103,816	24344	12172	67.62	0	0	24344	5139	125,103,816	0.2111	360	76.00
IT25	17	360	56	24520	3814	93,519,280	24520	12260	68.11	0	0	24520	3814	93,519,280	0.15555	360	56.00

Used Image Parameteres

	Reduction factor	Dimensions of the panorama for the specific FOV			Dimensions of the panorama for the 360°X180° FOV		Final Image crop			Pixel / Angle Resolution
Pano.		W	H	W x H	W	H	Upper H	Lower H	Right W	
IT01	0.669663289	**24582**	**3360**	82,604,625	**47072**	23536	**9939**	10237	22490	130.76
IT02	0.483347756	**21784**	**4132**	90,004,008	**33803**	16902	**6385**	6385	12019	93.90
IT03	0.479915482	**20896**	**4308**	90,014,146	**32994**	16497	**6095**	6095	12098	91.65
IT04	0.512193269	**20226**	**3300**	66,747,038	**36407**	18203	**6877**	8027	16181	101.13
IT05	0.473407501	**20170**	**4462**	90,005,380	**32130**	16065	**5801**	5801	11960	89.25
IT06	0.507681366	**17845**	**5043**	89,997,808	**34914**	17457	**6207**	6207	17069	96.98
IT07	0.69195707	**21405**	**4204**	89,993,708	**45867**	22934	**9365**	9365	24462	127.41
IT08	0.885879545	**19298**	**4663**	89,991,783	**57894**	28947	**12142**	12142	38596	160.82
IT09	0.874707049	**19408**	**4638**	90,008,419	**61831**	30916	**13139**	13139	42423	171.75
IT10	0.85862069	**18675**	**4819**	90,003,003	**54218**	27109	**11145**	11145	35543	150.60
IT11	0.906938076	**18000**	**5000**	89,999,093	**60001**	30001	**12500**	12500	42001	166.67
IT12	0.858029218	**15212**	**4617**	70,234,644	**60848**	30424	**13553**	12254	45636	169.02
IT13	0.766085713	**19824**	**3967**	78,637,681	**54478**	27239	**11350**	11923	34654	151.33
IT14	0.632751135	**19092**	**3866**	73,811,761	**42427**	21214	**8250**	9098	23335	117.85
IT15	0.537489946	**18043**	**3643**	65,722,879	**38209**	19105	**7058**	8404	20166	106.14
IT16	0.483737739	**16866**	**3740**	63,083,228	**34304**	17152	**5908**	7504	17438	95.29
IT17	0.476505294	**18091**	**3600**	65,127,555	**32564**	16282	**5653**	7029	14473	90.46
IT18	0.556047282	**19475**	**3548**	69,089,153	**39611**	19805	**7592**	8666	20136	110.03
IT19	0.75370527	**20494**	**3619**	74,158,338	**52699**	26350	**10979**	11752	32205	146.39
IT20	0.819727502	**14319**	**3967**	56,798,624	**56030**	28015	**12842**	11206	41711	174.62
IT21	0.524980614	**14217**	**4813**	68,426,738	**37360**	18680	**6175**	7692	23143	103.77
IT22	0.810144749	**19757**	**4555**	90,001,906	**19758**	9879	**2662**	2662	1	54.88
IT23	0.695664622	**17009**	**4344**	73,882,502	**17009**	8505	**1606**	2554	0	47.25
IT24	0.848135064	**20647**	**4359**	89,991,314	**20647**	10324	**2982**	2982	0	57.35
IT25	0.980995106	**24054**	**3742**	89,998,410	**24054**	12027	**4143**	4143	0	66.82

	Orientation Parameters						Texture Parameters			
	Translation			*Rotation*			*Tiling*		*Offset*	
Pano.	*X*	*Y*	*Z*	*X*	*Y*	*Z*	*U*	*V*	*U*	*V*
IT01	983.629	889.970	89.838	0.41004	0.36693	255.74526	1.915	7.004	-0.239	0.006
IT02	920.141	887.947	82.174	1.0548	-0.5886	241.85034	1.552	4.091	-0.178	0
IT03	847.862	891.426	79.154	0.16272	-0.0378	242.06976	1.579	3.830	-0.183	0
IT04	1016.796	895.164	80.000	0.17586	0.22626	257.17419	1.800	5.516	-0.222	0.032
IT05	1054.831	908.935	78.573	-0.16947	-0.07794	243.69687	1.593	3.600	-0.186	0
IT06	1054.308	893.444	89.324	0.09486	0.28962	268.4313	1.957	3.461	-0.244	0
IT07	1126.104	897.201	90.223	-0.56007	-0.5985	265.00383	2.143	5.455	-0.267	0
IT08	772.177	933.623	91.641	1.0539	0.54144	7.25571	3	6.207	-0.333	0
IT09	763.538	901.307	93.610	-0.12114	-0.12114	4.15485	3.186	6.666	-0.343	0
IT10	802.233	885.651	87.609	2.36412	0.35775	328.27311	2.903	5.625	-0.328	0
IT11	750.755	963.208	93.632	1.73682	1.85157	36.42714	3.333	6.000	-0.350	0
IT12	731.341	984.817	94.114	1.61181	0.96804	54.3375	4	6.589	-0.375	-0.021
IT13	762.009	1003.285	82.079	1.56087	0.17244	54.24876	2.748	6.867	-0.318	0.011
IT14	822.506	1041.901	83.262	1.46295	-0.05229	50.17671	2.222	5.487	-0.275	0.020
IT15	873.697	1082.970	82.891	1.01934	0.45495	69.28596	2.118	5.245	-0.264	0.035
IT16	998.784	1107.611	79.838	-0.74646	0.60759	83.42388	2.034	4.586	-0.254	0.047
IT17	1062.153	1090.874	80.530	0.30537	0.16623	102.18132	1.800	4.523	-0.222	0.042
IT18	1130.769	1066.822	80.024	0.72747	0.05418	119.80782	2.034	5.583	-0.254	0.027
IT19	1195.551	1016.835	78.838	0.47925	1.16397	168.85818	2.571	7.282	-0.306	0.015
IT20	1219.518	997.778	87.568	-1.10178	0.50364	205.42572	3.913	7.063	-0.386	-0.029
IT21	1027.400	1078.927	91.167	1.41723	0.10296	124.39368	2.628	3.881	-0.310	0.041
IT22	1019.717	980.368	89.136	0.1125	-0.04698	169.50303	1	2.169	0.000	0
IT23	1021.732	1006.033	88.125	0.31077	0.26109	177.62103	1	1.958	0.000	0.056
IT24	991.879	974.225	89.836	0.31689	-0.13671	231.45363	1	2.369	0.000	0
IT25	1005.448	937.649	91.227	0.91062	0.23202	57.53412	1	3.214	0.000	0


29 / The panoramas as maps in the material editor.



30 / The coordinates of the first panorama.

31 / Snapshot of a part of the model

32 / Snapshot of a part of the model

Notes
1. *Topographical Dictionary of Ancient Rome , London: Oxford University Press, 1929.*

Sintesi

La tecnica è stata applicata su quattro differenti tipi di rilievo:

A) il rilievo di uno spazio interno (la Chiesa di S.Ivo alla Sapienza) con quattro panorami a 360° fatti con obbiettivi di 14 e 18mm;

B) una facciata apparentemente semplice nella configurazione geometrica ma complessa nella sua stratificazione (portico d'Ottavia) in cui sono state usate tre foto singole con obiettivo di 17 mm, corrette dalle distorsioni e poi proiettate e trattate come le foto panoramiche multi-immagine;

C) un isolato urbano omogeneo composto da più edifici a corte interna (un'opera dell'architetto Mario De Renzi) per cui sono stati usati 22 panorami con obbiettivo di 17mm;

D) un contesto urbano particolarmente articolato e ricco di episodi storici (l'isola Tiberina) con 25 panorami usando il 50mm per i panorami lontani e il 17mm per quelli vicini.

Si nota che nei panorami con i centri lontani dall'oggetto rilevato è meno importante la precisione del centro del "no-parallasse" perché è un errore relativamente molto piccolo rispetto alla dimensione del modello; invece in un rilievo di piccola dimensione il mancato controllo di questo dato può comportare una imprecisione notevole.

Il cambiamento della lunghezza focale secondo la distanza ha permesso di avere immagini di alta risoluzione anche da centri lontani (come il caso dell' isola Tiberina). La precisione ricavata è inversamente proporzionale con la dimensione dell'oggetto rilevato ma può dipendere anche dai limiti di precisione riscontrabili nei software di modellazione e nell'impostazione dei parametri di proiezione delle mappe.

Per i primi due rilievi i panorami erano sufficienti rispetto alla dimensione ma nel terzo è stato necessario avere altri panorami dall'alto per coprire tutti i tetti. Nell'applicazione dell'isola Tiberina la maggior parte dei panorami sono stati fatti intorno all'isola principalmente su due quote, dal lungotevere e dalla banchina che costeggia il fiume con una differenza di quasi 12 metri tra il panorama più alto e quello più basso; i panorami sono stati realizzati su un'area molto estesa (la distanza tra i due più lontani tra di loro è quasi 450m) perciò sono relativamente complanari rispetto al modello. In casi come questi una piccola imprecisione nella mappatura può abbassare la qualità del modello. Si può però ovviare facendo altri panorami più vicini o associando una foto aerea georeferenziata.

IX. Comparative analysis

Analysing method and results

Accuracy is the agreement of a measurement with a recognized standard or the “true” value; and Precision is the degree of which similar or repeated measurements show the same results.
You need high precision to get high accuracy but, highly precise measurements are not necessarily accurate.
In measurement, and photogrammetry in particular, precision and accuracy are words that are sometimes confused. Why would that be? It may be that photogrammetric programs calculate good estimates of precision solely from their internal information.
Since these figures can be presented clearly, it is easy to fall into the trap of looking at these precision values as if they represent true accuracy.

In fact, accuracy validation can only be done by comparing results against an accepted measurement (a standard or a measurement of known higher accuracy).

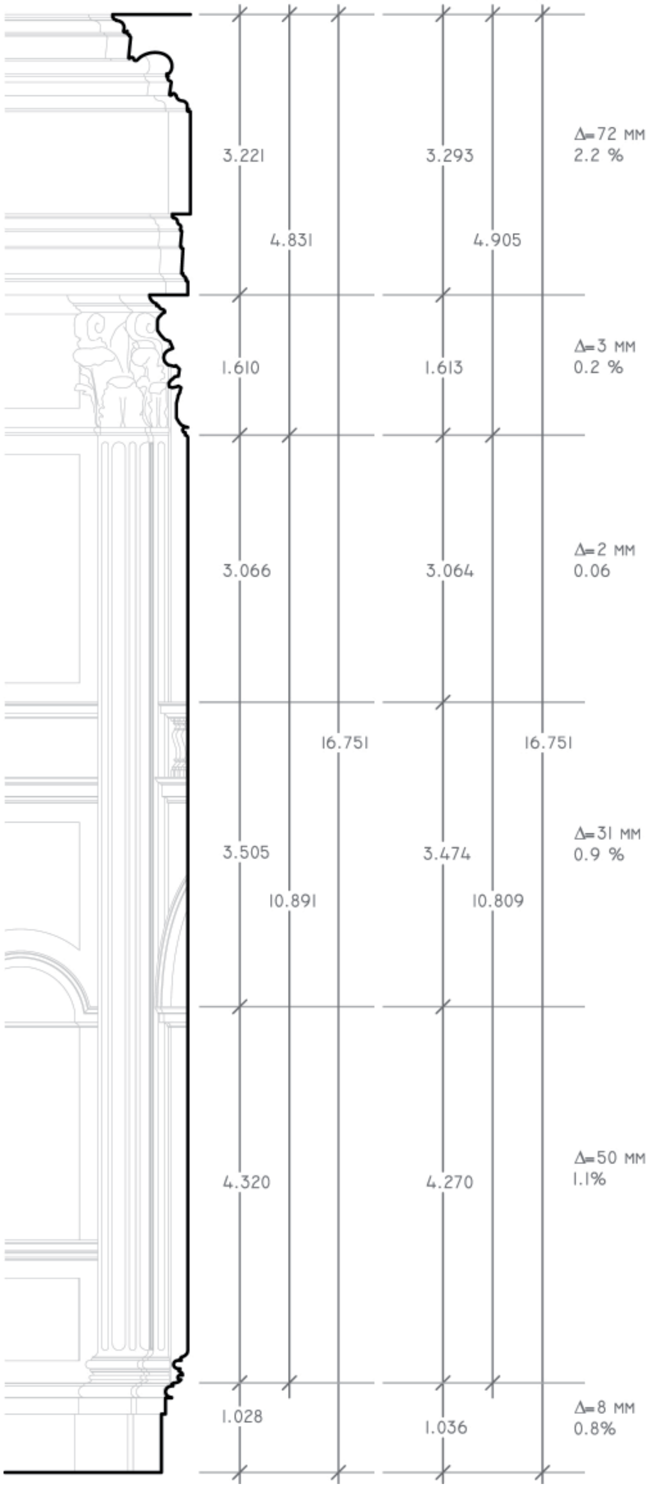
The analysis here was studied by comparing the Image-based Interactive modelling with a higher quality technique (3D laser scanning) to study the accuracy.
First of all, it was tried to study the accuracy orienting the model using some reference point with the coordinates obtained from the laser scanning point cloud. The point cloud was relatively a low resolution one (5cm net) then after the orientation and modelling some arbitrary feature points are selected to examine them comparing the coordinates in the

X: 92.811m Y: 80.016m Z: 113.811m	[Pick @ (92.760, 80.054, 113.861) m])	*ΔX=5.1cm, ΔY=3.8cm, ΔZ=5.0cm*
X: 91.543m Y: 81.017m Z: 113.811m	[Pick @ (91.495, 81.049, 113.848) m])	*ΔX=4.8cm, ΔY=3.2cm, ΔZ=3.7cm*
X: 91.504m Y: 75.908m Z: 113.601m	[Pick @ (91.455, 75.929, 113.599) m])	*ΔX=4.9cm, ΔY=2.1cm, ΔZ=0.2cm*
X: 90.971m Y: 77.345m Z: 112.214m	[Pick @ (90.927, 77.352, 112.278) m])	*ΔX=4.4cm, ΔY=0.7cm,* ***ΔZ=6.4cm***
X: 92.431m Y: 79.851m Z: 112.214m	[Pick @ (92.372, 79.879, 112.247) m])	*ΔX=5.9cm, ΔY=2.8cm, ΔZ=3.3cm*
X: 91.248m Y: 80.533m Z: 111.962m	[Pick @ (91.209, 80.565, 112.032) m])	*ΔX=3.9cm, ΔY=3.2cm,* ***ΔZ=7.0cm***
X: 91.049m Y: 85.141m Z: 107.683m	[Pick @ (91.006, 85.194, 107.663) m])	*ΔX=4.3cm, ΔY=5.3cm, ΔZ=2.0cm*
X: 91.316m Y: 86.119m Z: 103.698m	[Pick @ (91.335, 86.184, 103.661) m])	*ΔX=1.9cm,* ***ΔY=6.5cm****, ΔZ=4.1cm*
X: 90.886m Y: 77.594m Z: 102.633m	[Pick @ (90.822, 77.657, 102.635) m])	***ΔX=6.4cm, ΔY=6.3cm****, ΔZ=0.2cm*
X: 90.612m Y: 82.155m Z: 101.743m	[Pick @ (90.579, 82.146, 101.763) m])	*ΔX=3.3cm, ΔY=0.9cm, ΔZ=2.0cm*

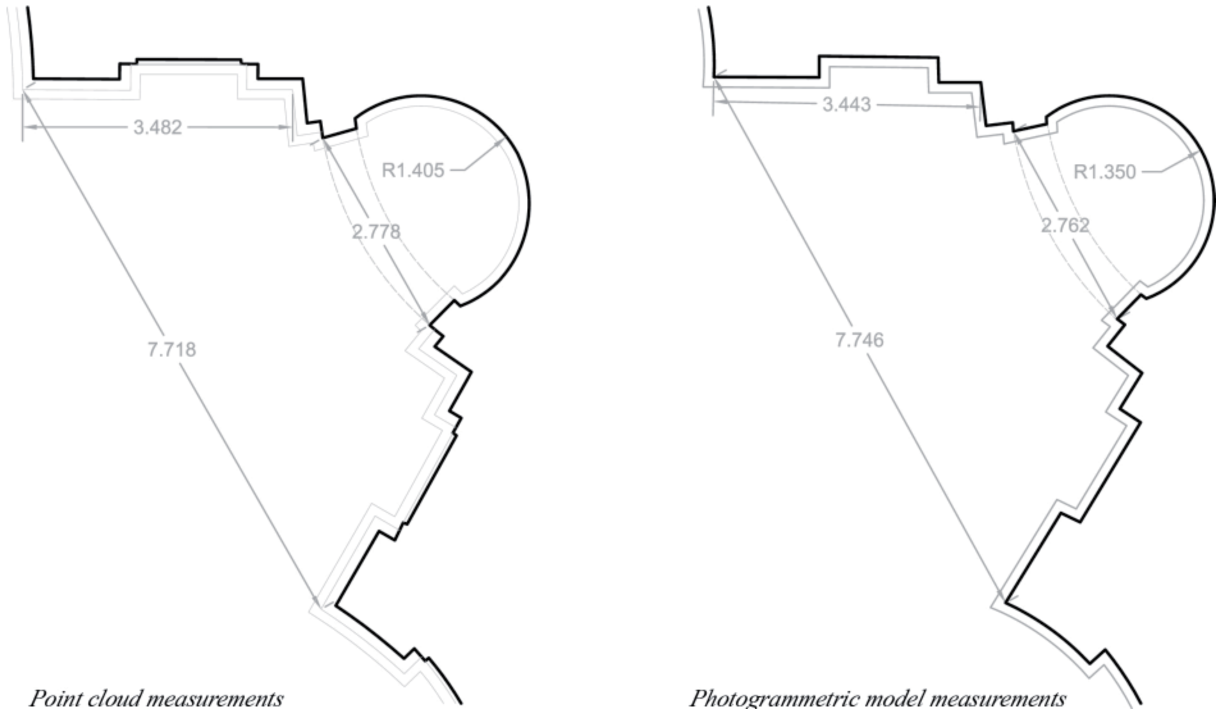
1 / Comparing the coordinates of some Feature points obtained from photogrammetric model (3dsMax), and laser scanner point cloud (Cyclone).

photogrammetric model, the scanner point cloud and the results as in the figure 1.
Those numbers give us a general idea about the accuracy, but obviously with an ± 25mm error's margin. Actually, selecting the right requested point in a low density point cloud is quite difficult, and it wouldn't be very accurate nor the accuracy analysis could be based on it, because this will affect the accuracy twice. Firstly, in the absolute orientation phase and secondly, in verifying the accuracy phase; especially because in the absolute orientation phase a small error in the coordinates of the reference points is amplified in the relatively far points.
Since the photogrammetric model is an human interpolation of the intersection between two image projections as a final survey product, it is not correct to compare this interpolation with a point cloud, which is not a final modelling product. But it has to be compared with the interpolation of this point cloud, as a section or plan plot.
The precision was verified comparing the point position obtained from different couple of panoramas. The average of these differences for many diverse points was around 2 cm (obviously depend on the position, the distance and the angulations of the used panoramas) using points belongs to the walls till the height of the drum moulding. After that, the accuracy was studied comparing the model measurements with the 2D drawings interpolated from the 3D point cloud. To find the average percentage error this can be calculated by this equation:

$$\textit{Percentage difference} = \frac{\textit{Measured 1 - measured 2}}{\frac{\textit{Measured 1 + measured 2}}{2}} \textit{ x 100\%}$$



2 / (right) Comparing some lengths in vertical section, left: laser scanner point cloud, right: photogrammetric model, then the differences.



3 / Comparing some lengths in horizontal section.

The average of the percentage difference of 30 measurements is 0.87 %
It is noticed that errors are greater in high points (the dome) for two reasons. (1) The far distance and, (2) the very small angle between the projection rays in those points.

Increasing the accuracy and the precision

In general, no measurement technology can be perfect and all measurement involves performing approximations, but the accuracy of a Modelling Project is dependent on a number of factors:

- the quality of the calibration of the camera and digitizer used,
- the resolution of the camera and digitizer used,
- the geometry of the camera positions, and
- the precision in which the user marks object features as they appear in the images.

The errors will be minimized and measurement accuracy maximized by taking those points into consideration:

- Using a well-calibrated camera for the project.
- Ensure that the angle between the camera positions is as close to 90 degrees as possible.
- Ensure all point and line markings and object positioning corresponding to the images are precise in the orientation and in the restitution phases.
- Guarantee a good distribution of reference points in the relative orientation phase.

Sintesi

L'accuratezza e la precisione sono due cose diverse. Nel campo della fotogrammetria a volte si tende a confonderle quando si parla di qualità del rilievo. L'accuratezza definisce la rispondenza di una misura calcolata rispetto a quella reale; la precisione si valuta confrontando i valori acquisiti in tempi o modi diversi.

La precisione è stata verificata tramite l'individuazione delle coordinate tridimensionali di un punto in due momenti distinti utilizzando due coppie diverse di foto sferiche per misurarne poi la differenza nei risultati. L'accuratezza invece è stata studiata confrontando, nel lavoro svolto all'interno di Sant'Ivo alla Sapienza, le misure del modello ottenuto dalla fotomodellazione interattiva con quelle ottenute da un sistema di alta accuratezza cioè una nuvola di punti generata da una scansione laser.

Verificando la precisione la media ottenuta dell'errore è stata di 2 cm nei punti dentro la chiesa fino all'altezza del tamburo; la precisione cambia ovviamente in funzione della distanza dal punto di presa e dell'angolo tra le due proiezioni sferiche nel punto rilevato. Per quanto riguarda l'accuratezza come prima prova è stato orientato il modello usando punti di riferimento con le coordinate ottenute dalla nuvola di punti della scansione; dopo la modellazione sono stati scelti dei punti significativi in modo arbitrario per verificare la differenza tra le loro coordinate del modello e le stesse ricavate dalla nuvola di punti. Sono state riscontrate delle differenze fino a 70 mm su uno dei tre assi coordinati.

Questo risultato può dare una prima idea generale dell'accuratezza del lavoro anche se occorre fare una riflessione. La nuvola di punti utilizzata per il confronto è una nuvola con una risoluzione abbastanza bassa (in media 5 cm) quindi è difficile poter individuare nella nuvola i veri punti corrispondenti che servono a valutare l'accuratezza. Rispetto a quest'ultimo dato pertanto vi è un margine di errore nella scelta del punto di ± 25mm. I dati ricavati dalla fotomodellazione sono un'interpolazione dell'operatore per intersezione tra due proiezioni al fine di determinare quei punti e quelle linee che sono alla base del prodotto finale, cioè del modello. Nel caso della nuvola di punti, il prodotto finale viene dopo l'interpolazione semplificando i punti della nuvola in linee che rappresentano pianta o sezione architettonica. Per questo motivo più che il confronto tra punti specifici nelle due tecniche si è ritenuto più importante fare un confronto tra le misure del modello e quelle della sezione e della pianta architettonica a loro volta ricavate dalla nuvola di punti. Il risultato è visualizzato nelle figure 2 e 3 e la differenza media è stata dell' 0.87% .

Dopo diverse applicazioni da me eseguite su più oggetti architettonici si possono segnalare alcuni fattori critici che possono influenzare l'accuratezza e la precisione del modello finale, e sono:

- *la qualità della calibrazione*
- *la risoluzione della macchina fotografica*
- *la geometria del poligono delle stazioni di presa fotografica*
- *la precisione nella fase di restituzione*
  quindi l'errore può essere ridotto quando
- *si utilizza una macchina fotografica ben calibrata*
- *è possibile assicurare la distribuzione dei centri di presa fotografica in modo che l'angolo tra due proiezioni (dove serve) sia il più vicino possibile a 90°.*
- *è possibile garantire una buona distribuzione di punti omologhi tra le foto nella fase di orientamento*
- *si è precisi nella modellazione rispetto alle proiezioni e nella collimazione dei punti nella fase di orientamento.*

X. Brief History

It is clear that no photogrammetry without photography but the history of photogrammetry starts few centuries before the invention of the photography, because many of its concepts may be traced back to the 1500s by Artists like Durer who effected stereoscopic drawings and Leonardo da Vinci who studied camera prospective projections. And without doubt, Filippo Brunelleschi, the founder of the geometrical method of perspective, can be considered the inventor and the founder of the modern photogrammetry.
About fifteen years ago significant differences between digital photogrammetry used with aerial photographs and close range images appeared. It starts to be possible to use digital cameras for close range photogrammetry, when no digital cameras were developed yet for aerial photogrammetry but digital scanning had been used to convert film camera photos into Digital images.

The developments in photogrammetry, from around 1850, have followed four development cycles:

- Plane table photogrammetry, from about 1850 to 1900,
- Analog photogrammetry, from about 1900 to 1960,
- Analytical photogrammetry, from about 1960 to 2000, and
- Digital photogrammetry from 1990 to present.

Laussedat is usually regarded as the father of the close range Photogrammetry. He developed methods in the 1850s to construct a map of Paris based on the geometric information which he could extract from his photographs taken from the rooftops of the city. Meydenbauer, The Prussian architect, adopted Laussedat's techniques and in 1858 commenced surveys of historical monuments, he called this techniques Photogrammetry for the first time in the 1893 which comes from a combination of Greek words which can be loosely translated as "Light drawn to measure".[1]

Here is a timeline of the most important events which participated to found the actual Photogrammetry, photography and computer vision:

1787 **Robert Barker** invented Panorama form of painting (London).

1794 **Least-squares** method was described by **Carl Friedrich Gauss**

1819 **Kern of Aarau**, Switzerland, was founded and began manufacturing precision surveying and mapping instruments.[2]

1826 **JN Niepce** produces first photograph from nature (France).

1830 Stereoscopes invented.

1883 **Guido Hauck** developed the relationship between projective geometry and photogrammetry.[2]

1839 Official invention of photography by **Louis Daguerre**. photographic process publicly announced (France).

1846 **Carl Zeiss** optical factory opens, Jena, (Germany).

1858 **Paulo Ignazio Pietro Porro** developed a panoramic camera that was equipped with a sighting telescope, compass, and level. The image was recorded on sensitized paper mounted on a cylinder (Italy).[2]

1861 **Maxwell** demonstrates 3-colour theory (Britain).

1862 **Laussedat**'s use of photography for mapping was officially accepted by the Science Academy in Madrid.

1865 **Paulo Ignazio Pietro Porro** designed the photogoniometer. This development is significant in photogrammetry because of its application in removing lens distortion.[2]

1867 **Laussedat** exhibited the first known phototheodolite and his plan of Paris derived from his photographic surveys.

1888 **Kodak** produces the first cameras with roll film and processing service (USA).

1893 **Cornele B. Adams** was given a patent for his "Method

of Photogrammetry”. His approach was to obtain two aerial photos of the same area with a camera from two positions of a captured balloon.[2]
The Prussian architect **Albrecht Meydenbauer** was the first person to use the term "photogrammetry".

1896 **Edouard Deville** invented the first stereoscopic-plotting instrument called the Stereo-Planigraph (Canada).

1901 **Dr. Carl Pulfrich** designed the first stereocomparator employing x and y coordinate scales and presented the results at the 73rd Conference of Natural Science and Physicians in Hamburg. This was the first photogrammetric instrument manufactured by Zeiss (Germany).

1908 **Eduard von Orel** developed the first stereoautograph. This plotter was significant because its construction principles made terrestrial photogrammetry practical in mountainous areas(Germany).

1909 First analog stereoplotter production.

1913 **E. Doleźal** organized the first International Congress for Photogrammetry held in Vienna, Austria on September 24- 26.

1914 brothers **Arthur** and **Norman H. Brock** were the first to create an aerial camera that was mounted in the plane.[2]

1917 **Nikon** corporation founded in Tokyo, (Japan).

1920 **Santoni**, who was at the Officine Galileo, developed the Autoreductor (Italy).[2]

1921 **Reinhard Hugershoff** the first analog plotter called the Hugershoff Autocartograph.[2]
Wild Heerbrugg was founded they became a world leader in the manufacture of accurate surveying and mapping instruments.[2]

1924 **Leitz** manufacture first Leica camera, (Germany)
Otto von Gruber developed the projective equations and their differentials, which are fundamental to analytical photogrammetry.[2]
IBM formed.

1925 **Santoni** developed the Stereocartograph (Italy).[2]

1926 **Hugershoff** developed the Aerocartograph This instrument used space rods instead of the complex mechanical system used in his earlier instrument.

1933 **R. Feber** developed a direct projection plotter that used alternating image projection.[2]

1934 The American Society for Photogrammetry was formed.

1935 135 film, commonly called 35 mm film, introduced by **Kodak** (USA).[3]

1936 **Robert Ferver** was awarded a U.S. patent for the Gallus-Ferber Photorestituteur the first orthophoto production instrument.

1937 **Canon** Inc. founded in Tokyo (Japan).

1943 First Generation Computers.

1948 First model, **Hasselblad** rollfilm SLR.[3]

1950 **Everett Merritt** published works on analytical photogrammetry for camera calibration, space resection, interior and exterior orientation, relative and absolute orientation.

1953 **Dr. Hellmut Schmid**, at the Ballistic Research Laboratory, Aberdeen, Maryland, developed the principles of modern multi-station analytical photogrammetry using matrix notation.[2]

1956 **Russel Kerr** was awarded a patent for an "Ellipsoidal Reflector Projector for Stereo-Photogrammetric Map Plotting". This plotter accepted stereoscopic imagery not only from vertical photography but also convergent low oblique and transverse oblique photography(US).[2]

1957 The finnish **U. Helava** (The father of the analytical plotter) developed the analytical plotter.[2]

1958 **U. Helava** exposed the first analytical stereoplotter in Munich in the "fotogrammetriche woche in München".[4]

1959 was awarded a patent for an orthoscope. This instrument produced photography at the same level of accuracy as a map.[2]

1967 The Canadian **Gilbert Louis Hobrough** developed the Gestalt Photo Mapper (GPM). This was an automated orthophotographic system utilizing correlation of stereo imagery.[2]

1968 **Intel** Founded.

1971 **Houssam Mahmoud** with **Y.I. Abdel-Azis**, developed the Direct Linear Transformation (DLT) they found a way to perform a direct transformation from comparator measurements to object-space coordinates that did not require camera calibration.[2]

1975 Formation of **Microsoft**

1976 **Apple** Computer Inc. founded

1979 **IBM** started development of the PC
1982 **John Walker** founded Autodesk in San Rafael, California.
1984 First digital electronic still camera.[3]
Apple Macintosh computers first appear.
1985 **Microsoft Windows** launched
1986 AutoLisp was introduced in AutoCAD Version 2.18.
1987 First 3D video games.
1988 3D Studio /Max was published for the first time by Autodesk with the Yost group After their success on the Atari.
Kern of Aarau and **Wild Heerbrugg** merged.[2]
1990 **Kern of Aarau** and **Wild Heerbrugg** formed **Leica Geosystems**.[2]
Adobe Photoshop digital image manipulation program introduced.
1991 **SOCET SET** was the first commercial digital photogrammetry software program.
1994 "**Photomodeler**", the software initial release by "EOS Systems".
The theory of the multi-image spherical panorama has been developed by **R. Szeliski** for the Apple Computers.
1998 **H. Dersch** started development on «Panorama Tools»
First digital compact cameras.
2001 **Leica Geosystems** acquired Azimuth Corporation, ERDAS, and LH Systems giving Leica the capabilities of offering clients LIDAR scanning systems, remote sensing/image processing software packages, and digital stereoplotter capabilities.
"**PTGui**" initial release.
2002 Digital cameras outsell film cameras for the first time.
2006 **Nikon** and others announce that they are discontinuing production of all but a few models of film camera.
2007 **G. Fangi** uses for the first time the Panoramic photo as a virtual theodolite.
2007 **A. van den Hengel** proposed a system called videotrace to interactively model geometry from video.
2009 **"Image modeler"** initial release by "Autodesk".

Notes:
1. J.G.Fryer, "Close Range Photogrammetry and Machine Vision", 1996
2. The Center for Photogrammetric Training, Ferris State University "History of Photogrammetry"
3. M.Langford, A.Fox, R.Sawdon Smith, "Langfrod's Basic Photography Guide-9th", 2010
4. L. Paris, "Il problema inverso della prospettiva", Roma, 2000

XI. Glossary

Definitions of several Photogrammetry and computer vision as indicated in our text:

Aberration
Defect in a lens resulting in less than optimum sharpness over part of the image plane.
Chromatic aberration: A lens defect where the lens fails to focus different colours at the same point. Coloured fringes appear around objects, especially at the edges of the frame.
Spherical aberration: Lens defect which causes the image to be formed in a partially curved instead of flat plane resulting in poor image definition over the whole area. Effects can be reduced by using a small aperture to increase depth of focus.

Absolute orientation
Is intended to «grab» the stereoscopic model to the ground by reading some points with known coordinates.

Analytical Stereoplotter
A photogrammetric instrument which uses electronics, motors, and lenses to view two overlapping aerial photos in 3D. The stereoplotter corrects for distortions caused by rotations in the camera and relief displacement. This allows the operator to view the stereo model in a binocular viewing system and make measurements based on the ground coordinate system.

Angle of view
The area of a scene, expressed as an angle, which can be reproduced by the lens as a sharp image. The nominal diagonal angle of view is defined as the angle formed by imaginary lines connecting the lens' second principal point with both ends of the image diagonal (43.2mm). Lens data for EF lenses generally includes the horizontal (36mm) angle of view and vertical (24mm) angle of view in addition to the diagonal angle of view.

Aperture/effective aperture
The aperture of a lens is related to the diameter of the group of light rays passing through the lens and determines the brightness of the subject image formed on the focal plane. The optical aperture (also called the effective aperture) differs from the real aperture of the lens in that it depends on the diameter of the group of light rays passing through the lens rather than the actual lens diameter. When a parallel pencil of rays enters a lens and a group of these rays passes through the diaphragm opening, the diameter of this group of light rays when it enters the front lens surface is the effective aperture of the lens.

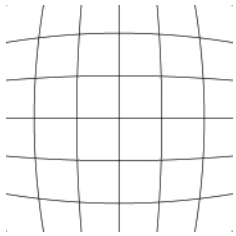
Azimuth
The angle, measured in degrees, between a base line radiating from a centre point and another line radiating from the same point. Normally, the base line points north, and degrees are measured clockwise from the base line.

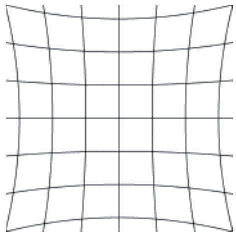
CCD
Charge-coupled device. Electronic light-sensitive surface, e.g. modern substitute for film in digital cameras. In simpler form used in AF systems to detect image sharpness.

Close Range Photogrammetry
According to M.A.R. Cooper and S. Robinson is a term used to describe the technique when the extent of the object to be measured is less than about 100 meters and cameras are positioned close to it. Other characteristics have come to be associated with close range photogrammetry which makes it different from aerial mapping. Image are obtained from camera positions all around (and sometimes inside) the object. Camera axes are parallel only in special cases; usually they are highly convergent, pointing generally towards the middle of the object. The accuracy is much higher than aerial photogrammetry.

Depth of field
The area in front of and behind a focused subject in which the photographed image appears sharp. In other words, the depth of sharpness to the front and rear of the subject where image blur in the focal plane falls within the limits of the permissible circle of confusion. Depth of field varies according to the lens' focal length, aperture value and shooting distance.

Distortion
One of the conditions for an ideal lens is that "the image of the subject and the image formed by the lens are similar," and the deviation from this ideal where the straight lines are bent is called distortion. The extended shape in the diagonal view angle direction (+) is called pincushion distortion, and, conversely, the contracted shape (—) is called barrel distortion. With an ultra wide-angle lens, rarely do both of these distortions exist together. Although this seldom occurs in lenses where the lens combination configuration is at the aperture boundary, it occurs easily in configuration lenses. Typical zoom lenses tend to exhibit barrel distortion at the shortest focal lengths and pincushion distortion at the longest focal lengths (the distortion characteristics change slightly during zooming), but in zoom lenses that use an aspherical lens, the aspherical lens is effective at removing distortion, so the correction is good. This difference is caused by the difference in refraction of the principal rays passing through the centre of the lens, so it cannot be improved no matter how much the aperture is stopped down.
Barrel distortion is a lens effect which causes images to be spherised or «inflated». Barrel distortion is associated with wide angle lenses and typically occurs at the wide end of a zoom lens. The use of converters often amplifies the effect. It is most visible in images with perfectly straight lines, especially when they are close to the edge of the image frame.
Pincushion distortion is a lens effect which causes images to be pinched at their centre. Pincushion distortion is associated with tele lenses and typically occurs at the tele end of a zoom lens. The use of converters often amplifies the effect. It is most visible in images with perfectly straight lines, especially when they are close to the edge of the image frame.


Barrel distortion


Pincushion distortion

Ellipsoid
A mathematical figure that approximates the shape of the Earth in form and size, and which is used as a reference surface for geodetic surveys.

Entrance pupil/exit pupil
The lens image on the object side of the diaphragm, i.e. the apparent aperture seen when looking from the front of the lens, is called the entrance pupil and is equivalent in meaning to the lens' effective aperture.
The apparent aperture seen when looking from the rear of the lens (the lens image on the image side of the diaphragm), is called the exit pupil. Of the light rays from a certain subject point, the effective light rays which actually form the image create a cone of light rays with the subject point being the point of the cone and the entrance pupil being the base of the (cone. At the other end of the lens, the light rays emerge in a cone shape with the exit pupil forming the base of the cone and the point of the cone falling within the image plane. The entrance and exit pupils have the same shape as the actual diaphragm and their size is directly proportional to that of the diaphragm, so even if the construction of the lens system is not known, it is possible to graphically illustrate the effective light rays which actually form the image as long as the positions and sizes of the entrance and exit pupils are known. Thus, knowledge of the entrance and exit pupils is indispensable when considering performance factors such as the total amount of light entering the lens, the manner in which the image blurs and aberrations.

Epipolar geometry
The projective geometry between two views. It is independent of scene structure, and only depends on the cameras'

internal parameters and relative position. It is essentially the geometry of the intersection of the image planes with the pencil of planes having the baseline as axis (the baseline is the line joining the camera centres). This geometry is usually motivated by considering the search for corresponding points in stereo matching.

Fisheye Lens
Extreme wide-angle lens, uncorrected for curvilinear distortion.

Focal length
When parallel light rays enter the lens parallel to the optical axis, the distance along the optical axis from the lens' second principal point (rear nodal point) to the focal point is called the focal length. In simpler terms, the focal length of a lens is the distance along the optical axis from the lens' second principal point to the focal plane when the lens is focused at infinity.

Focal point, focus
When light rays enter a convex lens parallel to the optical axis, an ideal lens will converge all the light rays to a single point from which the rays again fan out in a cone shape. This point at which all rays converge is called the focal point.
familiar example of this is when a magnifying glass is used to focus the rays of the sun to a small circle on a piece of paper or other surface; the point at which the circle is smallest is the focal point. In optical terminology, a focal point is further classified as being the rear or image-side focal point if it is the point at which light rays from the subject converge on the film plane side of the lens. It is the front or object-side focal point if it is the point at which light rays entering the lens parallel to the optical axis from the focal plane side converge on the object side of the lens.

Grid
Two sets of parallel lines intersecting at right angles, forming a rectangular Cartesian coordinate system superimposed on a map projection. Sometimes the term «grid» is used loosely to mean the projection system itself rather than the rectangular system superimposed on the projection.

Internal orientation
it is the term employed by photogrammetrist to describe the internal geometric configuration of the camera and lens system. photogrammetrist must know, or be able to compensate for, what happens to the bundle of rays coming from the object and passing throw the lens of their imaging device. This configuration can be described mathematically by a set of parameters

Latitude
Angular distance, in degrees, minutes, and seconds measured from the centre of the Earth, of a point north or south of the Equator. Latitude may also be measured in decimal degrees.

Longitude
Angular distance, in degrees, minutes, and seconds measured from the centre of the Earth, of a point east or west of the Prime Meridian. Longitude may also be measured in decimal degrees.

Nodal Point
The nodal points of a lens are defined this way: If we have a light ray that arrives at the front of the lens headed for the first nodal point, then it will emerge from the rear of the lens along a line that starts at the second nodal point and is parallel to the line along which the ray arrives.

Optical axis
A straight line connecting the centre points of the spherical surfaces on each side of a lens. In other words, the optical axis is a hypothetical centre line connecting the centre of curvature of each lens surface. In photographic lenses comprised of several lens elements, it is of utmost importance for the optical axis of each lens element to be perfectly aligned with the optical axes of all other lens elements. Particularly in zoom lenses, which are constructed of several lens groups that move in a complex manner, extremely precise lens barrel construction is necessary to maintain proper optical axis alignment.

Orthophoto
In aerial Photogrammetry orthophotographs are photographic images constructed from vertical or near vertical aerial photographs. removing the effects of terrain

relief displacement and tilt of the aircraft. In close range photogrammetry an orthophoto of a facade is a photo parallel to the main plane of the facade.

Panorama camera
Camera giving a long, narrow image covering a very wide horizontal angle of view. Specialist models can rotate to give up to 360°.

Parallax
Difference in viewpoint which occurs when a camera's view finding system is in a position separate from the taking lens, as in compact and TLR cameras.

Photo modelling
A generic term to describe the operation of modelling based on photographs as input data and the output as a virtual model could be solids, mesh or point cloud. It could be an automated or manual modelling operation.

Photo rectification
Many parts of architectural objects can be considered as plane. The process of deforming the image to produce from a tilted or oblique photograph, an orthophoto parallel to this plane . Or in aerial photogrammetry, the process of projecting a tilted aerial photograph on to a horizontal plane.

Photogrammetry
”Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena.” (ASPRS, 1980)

Analogue Photogrammetry
Using optical, mechanical and electronic components, and where the images are hardcopies. Re-creates a 3D model for measurements in 3D space.

Analytical Photogrammetry
The 3D modelling is mathematical (not re-created) and measurements are made in the 2D images.

Digital Photogrammetry
Analytical solutions applied in digital images. Can also incorporate computer vision and digital image processing techniques. or Softcopy Photogrammetry.

Principal point
The focal length of a thin, double-convex, single-element lens is the distance along the optical axis from the center of the lens to its focal point. This centre point of the lens is called the principal point. However, since actual photographic lenses consist of combinations of several convex and concave lens elements, it is not visually apparent where the centre of the lens might be.
The principal point of a multi-element lens is therefore defined as the point on the optical axis at a distance equal to the focal length measured back toward the lens from the focal point. The principal point measured from the front focal point is called the front principal point, and the principal point measured from the rear focal point is called the rear principal point. The distance between these two principal points is called the principal point interval.

Relavive orientation
Determine the relative position of two photographs, or a relation to another, for the reconstruction of the epipolar plane.

Resolution
(1) Digital image quality as measured by multiplying the number of horizontal and vertical pixels. Results in a figure for resolution in pixels per inch.
(2) Ability of a lens to record fine detail, sometimes referred to as resolving power, expressed in lines per mm.

Stereo vision
Is the process of reconstructing a 3D scene from two views of the scene.

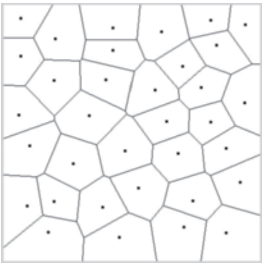
Stitching
The process of aligning and projecting images to create a multi-image photo, this process in some software may contain calibration and image correction

Stop/diaphragm/aperture
The opening which adjusts the diameter of the group of light rays passing through the lens. In interchangeable lenses used with single lens reflex cameras, this mechanism is usually

constructed as an iris diaphragm consisting of several blades which can be moved to continuously vary the opening diameter. With conventional SLR camera lenses, the aperture is adjusted by turning an aperture ring on the lens barrel. With modern camera lenses, however, aperture adjustment is commonly controlled by operating an electronic dial on the camera body.

Texel

In computer graphics means «Texture Pixel» which is the voronoi polygon created projecting an image pixel to an object. and the voronoi polygons are polygon have segments as division between them. those divisions are at the half-way point between the centroid of each texel and the centroids of every surrounding texel for the entire texture.



Voronoi diagram

Conclusion

The aim of this research was to put in evidence the importance and the value of the disponible data in every digital photo, took by somebody for whichever motive and kept in a hard support. The geometrical information could be obtained from any photo by means of different photogrammetric techniques, after that, it was concentrated on the panoramic photograph which has a particular importance. Even if it has no stereo viewing, it has the closest representation to our space perception using the interactivity offered by the computer.

The panoramic photograph is easy, rapid and economical documentation element. And it is dissimilar of the normal photographs for two principal reasons: First, it has a field of view which covers all the space around “360°”. Second, it has an unlimited resolution in case of the multi-image panoramas.

In conclusion, the use of the panoramic image, which has a widespread use nowadays, thinking about the Google steet-view project, we can survey any architecture element of any building and even for the entire city.

The orientation of the photographs is critical step. It is simplified in many image-based modelling software, supposedly , if it could become simple enough to get the precise position and direction of the photograph, the orientation will be considered as an addition information to be saved with every image as metadata information. Then the survey will be merely a modelling problem.

That will not be so far. As currently we can get the position using the GPS with a relatively big error margin for an approximate positioning. If the precision in the future can reach an acceptable error we can overcome the orientation problem. We can get the precise position and even the direction using two GPS sensors with a known position relative to the camera.

Another method could be a high precision automatic homologue point’s recognition for two photos to simplify the process of identifying them. Therefore, future technologies will help us to simplify every process, but in particular the orientation process will be the most simplified one.

Consequently, the understanding of the geometry of the surveyed architecture and the recognising of the architectural modelling constraints are the keys to obtain a simple modelling subsequently a fast survey operation.

In laser 3D scanning, there are still some complications and limitations such as the high cost of the equipment, the availability and the needs of the photographic coverage for scanning to complete the documentation process. Its most critical problem in the architectural survey (which is present in photo-modelling programs that generates point clouds too) is the point by point survey technique. Such technique ignores the need of the description of the architecture by its geometrical elements.

In conclusion: Identifying the invention in this technique to be a new process or a new use for an existing material, we can highlight this in our study which proven that “Image-based modelling” is using the camera as a common gadget, utilizing the same photographs especially the panoramic ones, applying the existing 3D modelling programs which is presented in every architectural, engineering or 3d graphics studio, to get accurate, adequate and convenient result. That’s why Image-based modelling and photogrammetry is an interesting field, that’s why this research has been started, and to be continued.

Conclusione

All'inizio della ricerca l'obiettivo era mettere in evidenza l'importanza delle informazioni salvate con ogni fotografia digitale scattata per un qualsiasi motivo su vari supporti. Le informazioni sulla geometria degli oggetti fotografati può essere ricavata dalle foto tramite varie tecniche di fotogrammetria, ma la fotografia panoramica ha una caratteristica importante. Non riproduce la visione stereoscopica, ma ha una rappresentazione che si avvicina molto alla nostra percezione dello spazio sfruttando la potenza di calcolo e l'interattività offerte dal computer.

La foto panoramica è un metodo di documentazione veloce è di basso costo e a differenza della foto normale ha due qualità molto importanti; primo, ha un campo visivo che copre tutto lo spazio intorno (360°); secondo, ha una risoluzione che può essere molto alta nel caso delle foto panoramiche multi-immagine.

La conclusione è: tramite immagini panoramiche che sono recentemente diventate di uso abbastanza comune, pensando per esempio al progetto di street view di google, possiamo rilevare qualsiasi elemento architettonico, edificio o ampi spazi urbani.

L'orientamento dei panorami è al momento uno dei passaggi più critici della foto-modellazione, anche se è stato semplificato nei nuovi software. Si ritiene comunque che in un prossimo futuro grazie alla rapida evoluzione della tecnologia informatica l'operazione di orientamento sarà ulteriormente sviluppata e semplificata, per diventare una informazione in più nel metadata nel file dell'immagine.

Un esempio di possibile implementazione della procedura è legato all'utilizzo dei sensori GPS attualmente disponibili in alcune nuove macchine fotografiche. Se tali sensori miglioreranno la loro precisione nel futuro l'orientamento assoluto potrà essere automatico al momento stesso dello scatto usando due sensori GPS legati alla macchina fotografica. Un'altra possibilità potrebbe scaturire da procedure di orientamento tramite un riconoscimento automatico di alta precisione dei punti omologhi di due diverse foto.

Una volta affrontato e risolto il problema dell'orientamento il rilievo diventa semplicemente una questione di modellazione che può essere fatta con un qualsiasi programma di modellazione 3D.

Capire la geometria dell'architettura rilevata e il riconoscimento dei vincoli geometrici per la modellazione è la chiave di una modellazione rapida e semplice.

La scansione laser ha ancora dei limiti, soprattutto dal punto di vista pratico, come il costo e la disponibilità delle attrezzature che sono pesanti e difficili da trasportare. Inoltre c'è da osservare che dopo la scansione laser la nuvola di punti va sempre elaborata ed integrata con scatti fotografici per completare la documentazione.

La macchina fotografica è un oggetto di uso comune con una tecnologia in continua crescita; la fotografia è un elemento ottimo di documentazione, i programmi di modellazione 3D sono presenti in tutti gli studi di architettura, ingegneria e grafica. Per questo la fotomodellazione e più in generale la fotogrammetria è un campo interessante e più che mai attuale; ed è per questo che è nata questa ricerca che si intende ancora portare avanti.

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Abstract

This study is to exploit texturing techniques of a common modelling software in the way of creating virtual models of an exist architectures using oriented panoramas. In this research, **The panoramic image-based interactive modelling** is introduced as assembly point of photography, topography, photogrammetry and modelling techniques. It is an interactive system for generating photorealistic, textured 3D models of architectural structures and urban scenes.
The technique is suitable for the architectural survey because it is not a «point by point» survey, and it exploit the geometrical constraints in the architecture to simplify modelling.
Many factors are presented to be critical features that affect the modelling quality and accuracy, such as the way and the position in shooting the photos, stitching the multi-image panorama photos, the orientation, texturing techniques and so on.
During the last few years, many Image-based modelling programmes have been released. Whereas, in this research, the photo modelling programs was not in use, it meant to face the fundamentals of the photogrammetry and to go beyond the limitations of such software by avoiding the automatism. In addition, it meant to exploit the potent commands of a program as 3DsMax to obtain the final representation of the Architecture. Such representation can be used in different fields (from detailed architectural survey to an architectural representation in cinema and video games), considering the accuracy and the quality which they are vary too.
After the theoretical studies of this technique, it was applied in four applications to different types of close range surveys. This practice allowed to comprehend the practical problems in the whole process (from photographing all the way to modelling) and to propose the methods in the ways to improve it and to avoid any complications. It was compared with the laser scanning to study the accuracy of this technique.
Thus, it is realized that not only the accuracy of this technique is linked to the size of the surveyed object, but also the size changes the way in which the survey to be approached.
Since the 3D modelling program is not dedicated to be used for the image-based modelling, texturing problems was faced. It was analyzed in: how the program can behave with the Bitmap, how to project it, how it could be an interactive projection, and what are the limitations.

Abstract

La presente ricerca è uno studio per utilizzare le tecniche di texturizzazione offerte dai programmi più comuni di modellazione 3D per creare modelli di architetture partendo da loro immagini fotografiche opportunamente orientate. La foto-modellazione interattiva usando i panorami sferici è un punto di incontro tra la fotografia, topografia, fotogrammetria e tecniche di modellazione tridimensionale. E' un sistema interattivo per generare modelli 3D di architetture e complessi urbani.

E' una tecnica particolarmente adatta per il rilievo architettonico perché non è un rilievo "punto per punto" ma sfrutta al meglio i vincoli geometrici dell'architettura per semplificare la modellazione.

La ricerca ha riguardato lo studio dei diversi fattori che possono influenzare la qualità del modello come la posizione e le modalità in cui si scattano le foto, il montaggio dei panorami, l'orientamento o la proiezione delle mappe nel modello.

Negli ultimi anni sono stati prodotti tanti programmi di foto modellazione, ma questa ricerca deliberatamente non ne fa uso per evitare prima di tutto l'automatismo presente in tanti passaggi all'interno di questi software; per consentire di acquisire le basi teoriche che sono alla base di questi software senza le quali spesso non si riesce ad arrivare al risultato finale; infine la ricerca ha inteso analizzare i fondamenti della fotogrammetria attraverso cui poter sfruttare al meglio la potenza di un modellatore come 3DsMax o un altro di simili caratteristiche per ottenere una presentazione finale di una determinata architettura che può essere usata in molti campi secondo la precisione e la qualità del modello, da un rilievo architettonico fino all'uso nel cinema e nei videogiochi.

Dopo un primo studio teorico la tecnica è stata applicata su vari tipi di rilievi, differenti per qualità dell'oggetto architettonico e per ampiezza dell'intervento, da una semplice facciata al rilievo di un contesto urbano e da queste applicazioni sono scaturiti e si sono affrontati i vari problemi dalla fotografia fino alla modellazione e sono stati proposti dei metodi per evitare i problemi e migliorare la qualità del modello. Questa tecnica è stata confrontata con una nuvola di punti ottenuta da una scansione laser per verificarne l'accuratezza.

Si è capito che non solo la precisione del rilievo è in proporzione con la misura dell'oggetto rilevato, ma la misura dell'oggetto rilevato influisce, anche sensibilmente, sul modo stesso di modellare.

Dato che i programmi di modellazione 3D non sono progettati per fare modellazione a base di immagini, tale ricerca ha consentito di affrontare anche questo discorso, cioè capire come questi programmi si comportano utilizzando la mappatura e quali sono i loro limiti.