IATH BEST PRACTICES GUIDE TO DIGITAL PANORAMA PHOTOGRAPHY

1. OVERVIEW AND OBJECTIVES

1.1. WHO IS THIS GUIDE FOR?

The IATH Best Practices Guide to Digital Panorama Photography is written for researchers and photographers looking to use digital technology to build digital panoramas of cultural heritage sites, architecture, and art works. There are several types of expertise required to create this kind of tool, and the guide contains advice and guidance on some of the technical, administrative, legal, and interpretive issues that may arise at each step of the process.

The contents are designed for three groups of users: the commissioner, the photographer, and the developer. The commissioner is the person or group who commissions the panorama, whether for research or educational use. In many cases the photographer and developer are the same person, but this guide deals with their tasks separately: the photographer is the person (or persons) who travels to the site and creates the source images and the developer creates digital panoramas from the source images and makes them available in some way, usually through a virtual tour on a website.

This guide will focus mainly on the workflow for academic uses of panoramic photography. The guide aims to give practical guidance on the many issues involved in the creation and use of digital panoramas, as well as to provide suggestions for the creative use of the resource. We urge the reader to begin by considering the project's end use, the intended audience and their information needs. These considerations will be the crucial basis for numerous decisions that need to be made throughout the process. For example, if the end user will be viewing the panorama on a normal computer display and will not need to zoom in on decorative details of a building, then lower resolution jpegs will be sufficient in the initial data capture phase. However, if zoom functionality will be important to the end users or if the panorama is to be printed by offset press or larger display prints, then the data capture process must yield high-resolution tiffs.

We advise both novices and experts to read the entire guide. There are many steps involved in this type of undertaking and even a seasoned photographer may not have thought of all of them. Many of the topics are interrelated and various aspects of the topics are covered throughout the guide.

Please note that the guide assumes a general knowledge of photography, computer literacy, and experience in travel. There are many fine books and web sites that specialize in those topics and readers are encouraged to seek them out. Whenever possible, World Wide Web links are provided to illustrate examples and point towards further information.

1.2. INTRODUCTION AND EXAMPLES

Panoramas began as a way to broaden the field of view of ordinary cameras, but have evolved through digital techniques to provide an entire "sphere of view," that is the entire field of view surrounding one point in space. The "sphere" is further enhanced by zoom options that allow the viewer to focus on details that would normally be difficult to discern from the original vantage point. Multiple panorama techniques extend the range of viewpoints and provide a functionality for more complete guided tours. This evolution of digital panorama photography has made it particularly well-suited to virtual representation of three-dimensional sites such as architecture, archaeological sites, and sculptural works.

Digital panoramic photography is sometimes referred to as "QTVR," referring to Apple Computer Corporation's QuickTime Virtual Reality software. "QTVR" is not quite accurate at two levels: other companies provide software with much of the same functionality, and the fixed point of view (albeit with pan and zoom) on each panorama does not allow the unrestricted "fly through" control often part of "virtual reality" displays. To obtain the "fly through" functionality virtual reality displays are most often based on Computer Aided Design (CAD) modeling, in which case the structures and textures on the surfaces of those structures are computer generated. In contrast, the panorama displays are more realistic in that they derive from photographs of the original building, site or sculpture.

Digital panoramas, as with other digital presentation methods, do provide a very natural connection to additional information sources that enable extremely rich guided tour experiences. At its most intricate, multiple digital panoramas are combined into a virtual tour that provides varied viewpoints into and about a space, accompanied by ambient three-dimensional audio recorded on-site and video clips and additional high-resolution still images. As with any guided tour, a floor plan of the space provides the visitor with an important abstraction for orientation and navigation. In the digital media domain, the floor plan can be made interactive and thus form the basis of a deeper understanding of the space through the availability of additional contextualizing information.

Digital panoramas have recently been used in the classroom and for scholarly research. They are particularly well-suited to virtual representation of three-dimensional sites such as architecture, archaeological sites, and sculptural works, and when documenting geographically or politically inaccessible places. There are many wonderful examples of stand-alone digital panorama and full-featured virtual tours available via the World Wide Web. A few notable sites are:

- BetterLight
- The Original Worldwide Panorama Event

- Panoramas.dk
- A Virtual Walking Tour: The Alhambra

There are also good websites and lists that provide guidance on the creation and displaying of digital panoramas. For example, Panoguide has guidance on creating and displaying panoramas as well as an active user forum.

1.3. Brief history and use of panoramic photography

Human vision is essentially a spherical panorama of approximately 140°. Although our vision is in sharp focus only in the center, our peripheral vision is sharp enough to help us navigate safely. The seamless flow of information in vision is intellectually beyond computing. We can identify and avoid an obstacle that we have seen days or months in the past. The importance of panorama as a human experience can be found in Paleolithic cave art dating from 35,000 years ago in Chaveut and Lascaux, France. These unconstrained artists drew grazing animals and carnivores on the walls and ceilings up to fifteen meters in width.

Over time, the proportions of five units in one dimension and four in the other became normal in response to the media that conveyed the image; canvas stretched over wood frames, book printing and, more recently, early photographic processes.

The notion of a sweeping panoramic view goes back well beyond the invention of photography. The Roman poet Horace, in one of his odes, complains of hilltops with fine views being levelled for the building of houses, and Pliny the Younger refers to the importance of panoramic views to the owners of Roman villas. At the excavated Roman seaside town of Herculaneum, some the finest houses were positioned overlooking the Bay of Naples. There has been a long tradition of drawn and painted depictions of panoramic views (usually thought of as panoramic if width exceeds height by a factor of 2:1 or greater).

However the word "panorama" itself did not enter the language until it was coined in the late eighteenth century to specifically describe a new type of large curved painting depicting vistas,[1] an early example being those of Edinburgh by Robert Barker (who received a patent for his method) exhibited in London in 1792. These large-scale works were mounted on the inside surface of a cylinder and viewed from the cylinder's center, generally with an attempt to fill the viewer's field of view through the full 360° and create a sense of immersion. During the nineteenth-century displays of this kind — usually depicting landscapes or historical events and created by teams of specialist artists — grew in size, ingenuity, and variety. They were generally exhibited in specially built rotundas

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1   With the disappearance of the art form it was invented to describe, the original, quite specific, definition has now been effectively replaced by other usage and meanings: a circular or extra-wide vista, overview, even a survey. These new forms themselves developed not long after the term was coined.

and enjoyed great popularity. Many of these works were of epic proportions, perhaps ten meters high and one hundred meters or more long.

Soon after the 1839 introduction of the first widely used photographic process (the daguerreotype), photographers were rotating their cameras to capture several views of a scene, then assembling the resulting pictures to create the impression of a single panoramic image (although these would almost inevitably be flawed by visible seams and jarring mismatches of perspective). This period also saw early experiments with rotating cameras or lenses and curved focal planes in efforts to overcome these deficiencies. As time went on, especially after the introduction of flexible film in 1887, many new and increasingly successful cameras were specifically designed to create seamless panoramic images. One such improvement was the short rotation or swing lens camera, which typically captured a horizontal field of view of 100-140° or so. Other designs allowed for full 360° rotation; the rotational scanning camera employed clockwork or motorized systems to synchronize the rotation of the entire camera. During exposure the film moved around a curved focal plane. A narrow slit (typically less than one millimeter wide) often interposed between lens and film, so that the scene was "painted" onto the film during the rotation. Descendants of such cameras, in one form or another, continue to be manufactured and used today.[2] Both of these types of cameras produced images with cylindrical perspective, an unavoidable result of their rotation: straight horizontal lines in the subject take on distinctive cigar-shaped curves once imaged (though not vertical features, as with fish-eye lenses). Another invention was the fixed lens camera, where the perspective was rectilinear (i.e., normal). Most conventional cameras use this approach; it employs stationary lenses and flat film planes, relying on the use of wide angle lenses and/or extended film planes to achieve a panoramic field of view. Another variant is the panoramic pinhole camera.

Figure 1. Circuit camera panorama.

A student engineer, named Arthur C. Pillsbury, invented the circuit camera in 1906. Today we take "circuit" to mean an electronic circuit, but the circuit camera was a spring-wound, gear-driven camera weighing about twenty pounds. It exposed a piece of 8"x20"

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2   Some typical modern examples of short rotation cameras include the Noblex, Widelux, and Horizon. Full rotation models include the Hulcherama and Seitz Roundshot. Of the latter group there are now digital models, which include (at the time of writing) the Panoscan, the Seitz Super Digital model, Spheron, and others.

negative film which was then contact-printed on photographic paper. These cameras are still in use. Many veterans of World Wars I and II had their platoon pictures taken with the circuit camera.[3] If the negative and print were properly fixed and washed, these images last hundreds of years. With digital technology we can recreate the look of the circuit camera portrait (**Fig.1**). The image, when reproduced with archival ink on acid-free paper, will last an estimated two hundred years.

Late twentieth-century developments in digital imaging gave a new lease of life to the assembling of multiple images. Where early panorama photographers used a segmented approach (taking a series of photos of segments of a panorama and then placing them next to each other to create a single view), it became possible to use digital tools to stitch a number of discrete digital images into a single seamless panorama, making the seams and discontinuities of tone, contrast and color mostly invisible. Since about the mid-1990s, this has been the most commonly employed technique for creating digital photographic panoramas. Not only can stitching replicate the kinds of cylindrical images made with often costly purpose-built panoramic cameras, but it can create images recording an entire 360° by 180° scene, including the zenith and nadir (imagine standing at the centre

Figure 2. Cylindrical projection, 110° vertical field of view.

of a sphere instead of a cylinder). Such images are usually mapped in equirectangular projection and have an aspect ratio of 2:1. The recent introduction of digital versions of rotational scanning cameras also enables direct creation of such images. An equirectangular projection exhibits increasingly severe distortions away from its center, and photographers who are primarily interested in printing their images (or displaying them digitally as stills) consequently most often use cylindrical (**Fig. 2**) or equirectangular (**Fig. 3**) projections.

It also became possible to view digital panoramas on computer displays in such a way that the images are warped back into 'normal' rectilinear perspective (image-based rendering). These systems offered viewers interactivity: by clicking and dragging with a mouse, any

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3   Someone will always be in the picture twice, having run from one end of the picture to the other while the camera swings through its arc.

Figure 3. Equirectangular projection, 180° vertical field of view.

arbitrary viewpoint could be panned left and right, and up and down. This interactive immersion in a scene naturally invites comparison with concurrent developments in virtual reality systems and recalls the experience of viewing nineteenth-century painted panoramas where the viewer's position near the center of a cylindrical environment provided a natural perspective.

The most well-known and widely used example of this is Apple's QuickTime VR (QTVR). The technology was developed around 1995 by Eric Chen and other members of Apple's Advanced Technology Group and was an extension of the existing QuickTime digital media framework (as such it became an integral part of any installation of the Macintosh operating system[4]). While any installation of QuickTime allowed playback of QTVR content both in movie-playing applications and on web pages, the early authoring software employed to create QTVR content lacked a graphical user interface and was difficult to use. By 1997, Apple (and others) had introduced user-friendly stitching and authoring tools. QuickTime VR Authoring Studio software (QTVRAS, released in late 1997) simplified the creation of multinode QTVR panoramic "scenes," where a series of individual panoramas (or nodes) could be linked to create virtual tours. A "hotspot" in an image (such as a doorway) could be clicked to switch the view to a new node, so that the viewer could explore a complex location. QTVRAS also had a capable stitcher. At this point, QTVR was limited to creation and playback of cylindrical panoramas; version 5 of QuickTime, released in early 2001,

Figure 4. Six rectilinear cube faces (90° by 90° each) derived from the equirectangular image in Figure 3.

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4   A version of QuickTime (which includes QTVR playback capability) is also available for the Microsoft Windows operating system.

added support for cubic QTVR, enabling playback of full 360° by 180° equirectangular mappings (cubic because the source image was mapped onto six cube faces, although the end result for the viewer is essentially indistinguishable from a spherical environment [**Fig. 4**]). At the time of this writing, Apple has not upgraded QTVRAS, nor made available a stitcher capable of making equirectangular images (the ability to view QTVR content remains unaffected). But such has been the popularity of navigable panoramas in general, and QTVR in particular, that many other companies have developed a range of stitching and authoring applications.

A notable and influential early contributor to the field of stitching, image mapping, and panorama creation and playback, was a German professor of mathematics, Helmut Dersch, who freely distributed his suite of software utilities, known as Panorama Tools. Versions of this software, still widely used, are available for Linux, Mac OS, and Windows.

Since the introduction of interactive navigable panoramas (which occupy an uncertain space somewhere between the still image and the time-based linear movie), the continued growth in the power and speed of computers has meant that photographers can now deploy their panoramas at high resolution and at screen-filling image scales, something barely imagined in the mid-1990s. Today a richly detailed digital panorama can not only fill a large computer display, but can move (**Fig. 5**).
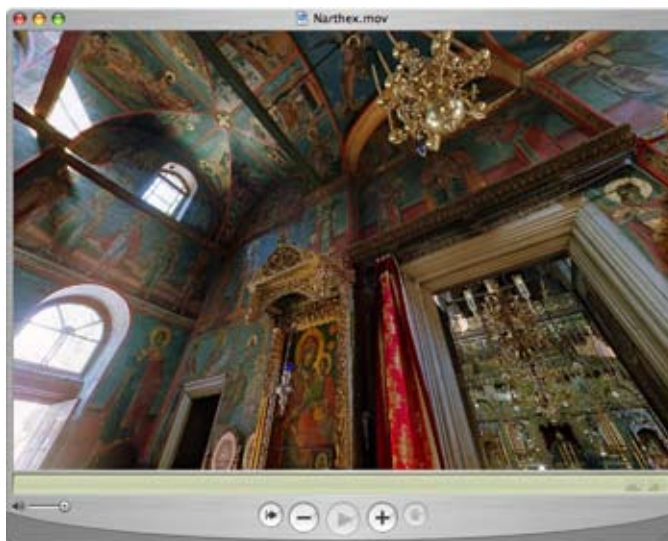

Figure 5. A screenshot from the QuickTime Player viewing application.

1.4. BASIC DIGITAL PANORAMIC PHOTOGRAPHY METHODS

There are many methods for capturing panoramic images. Generally, a photographer will take a series of photographs or use a scanner to scan a space. These source images can be made with traditional film or digital cameras. They are then either digitized or imported into a computer where they are edited and "stitched" into complete digital panoramic image. These images can then be projected by a computer and printed on paper in a flattened form. The various methods of photography, editing, stitching and display are discussed in depth throughout the guide.

1. **Segmented, stitched**
   A camera is mounted on a turntable that segments arcs of a circle. An image is made, the camera is turned a few degrees manually, another exposure made etc. The images are stitched together later to make a complete panorama.

2. **Continuous**
   A camera is mounted to a step motor that is connected to a computer. The operator enters the degrees of rotation, the lens length, and exposure requirements. The software captures a seamless panorama (**Fig. 6**) and little or no post production is necessary. This method induces curvilinear distortion.

3. **Flat stitched**
   This method takes advantage of the fact that light passes through a camera lens as a cone, the radius of which is much larger than a single piece of 4x5 film. A digital scanning array makes an image on the right and then on the left and stitching them (**Fig. 7**). Done carefully, this is the most accurate method of stitching and induces no curvilinear distortion.

Figure 6. Port of Seattle.

1.5. HOW TO USE THIS GUIDE

The guide is divided into five main sections, each divided into smaller subsections. Below is a list of the sections of this guide and a brief description of what is covered:

PRE-PRODUCTION
This discusses choosing a subject and a goal for the project, as well as choosing a site and specific site nodes, and the legal issues involved, such as intellectual property rights, restrictions and permissions, copyright, agreements, and professional liability insurance. There is also discussion of environmental considerations and scheduling the shoot, choosing equipment, travel preparations, local site liaison, site access and resources, and project budgets.

Figure 7. Museum of the Earth.

PRODUCTION

Production covers methods of image capture and the photographic workflow. Topics include selecting image file formats, using image capturing systems and lenses, hardware, lighting, color management, environmental issues and special situations, site data documentation, short-term image storage and back-up, and organizational structure.

POST-PRODUCTION

This section includes in-depth discussion on stitching and rendering and data documentation. Subsections include preparing raw data, software, color management, high dynamic range (HDR) and multiple exposure compositing, batch processing, scripts, hot spots and hyperlinks, executable scripts, selecting file formats and output types, watermarks, sprite tracks, copyright, and converting historical images.

VIEWING, PUBLICATION, AND USE

Topics include viewing platforms, presentation, viewing pitfalls and solutions, incorporating additional media, virtual tours, track synchronization, controlling access, and standards for data interchange. The section also discusses some possible applications for the end-user, including use of panoramas and VR in the lecture/classroom/labs/home, scholarly use, practical use for engineers, hand-held devices at site/landscapes, and historical and heritage site preservation and restoration.

PRESERVATION

This section focuses on the long term physical storage and preservation of the archive and the global digital preservation arena

WEB REFERENCES

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        http://geoimages.berkeley.edu/worldwidepanorama/wwp304/

Panoramas.dk. http://www.panoramas.dk

A Virtual Walking Tour: *The Alhambra*.
        http://www.saudiaramcoworld.com/issue/200604/

Panoguide. http://www.panoguide.com

Chaveut. http://www.culture.gouv.fr/culture/arcnat/chauvet/en/index.html

Lascaux. http://www.culture.gouv.fr/culture/arcnat/lascaux/en/

Arthur C. Pillsbury . http://en.wikipedia.org/wiki/Arthur_Clarence_Pillsbury

Helmut Dersch suite of tools. http://webuser.fh-furtwangen.de/~dersch/

2. PRE-PRODUCTION

2.1. ESTABLISHING PROJECT GOALS

As with any project, the project's goals must be clearly identified and defined. This is particularly crucial for digital panorama production, since all later steps will be defined by what is accomplished in the data-acquistion phase. For the purposes of this document, the final authority on the project goals is the person or group commissioning the work, referred to here as "commissioner."

The commissioner determines the primary subject of the project, the primary audience and the overall intent of in providing access to that subject and related contextual information. The subject may be a cultural heritage site, a built work of architecture, an art object, or some other kind of significant physical space. The extent and scale of that space must be delineated and then the coverage of the space determined. Since each panorama is anchored at a single viewpoint, the selection of the viewpoint (or sequence of viewpoints for multi-node panoramas) will determine the portions of the space presented to the audience.

However, simple percent-of-coverage is not the only goal: the commissioner should weigh intellectual, creative, physical and professional aspects of the access to the physical space to be provided by the panoramas. Often there is much more happening in a space than simply the architecture. Works of art in context, such as an altar or statuary, can be photographed and generated into an object panorama. The intended perspective of the viewing audience should also be considered and what, if any, contextual information will be required.

Lastly, consider how the final product will be used. This depends in part on who will be using the work, but also on who will be generating the data and creating the end-user presentation. Will it be projected alongside conventional slides projected on a screen during lecture, or will it be used by students at home? Will it be distributed over the internet to viewer with slow internet connnections or via school equipment that is configured to specific settings? Will an narrator be required to provide context and explanations? This type of planning will save many hours of work later on.

A digital panorama project is a lengthy process and requires sharp and sustained focus. Competing priorities and a lack of necessary skills have led to mixed results for many ambitious technology projects undertaken by large universities: it may be wise to outsource elements of the project to third-party contractors that specialize in digital panoramas and web design. Depending on resources and budget, hiring external contractors may be the most cost-effective, efficient, and successful method for completing the project.

2.2. CHOOSING THE SITE

After the subject has been chosen it is important to evaluate practical access issues. It may not be possible to actually carry out a photographic campaign of the site. There are many factors with serious consequences to consider, the most important of which is access. The choice of subject may seem easy but often a site is physically inaccessible due to restoration work, unsafe conditions, or legal and adminstrative restrictions. In these cases the commissioner should re-evaluate the subject and chose an acceptable alternative. These kinds of problems may not become obvious until the photographer actually arrives at the site. For example, if you wish to photograph a Greek temple, and your subject is the Temple of Athena on the Acropolis in Athens, everything seems fine until you discover that the temple is completely covered in scaffolding and cranes. A flexible commissioner might switch to Paestum instead. For both the photographer and commissioner, it is helpful to have a local historian or other expert at the shoot if at all possible to handle such unexpected problems (see section 2.7).

2.3. CHOOSING SITE NODES

In an ideal shoot, there is unlimited time on location to capture panoramas in order to record every nuance and a few extras that might turn out to be interesting. Unfortunately, this happy circumstance rarely occurs, forcing the commissioner and photographer to compromise between time limits, access restrictions, and factors beyond your control. Accordingly, plan the shoot as carefully as possible to maximize everyone's efforts. This does not just mean shooting as many panoramas as possible, but also choosing which ones will best illustrate a point and bring the space to the viewer.

If possible, study existing floor plans and illustrations and consider line-of-site from any given node to any other, especially if they will be linked together via hotspots in panoramas (e.g., a clickable doorway that leads from one room to another). Start by working with a copy of a floorplan. Mark all of the places you intend to shoot a node in order of importance. If you start at the entrance to a building, you might logically move a little way in and shoot another node to create a virtual tour. Or, you might be better off moving all the way to the other end of the building in order to shoot it first. This choice will require more time between nodes, but will capture more of the space in case something goes wrong. Trade-offs like this should be expected and planned for, and the prioritized list of nodes should reflect the diminishing importance of each one.

Be sure to allow for light when planning the nodes. Very few panographers attempt to light their scenes for a number of reasons. If the panorama represents a moment in time,

the viewer would see various lights and cables somewhere in the photograph. If the photographer shoots still frames or multiple passes with a scanning camera, it may be possible to shift artificial lights around so that equipment does not appear in the final scene. However, there is a risk of the natural light changing significantly during that time, and blending or combining images will raise problem. Light reflects and interacts in both obvious and subtle ways that may result in extensive post-production work. Time of day and seasonal changes both affect lighting, and should be taken into consideration with choosing and prioritizing nodes. When shooting a cathedral, for example, it might be preferable to photograph a node on one side of the building in the morning and a node on the opposite side in the afternoon, in order to maximize light coming from each direction. Between those two critical times, the photographer can shoot other nodes that rely less on the light's direction. When shooting exteriors, it may be best to shoot when the sun passes directly overhead or to wait until the sun is low, for the shadows it will cast (but keep in mind that anything in the direction of the sun will wash out). Plan for the sun's movements rather than reacting at the shoot.

Consider also the ramifications of placing the camera in relation to the sun or other bright lights. Practically speaking, best results maybe be obtained by shooting in the shadow of a column, utility pole, or other object. Bright lights will wash out a panorama and effectively blind viewers for that portion of the panorama. Putting the camera in a shadow, however, makes it possible to shoot into the light while also achieving a useful result. In some cases, it avoids serious problems such as blooming (where a camera's pixels produce pure white informationless data). If there is a choice between putting the camera in a shadow and not, almost always choose the shadow. Aside from blocking the light, shooting from within a shadow negates the problem of shifting light. Even a quickly shot panorama can have tripod shadows between the first still image and the last or the beginning and end of a scan. The sun may appear to move slowly overhead, but shadows can shift significantly in a short period of time and when the tripod shadows in different images fail to align it results in extra work in post-production. Minimizing shifting shadows is one good reason to shoot with the sun as high as possible.

Other practical and predictable factors include traffic (both foot and vehicular); elements such as water, snow, dirt, or mud; barriers; safety; permissions; copyright; background; and security. Setting up to shoot a node where many people are walking by may be awkward, particularly if people are not supposed to end up in the image. They may bump the photographer or the equipment and if they are too prominent in the panorama there may be problems with privacy. Similarly, shooting a node near heavy traffic can be dangerous, especially when the photographer's attention is directed at the camera. If you use a scanning camera that feeds into a computer, the choice of nodes may be restricted by the immediate terrain (the laptop should not be sitting in the mud). If ropes or gates block access to particular areas, it might be possible to reach over or through them and

shoot from the other side without crossing the barricade.[1] Choosing a location nearby might be less than optimal, but better for the equipment and the photographer. Line of sight can play prominently in spherical panoramas because viewers can look in every direction. If node placements are chosen for optimal viewing in a particular direction, it may compromise what the viewer sees when turning around. Sometimes just a meter's difference will capture both the desired feature and eliminate less desireable objects in the reverse view. The commissioner and photographer should build in enough flexibility to allow for these kinds of small changes on site.

Many places restrict who may access particular areas, but every effort should be made to shoot panoramas in such places, for the simple reason that they are not normally accessible. Shooting in restricted areas can substantially enhance the subject matter for viewers who have no other way of seeing that material.

The commissioner should also consider the artistic quality of each panorama. Placing the tripod in the dead center of a room may show a balanced view in all directions, but unless some particular feature lies directly overhead or below, an off-center location will give a better result. Consider placing the camera somewhere that will offer viewers both foreground and background changes. Placing the camera in the center of the room will minimize features, but placing it nearer to or further from items within the room will heighten and sustain viewer interests.

Placing the camera directly above or beneath particular features will also make the panorama more interesting. If possible, give them something besides ceiling and sky when they look up, and provide them with more than bare floor or dirt when they look down. If the photographer can shoot a node directly on top of a small wall or beneath an overhang, for example, it encourages the viewers to take full advantage of fully spherical panoramas (since, in addition to spinning around, they can look up and down). People like to see the entire context of a place and anything that enhances their experience can only improve the result.

Once all of the shooting subjects are selected, consider the height of your camera. For a given set of nodes, it makes sense to keep the camera height the same through the panorama, so that viewers do not become confused or disoriented. Placing the camera at about eye-level makes sense if the panorama is to show an average person's viewpoint. Alternatively, it might be better to reflect a child's viewpoint or to place the camera on a raised platform or crane so as to get a clearer, straight-on view of the subject matter. Whatever the choice, especially if it is not an intuitive location, it should be explained in the accompanying documentation.

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1   This was done in one location in Rome; a locked metal gate prevented access to a small room, however the bars were wide enough apart that it was possible to set up a tripod and digital scanning camera within the locked area while leaving the controlling laptop on the outside. The entire unit was disassembled outside the gate, then reassembled inside, with cables running out to the controlling computer. The effort resulted in scanning the inside room, which otherwise would not have been visible if the panorama was made outside the locked gate.

No amount of pre-shoot preparation will substitute for securing the cooperation and expertise of those responsible for the site. Good communication will ensure a smooth time in the field and secure access to restricted areas or at special times (such as before public visiting hours begin). Likewise, every detail of a shoot should be discussed and agreed upon by the commissioner and photographer.

With all of the above in mind, then:

• Prioritize node choices to achieve the goal
• Choose both subjective and objective views where possible
• Shoot everything possible while on site
• Pick the best work for the final compilation

2.4. Environmental considerations/scheduling the shoot

Environmental considerations are not limited to the weather. Unique obstacles, such as religious services, holidays, festivals, siesta periods, and local customs, may interfere with a shooting schedule. It is important to research local customs (including appropriate attire) before arriving at the shoot. Some research with travel agencies, web sites, and local site liaisons (see section 2.7, below) will save you time and money.

As discussed above, predicting and tracking the light source on site is critical. The sun and weather play a huge role is the success of a shoot. Artificial light is not desireable for photographing a spherical panorama, so most panoramic photographers use natural light available at predicted times whenever possible. For example, when photographing a cathedral, capture the eastern end (chevet or apse) in the morning, the southern (and northern) transept mid-day, and the western façade in the afternoon setting sun. The time of year also plays an important role in dictating the quality of light. In the northern hemisphere the summer solstice, June 21, provides the most light to work with. This is usually the preferable time of year to shoot. There are exceptions to this: certain buildings, such as Die Wies in Bavaria, are better shot on a sunny day in the middle of winter, since the light reflects off the snow and through the windows up into the dome.

Though the standard proceedure for photgraphing architecture with natural lighting is to use sunny skies for the exterior and overcast skies for more even lighting in the interior, a creative photographer will constantly monitor weather and clouds to make the best of any weather situation. Clouds can be used to the photographer's advantage, providing the softer lighting often desired for interior shots, then parting to provide bright sun for an exterior shot. Even rain can create interesting effects; details of gargoyles spouting runoff water highlight the usefulness of otherwise ornamental features. While day-to-day weather and local cloud movements cannot be predicted in advance, normal weather conditions for the site can be checked through resources such as The Weather Channel, The Weather Underground, and the Lonely Planet guidebooks.

2.5. Equipment

Nearly any kind of still camera[2] (digital or film) can be used to create panoramas. Note that this equipment can be quite expensive, up to tens of thousands of dollars. In most cases, the photographer will probably use his or her own equipment on the shoot. However, it is in the commissioner's interest to know something about the equipment used for this type of photography and to know something about its limitations. The following discussion provides a guide to the pros and cons of various digital camera designs, which fall into two broad groups: single-shot systems (i.e., point and shoot cameras), and those that methodically scan the image (i.e., cameras equipped with a scanning back). Generally, single-shot cameras (and accessories) produce pictures that must be stitched together to produce a panorama, while scanning systems produce panoramas that require less post-production processing.

When it comes to choosing your panorama tools, it is reasonable to buy as much as you can afford but it is not always best to purchase the most expensive equipment. It might be better to purchase two identical systems in case of mechanical problems, accident, or theft. From time to time, used digital scanning camera systems can be purchased in online auction houses: such devices produce very high quality results, but the complexity of their components leaves much that can go wrong. It may be better to purchase two or even three sets of gear that produce good results rather than one set that produces outstanding images. A digital scanning camera system consists of a camera, lens, laptop computer (screen, logic board, hard drive, disc drive), application software, operating system, cables, computer battery, camera battery, adapters, and a tripod. That's at least thirteen vulnerable points: the camera could be knocked over and its lens destroyed, the laptop may freeze, etc., and it may be difficult or impossible to fix equipment on site. Though these systems produce excellent results, they can prove fragile. If your system will include specialized components, you may not be able to purchase replacements from a camera shop down the street. If you can afford a redundant system of this type and ensure its security in the field, by all means do so.

For most educators and scholars, a mid-level DSLR (such as the Canon 20D or Nikon D70) will be sufficient and will achieve appropriate quality. Generally, point-and-shoot digital cameras are undesirable because of the difficulty in controlling exposure settings and attaching external lenses. Many budgets that cannot encompass a high-end system can find funds for a high-quality camera and an identical model purchased for back-up. In terms of field use, this reduces risk to far fewer points of failure and a shorter time for recovery. A local camera shop is much more likely to be able to replace any of these components from stock, and it's even feasible that a back-up unit could be express-shipped from a remote location if necessary. The flexibility offered by commonly used equipment is a big benefit. Alternatively, it might be feasible to have two sets of gear operating in the field at all times, with more than one person operating them, for faster coverage of a site.

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2   The use of video and other moving image technologies in relation to panoramas is outside the scope of this guide.

When choosing equipment, don't forget to account for time and money required for software and post-production processing. Images collected by scanning systems are more easily and quickly converted into panoramas, but the required software may have to be purchased separately (especially for second-hand equipment). Still-shot cameras have a wide range of available image-stitching packages, but they may require much more pre- and post-production time to generate top-quality panoramas. If you use a still-shot camera, a precision panorama camera mount is an invaluable accessory. However, don't try to save money by using a low-quality panorama head, since that will lead to manual adjustment in the post-production stitching stage. The image will "float" between frames in each set of images. When pixels are misaligned, they must be corrected by hand in post-production in order to create a good panorama. Each pair of images must be precisely aligned, a time-consuming and exacting process. With high-precision panorama heads, sets of images overlap each other exactly and can be immediately batch-processed.

IMAGE CAPTURE SYSTEMS

There are several flavors of image capture systems can be used to create panoramas, including:

- Point-and-shoot
- Digital SLR (DSLR)
- Automatic scanning systems (35mm-equivalent, medium, and large format), such as Panoscan and BetterLight
- Video cameras
- Geared roll film cameras

Whatever system you end up with will require the same basic elements:a camera, a lens, a tripod that allows for accurate rotation of the lens, and a method of capturing images.[3]

When conventional film is used, the images must be transferred to digital form in order to be viewed on a computer screen. The most common system is a DSLR camera with a wide-angle lens mounted on a tripod with a special panning head (**Fig. 1-2**).

Though the greatest resolution can be gained from a scanning large-format system, the DSLR system is popular for several important reasons. It is more affordable and there is much less equipment required in the field at a shoot (and therefore less opportunity to break something). Compared to working with a camcorder, there is much less post-processing work required to stitch the image and the results are generally much better and of a higher resolution. Redundant DSLR systems are more readily available than scanning systems and roll-film cameras, and replacement parts are generally available at camera shops throughout the western world. And for conventional photographers, learning how to create a panorama with a common DSLR is a natural transition.

Digital cameras differ from film cameras in that they collect data about the image by means of electronic devices rather than film. There are two types of sensors that collect light

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3   Channel 360 has production kits that a tripod, panorama head, and software.

data about the image, charge-coupled devices (CCD) and complementary metal–oxide–semiconductors (CMOS). Most digital cameras use CCDs, but there are subtle but relevant differences between how these two types of sensors read and record data. CMOS chips have a lower light sensitivity and are generally more susceptible to noise, but use much less power and are therefore well-suited to smaller cameras. A full discussion is outside the parameters of this guide, but information can be found on several web sites.[4]

Figure 1. 35mm camera on a segmented panorama tripod head. Photo by Tom Watson.

LENSES

Anyone who spends time looking at a variety of panoramas will notice the difference between those shot with an 8mm lens and those taken with a 15mm lens. A smaller lens has a greater field of view but objects will appear to be further away and can have an apparent distortion on the edges when a panorama changes view. Some viewers have strong aesthetic preferences for one or the other. There are implications to lens size that may be relevant when choosing equipment. The ability to zoom in on details in a panorama is greatly affected by the lens. If the camera has a CCD chip one square centimeter in size, for example, the amount of detail captured on with an 8mm lens will be far less than with a 15mm lens, because the light captured from a much greater field of view must necessarily fall on the same space that captures more detail in a smaller field of view with a longer lens. This translated directly into the effective zoom achievable in the final panorama. The trade-off comes with the number of images needs to capture an entire sphere: an 8mm lens might do it in four frames,

Figure 2. 35mm camera on a segmented panorama tripod head, viewed from the side. Photo by Tom Watson.

whereas a 15mm lens might need twenty. (The terms used here, smaller/shorter and larger/longer refer simply to the number of the lens; the actual physical size of the lens does not necessarily correlate).

Many photographers prefer to use a wide-angle rectilinear lens with minimal distortion. Fish-eye lenses are also popular because fewer images are required to capture the 360°

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4   Channel 360 has production kits that a tripod, panorama head, and software.

field of view. However, there are limited software applications that can stitch these images due to patent issues. There are one-shot lenses that are capable of capturing the entire 360° in a single image, but these provide the least amount of resolution and are incapable of capturing complete spherical views.

Tripod and Tripod Head

A panoramic tripod head is an important piece of equipment that is used to position the lens of the point of rotation. Mounted on any normal, sturdy photography tripod, the head also allows for even measuring of rotation angles, both horizontally and vertically. Most are manually operated, but some (such as the Panoscan system) rotate automatically. A good panoramic tripod head will allow for proper positioning of the camera so as to avoid parallax. Parallax is the apparent displacement or difference in apparent direction of an object as seen from two different points not on a straight line with the object. In other words, it is the apparent doubling of objects in an image, and is a problem that plagues panoramic practitioners. It is essential to properly adjust the panoramic tripod head so that as you rotate the camera, the point of rotation equals the nodal point of the lens. When the head is not properly adjusted, even by a few millimeters, parallax will occur. Refer to various "how-to" websites such as PanoGuide for tutorials on how to properly adjust your tripod head. Manfrotto, Kaidan, and 360Precision produce good quality panoramic heads.

Resolution Requirements

A common question asked is: How much data do I need to collect? It depends in part on what you intend to do with it. Current library collection standards for scanned film require 3000 pixels on the long axis, shot on 100-400 speed film. If the panorama is only going to be viewed on a typical computer monitor, it should be at least 72 dpi. If it will be printed, it needs to be at least 300 dpi (or whatever the printer specifies). It is advisable, though, to collect data at as high a resolution as possible, so as to have more options in post-production. The systems that provide the highest resolution are the automatic scanning systems. The resulting files may be very large, however, and may require an external hard drive for storage.

Traveling With Equipment

Last but not least, be sure to consider international shipping and customs laws before you invest thousands of dollars. There are strict regulations for shipping hi-tech equipment over international borders and there are limitations to the amount of luggage that can be carried onto an airplane. Travelling is discussed in greater depth in a later chapter, but in general be sure that you do not attempt to travel with more equipment than the carrier or country permit.

2.5.1 Systems requiring stitching

In the early days of digital panorama creation (the mid-1990s), the usual method was to use a 35mm film camera equipped with a wide-angle lens, orient the camera in portrait

TOM WATSON: BUILDING A SCANNING SYSTEM

Digital scanning backs have been in use about ten years. They are derived from satellite imaging systems. Because scanning backs are scientific instruments that require a computer to run them, they have been used mainly in art galleries, museums, libraries, universities and offset printing companies where accurate color and precise detail are necessary to record art works and text. However, they are becoming more popular among architectural and landscape photographers migrating from film to digital while using the view camera they already own. The scanning back used with the Panowide adapter motorized tripod head is optimal for producing panoramas of various dimensions and ratios including 360° cylindrical and spherical panoramas. Two early adopters of digital scanning backs are Stephen Johnson and Shelley Lake. Pixel Light and Richardson Photography also use this technology.

The Better Light scanning back is engineered to slip into the film slot of a view camera. A view camera allows independent displacement of the lens plane and the film plane. To be sure, using a view camera is slower and a more contemplative way of making images, but it offers important advantages for image control. When creating a single image, the photographer can apply front and back rise or fall, swings, tilts and shifts to control focus, depth of field and parallel line convergence (the Scheimpflug principle). When creating a 360° panorama, the use of rise and fall changes the horizon line. Using tilt can change the depth of field. For flat stitch panoramas the rear shift movement is extremely useful.[1]

The look and feel of the scanning back are thoroughly professional. The insert is a thin, torsionally rigid box within which a precision step motor turns a gear drive that moves the Kodak trilinear sensor across the scanner opening, 72 x 96mm in dimension. The inner workings of the electronics are best described by this excerpt from the Better Light web site:

> The trilinear sensor is mounted in a ball bearing carriage that glides on a precision track cut into the metal body frame, and is accurately positioned by a matched polymer nut and stainless steel drive screw directly coupled to a high-torque step motor with up to 6400 micro-steps per revolution, for outstanding smoothness at any motor speed. This motor is driven by a dedicated microcontroller that also controls the sensor's exposure and timing, for crystal-accurate synchronization of these important functions.

> Within the image sensor, three rows of light-sensitive photodiodes are each covered by a red, green, or blue color filter, making the

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1   For more information, see "View camera" (Wikipedia), The Luminous Landscape, and MAGNAchrom, or *Using the View Camera* by Steve Simmons (Amphoto Books, 1992).

entire row sensitive to only one primary color. While Kodak's trilinear sensors use CCD (charge-coupled device) technology like many other digital cameras, in these devices the CCD structures are "blind" (not sensitive to light), and serve only as charge transport "conveyor belts" to carry the individual pixel signals from the photodiodes to an output amplifier for each row. Because there is no need to have the three rows of photodiodes immediately adjacent to each other, a wide CCD structure is positioned adjacent to each row of photodiodes, with the necessary electrical couplings between them. The CCD structure is wider than the photodiode structure so it can carry bigger charge packets (more electrons), which improves dynamic range.

Because of this dual photodiode/CCD structure, these sensors can be reading out three previous rows of color pixel information via the CCD structures while the next three rows of color pixels are being collected in the photodiodes. This allows continuous exposure and readout of the sensor during a scan, without requiring any mechanical shutter. Better Light scanning backs do not stop and start the scanning mechanism to allow the data-collection system to "catch up" – instead, the sensor is always moved smoothly and continuously throughout each capture.

Better Light scanning backs are widely acknowledged among digital photographers as the definitive image quality standard.

My system consists of a laptop computer, an external 80GB hard drive, a 4x5 view camera, a Better Light Scanning Back inserted into the camera, a tripod with a panorama adapter motor, and a small two-pound battery to power the scanning back (**Fig. 3**). Cables connect the scanning back and the panowide adapter motor, so as to coordinate the scan with the camera's rate of rotation. When I have set up my equipment, I enter lens length, rotation, and exposure values into the laptop and begin the scan. The Better Light software first runs and displays a pre-scan, which is 12% of the full resolution. Upon seeing the pre-scan, I can decide whether to change any settings before running the full scan. This all is run from the laptop. Once the full-resolution scan is recorded on the hard drive, I move it to my laptop and view it in Photoshop to verify my choices are correct. Voila! The panorama is 99% complete. Later in the day, I will make another copy on a disc or external hard drive, but very little post-processing will be required. The panorama is contained within a single image, so there is no stitching or pixel manipulation needed. I sometimes scan an image three times (once for the mid values, once for the highlights, and once for the shadows) and composite the three scans together.

Figure 3. Tom Watson's typical panorama photography set-up. Photo by Tom Watson.

The software is intuitive to anyone with photographic experience. I was able to do my first pre-scan thirty minutes after unpacking the unit. Every exposure is a timed event. One rectangular full-resolution image, 6000 x 8000 pixels, 276 MB file in bright sunlight takes 35 seconds. Scanning a 360° panorama takes about eight minutes. Because of the time it takes to make a scan, you must plan ahead to estimate what the exposure will be at the beginning and the end of your scan and be aware of what might occur in the image area during that time (e.g., people walking in front of the camera). One could also have problems with bloom, which occurs when a point source of light produces a thin line through the image. Usually this is very easily retouched. All time exposures are also subject to motion artifact which appears as tri-color lines (**Fig. 4**).

Three attributes put scanning ahead of competing technology as far as I am concerned. The scanning array writes columns of pixels 6,000 pixels tall by whatever has been programmed (I've done images of 6,000 by 65,000). These columns are seamlessly integrated one to another. You can watch the process during the pre-scan. Secondly, since the file is written on a continuous arc, the final image has no stitching artifacts (**Fig. 5**). With large, clear fields, such as an open sky at twilight, a scanning back is my choice. Thirdly,

Figure 4. Filmore Glen. The time lapse in taking the panorama led to the motion artifact in the waterfall. Photo by Tom Watson.

while stitching practitioners are making huge data bases of numerous images and losing 20-30% of each file in overlaps, scanning panoramas use 100% of the pixels recorded.

An example panorama is shown in **Fig. 6**. The shot was done with the equipment and techniques described in this section.

Figure 5. This continuous panorama has no motion artifact because the image was captured at a line time of 1/240th of a second. This image would be impossible to create using the segmented stitch technique. Photo by Tom Watson.

The cost for this technology is not trivial. Better Light is the leading manufacturer of digital scanning backs. Their hardware with Viewfinder software is priced from $6,495 to $22,995. These prices compare favorably with professional medium format instant capture systems. View cameras are "an acquired taste" for many photographers. I have always enjoyed using them and this 100-year-old camera design is enjoying a resurgence. Newer cameras are made of carbon fiber, polyethylene plastic and, of course, traditional wood. If you buy a view camera to use with a scanning back, be certain that the bellows are made of a composite rubber material instead of leather. Leather bellows leak IR light which is not

Figure 6. A panorama of the Academical Village at the University of Virginia in 2006. Photo by Tom Watson.

acceptable to scanning backs. View camera lenses are, by and large, sharp, have excellent contrast and have large image circles. The ability to move the image area around in the image plane makes the view camera lens an architectural tool. The image circle is often large enough to shift the camera back far right for one scan and far left for another scan, then merge them in Photoshop for a perfect flat stitch. The stitch overlap is only about 10% and the resulting image is perfectly rectilinear (**Fig. 7**).
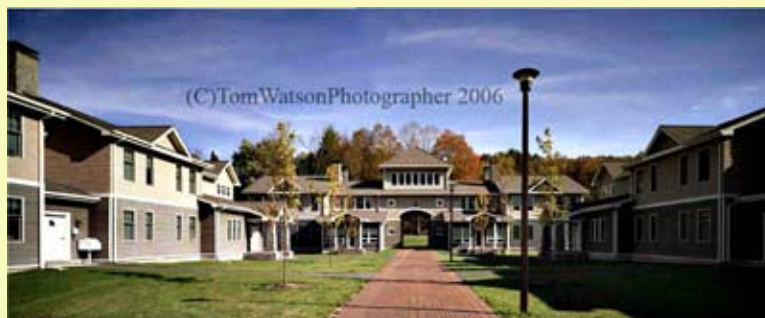

Figure 7. A rectilinear panorama. Photo by Tom Watson.

I carry to each job, a full view camera set and a special view camera with a machined rigid bellows. This special view camera, manufactured by SK Grimes, speeds up the image making process and has an extremely low wind profile.

The Better Light panorama adapter is the other big cost item (about $4,000). It is a step motor-driven automated tripod head. The step motor has zero gear lash which in practical

Figure 8. Better Light scan back mounted on a Better Light Panowide adapter. Photo by Tom Watson.

terms means the camera's rotation will start, stop and return to a precise pixel (**Fig. 8-11**). Images that are precisely the same can be layered or rendered by high dynamic range image software.

The Panoscan camera is another camera to be evaluated for panorama imaging. The trilinear image sensor and viewfinder software are supplied by Better Light. The camera engineering, original thinking on panorama production and uses (law enforcement) are the effort of Panoscan.

Other factors that should be considered before investing in a system:

Complexity: Any digital photographer working at this level has become comfortable with complex systems, but that it a factor with any panorama system. We all must carry the camera, tripods, laptop, cords, batteries, external hard drives, etc. A scanning camera kit contains more parts, but the image quality and the foreshortened workflow benefits outweigh the extra bits of hardware.

Reliability: The Better Light scan back has been very reliable, in my experience. In five years of ownership, I have never had to return one for repair. The scanning insert is strongly built and protects the CCD from dust and damage. The image sensor is easily cleaned at any time dust is detected.

Workflow: With the camera mounted on the pano adapter and the image plane plumb and level on the tripod, the scanning operator can pre-scan an image in seconds, recompose the image by adjusting the software settings, make exposure determinations, examine a histogram for the entire image, and plan multiple scans. The panorama can be loaded into Photoshop and examined for faults at very high resolution. The image is contained on a hard drive (mine is 80GB), which should be backed up for redundancy reasons.

Image Quality: DSLR cameras interpolate color. The Bayer array chips (in DSLR cameras) record 50% green, 25% red and 25% blue. The software then makes up the difference by interpolation. Scanning backs, on the other hand, do not interpolate color. They record each of the primary colors separately and equally; 100% green, 100% red and 100% blue. The image area of a scanning back is larger than any single capture area; 6,000 x 8,000 pixels which at 48-bit yields a file of 276 MB. It is an important difference that can be demonstrated in side by side comparisons. There is no green to magenta color shift across the image as there is with Bayer array chips. This green to magenta color shift must be corrected in the software.

Personal preferences: Photographing digital panoramas is closer, in fact, to a science project than to more glamorous forms of photography. However, there is enormous satisfaction spending each day in deep concentration trying to master this difficult art. Although the equipment is expensive, when you factor in the extra post-production time and the possibility of leaving a site without the job being done, scanning is a viable cost alternative when

Figures 9-11. Better Light with the view camera shifted to the left, right and center. The combination of left and right make a rectilinear panorama image. Photos by Tom Watson.

compared to other techniques, at least to this writer. The image quality, expressed as an inkjet print or a 4-color offset job, is the most compelling in the long history of photography.

Digital vs. Film: Cold weather is a big disadvantage to digital photographers. The imaging chip is not supposed to be subjected to below freezing temperatures. LCD displays begin to gray out when subjected to cold, batteries loose power quickly and in general digital cameras are not as hardy as film cameras. With film, the lubricant in the shutter blades may slow the shutter closer so that over exposure becomes a problem. In extreme cases, roll film becomes brittle and will break. All other considerations favor digital production vs. film production, in my opinion.

How much data do we need to collect? The Better Light workflow is done entirely in a TIFF format. We hope that this is a stable format that will be useful well into the future. For now, working entirely in TIFF and resampling for other uses into JPEG is our working method. Our files are large enough to meet ever increasing computer and internet speed capabilities. With programs like load-on-demand Zoomify, one can view enormous files over the internet.

Why I do what I do

I am closing in on forty years as a professional photographer. I am grateful that my family life and my career were and are so harmonious. Intrinsically, I am the happiest I have ever been as a photographer and these last five years I consider to be the high point of my career for these reasons:

- Freedom from the environment of chemical photography
- Superior image quality of the digital file
- Digital work flow
- The profound pleasure of working with large 48-bit color files

Most readers to this guide will not have spent thousands of hours processing color film (good for you!). Photographs without film grain and the longer contrast scales of digital files are more beautiful. The digital workflow supports Ansel Adams' "previsualization concept," which loosely stated, says that as you set up your camera, you are envisioning the final print. We have digital image tools that Mr. Adams never imagined, but would wholeheartedly embrace. He was an artist and a technician. Combining the 1860s' technology of the view camera and a large-format digital back are the most powerful set of tools in the history of photography. I am happy to be one of the practitioners.

mode, and take a dozen or so shots while rotating the camera in roughly equal steps through a 360° circle. With this technique, the camera should ideally be mounted on a tripod and the camera's position on the tripod should be offset so that the axis of rotation passes through a point in the optical system (commonly termed the "nodal point" and usually located somewhere through the body of the lens), in order to avoid or at least reduce parallax. Photographers used either homemade camera-mounting brackets or purchased specially designed tripod heads from commercial suppliers.

In its essentials, this method is still being used although as digital camera design and capability have improved, film has fallen out of favor; today the overwhelming majority of stitched panoramas are derived from born-digital images. Also, since the advent of cubic and spherical panoramas, there is a need to shoot more than just a single row of pictures around if the zenith and nadir of a scene are to be recorded.

A system for good-quality stitched output might consist of:

Camera: preferably (but by no means necessarily) a DSLR model. The main advantage of the DSLR design is the ability to use interchangeable lenses.

Lens: a rectilinear wide angle typically in the range of 14-24mm focal length (35mm equivalent) or a fish-eye (either circular or full frame). Longer focal lengths can be used; they will yield higher resolutions but require more pictures and a lengthier stitching time; fish-eye lenses are widely used because a full scene can be captured with a smaller number of shots.[5]

Tripod and panoramic tripod head: while some adventurous workers in the field have made very successful hand-held panoramas, the use of a tripod and panoramic head really is recommended.

2.5.2 SYSTEMS NOT REQUIRING STITCHING

Stitching can be a vexing and time-consuming process. Errors such as ghosting and mismatched features require often difficult digital retouching and repair in an image-editing application. As part of the stitching process, captured images almost always require remapping from their rectilinear or fish-eye perspective to cylindrical or spherical projections, and image quality can be somewhat degraded by this transformation. Shooting a series of pictures takes time, and non-static features in the scene (clouds, people, vehicles) move between exposures, resulting in ghosting, stitching errors, and associated problems. These difficulties can be largely overcome by non-stitching techniques, in which the camera captures a panoramic scene in a single exposure. There are three basic approaches you can use:

1. **Rotational cameras**
   There are different designs, some home-brewed, mostly commercially manufactured. They come in both film and digital versions with varying image scales or film formats. All have the ability to capture a panoramic scene in a single exposure/rotation (and without resorting to a panoramic tripod head). If the objective is to produce an interactive 360° panorama, one stitch is required to join up the two ends so that the image wraps, but this is a trivial matter requiring only an image editor. The main disadvantage of these

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5   However fish-eye images often need to be remapped to rectilinear projection, as some stitching software will not otherwise work with them.

cameras is that they are expensive (particularly the digital models) relative to the more modest equipment needs where stitching is employed.

2. **One-shot or single-shot systems**
   A relatively recent development has been the introduction of devices employing parabolic mirrors, the reflection of which can be imaged with conventional digital cameras. A single picture of the reflected scene can then be processed with software to output a cylindrical image.[6] Advantages: one shot; no stitching; capturing subject motion; ease of use; can be used with wide variety of cameras. The main disadvantage is that the panorama's resolution can only be as good as that of a single frame taken with the digital camera.

3. **Scanning systems**
   Digital scanning backs, originally developed by the military for satellite imagery, are similar to and provide equivalent resolution to medium- and large-format film cameras. Instead of capturing a sequence of individual shots like a digital single-lens reflex (DSLR), they scan the view and create a single complete panoramic image on the spot. With newer systems, the resolution is truly enormous, and the viewer can zoom in to incredible detail. One major difference between panoramic scanners and DLSR setups is that they require a computer be physically connected to the camera in order to operate. This may increase set-up time and introduce another level of complexity in the system. Another consideration is the large file size, which not all computers can handle. While the files can be downsampled to reduce size, they may actually provide far more data than the project requires.

2.6. TRAVEL PREPARATIONS

EQUIPMENT

Traveling with photographic equipment can be quite challenging. There are changeable restrictions on carry-on, checked baggage, and customs for all forms of travel. It is generally not a good idea to check expensive and delicate equipment into an airplane hold. Luggage is often mishandled and thefts do occur. Whenever humanly possible, carry media, film, and equipment by hand. However, the situation will vary depending on where you are going and how you are getting there: if you are not sure,

Check with airlines a few weeks before departure to give yourself sufficient time to pack your gear properly, and be aware of last-minute restrictions or political events that may complicate your trip. Also beware of the Warsaw convention, which regulates liability of international airlines for passengers and baggage. This limits an airlines liability for lost

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6   At the time of writing, commercial models include systems such as BeHere, Egg Solution, Remote Reality, 0-360, and 360 One VR Kaidan.

Michael Gross: Balancing resolution and budget

I've used many different systems, from video cameras to the latest DSLR available. What you use depends on the purpose of the documentation. If you are creating a documentation of a building that will be used in the classroom and added to library collections then, in my opinion, there's really no such thing as overkill.

With constant advancements in digital camera technology and rapidly increasing resolution, I try to use the camera with the most resolution possible that is within my budget. This strategy not only provides beautiful images with an incredible amount of information, it also increases the "shelf-life" of my panoramas before they are deemed obsolete relative to current expectations for resolution.

My current set-up (**Fig. 12**) includes a Canon EOS 1Ds Mark II (16.7 megapixels) with a 14mm f2.8 Canon lens. This camera/lens combination provides a good balance of very high resolution with minimal shots required per panorama. This is mounted on a Manfrotto 303 sph tripod head on a Bogen tripod. This, while not quite as precise as other tripod heads (such as the 360Precision), it is capable of taking almost any camera setup and is very easy to calibrate, whereas each 360Precision is built specifically for one camera/lens combination and cannot be adjusted for another setup. All of the equipment I use is relatively easy to find in many countries around the world. If I experience equipment malfunction in the field I will be able to use back-up gear and keep working.

Figure 12. Michael Gross in the cloister of the Sainte Foy Abbey Church in Conques, France (1050-1120). The system used consists of a Canon 1Ds Mark II (16.7MP digital full-frame SLR), Canon Wide Angle EF 14mm lens, Bogen/Manfrotto 303SPH Spherical Panorama Tripod Head, Bogen/Manfrotto 055MF4 Magfiber Tripod, and Canon Remote Switch. Photo by Barry Gross.

or damaged equipment to a startlingly low number (around US$25 per kilogram of cargo and US$500 for carried baggage). Warsaw was amended in 1955 at the Hague and in 1999 at Montreal, but the revised amounts are still small (approximately US$1500 for baggage and US$25 per kilogram for cargo). Independently purchased travel insurance may offer more coverage, but

Because baggage regulations are becoming more restrictive as of late, you may be required to check or ship your luggage. ATA cargo cases (such as Pelican ATA) can be custom-made to the specifications of your equipment and are probably the most reliable option when carry-on is not an option. However, you also must beware government import/export

restriction when moving hi-tech equipment. For example, shipping computers and hi-tech equipment into Italy is notoriously difficult. Using luggage Carnet forms sometimes facilitates the process. These are essentially passports for your gear, and some countries require them when bringing in professional equipment.

The Carnet is an international customs document to be presented at each port of entry. It is an itemized list of goods or equipment upon which no duties, fees or taxes are to be collected because the goods or equipment is to be reexported within twelve months. Think of it as a passport for objects. There are yellow, green and white counter foils for custom agents to sign and stamp upon entry and exit from each country traveled through. Failure to obtain entry stamps and signatures or exit stamps and signatures may result in a penalty of up to 40% of the listed value at your next point of entry.

Carnets are issued by the Corporation of International Business. They maintain an excellent website where one can browse all the categories of interest and assess quickly how to proceed. The application fee and the bond posting for US$10,000 worth of equipment would cost approximately US$300. If you are starting your journey from the US, before checking in with the airline, make sure that US Customs has done its job of checking your serial numbers, signing and stamping the Carnet. This will protect you from the eager US tax collectors when you return.

The CIB website portrays Carnet use with upbeat and positive language, but it is a news event when another country, recently Taiwan, became Carnet-compliant. Many countries, such as those in the Middle East, do not accept the Carnet. There is also a help line (1-800-282-2900). Veteran travelers know that frustration abounds at ports of entry. Business travelers especially know to have all the paper work in perfect order. Another thing to keep in mind is to always maintain a pleasant tone of voice, relaxed body language and gesture towards the exit saying, "où sont les taxis?"

FILM
The main concern for photographers travelling with film is the possibility of fogging caused by airport security screening. The ideal strategy would be to obtain film on site, and have it developed locally. But of course this is not always practical and it may not be possible to obtain particular types of film locally and/or find suitable processing labs.

The first thing to be said in this regard is that undeveloped film (whether exposed or unexposed[7]) should never be placed in checked baggage, where it is likely to be subject to high-intensity X-ray inspection. Undeveloped film should always be placed in carry-on baggage. But even the radiation from the lower-intensity scanners typically employed for carry-on baggage may cause fogging of higher speed films (say ASA/ISO 800 or above) and even of slower films if exposed repeatedly in multiple passes through such systems. Having said that, there is considerable anecdotal evidence (at the time of writing) that

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7   Film that has been developed will of course be unaffected by X-ray inspection.

medium-speed films can withstand multiple passes through carry-on inspection systems in North America and Europe with no noticeable effects. Lead-lined bags will in theory offer a level of protection, but they will also probably attract attention during the screening process, requiring hand-inspection, or even higher-intensity X-ray examination. In the US at least, it is possible to request that film (and camera equipment) be hand-inspected at security checkpoints. Manual inspection policies in other countries will vary, and it should not be assumed that such requests will be granted.

SAFETY

Security and safety for both people and equipment is a constant consideration. Most important, if you are faced with the choice of losing equipment or risking injury, remember that equipment can always be replaced. Some tips to traveling safely:

- Whenever possible, travel with at least one other person.
- Always keep a low profile when moving about a city or in transportation centers, like airports and train stations. E.g., keep equipment packed and inconspicuous.
- Avoid storing equipment in cases with obvious logos that suggest valuable contents.
- Be aware of your surroundings. Thieves can follow you after a shoot, so it is a good idea to take a cab directly from the site to your hotel and store your gear safely before going out for dinner.

For tips on traveling safely, refer to the Savvy Traveler, the Washington Post Travel Section, and the New York Times Travel section for more tips. Since many national and regional newspapers are available on the web, it may also be worthwhile to read the local news before finalizing your plans (Newslink.org has links to papers all over the world). You should also consult the State Department about travel considerations for the area you are visiting.

Some regions of the world are simply too dangerous to visit. In these cases it may be possible to hire local photographers. If they do not have experience with shooting panoramas, you may be able to arrange a meeting in a neutral countries and provide training.

INSURANCE

At the risk of stating the obvious, get proper travel health insurance and equipment insurance. Be sure to read the fine print: many policies do not cover equipment "in transit" (while it is traveling on an airplane or being shipped). And many policies that claim to cover equipment in transit in fact only cover catastrophic events, such as floods and fires. If boxes go missing or gear arrives broken, you may be out of luck. One of the best options is to ship equipment with FedEx. They allow you to declare the value of your packages. This is similar to insurance, but they will replace the equipment for you (rather than issue you a claim check). Be aware that when you declare a value of your equipment you will be responsible for any duties calculated from the total. Many film photographers develop their negatives at a trusted local developer before returning home in order to avoid problems with x-ray scanners at airports. The Large Format Photography

Brian Donovan: Film versus Digital Capture

In the early period of digital panorama creation, film was the preferred option as digital cameras were in their infancy, and relatively expensive. At the time of writing however, digital cameras are by far the most frequently used for image capture. And with good reason — an obvious disadvantage with film is that it has to be digitized. This adds another step in the workflow and costs more in both time and money (not to mention problems with dust, scratches, and fingerprints). However, there is another side to this coin: color negative film does offer one outstanding characteristic of particular interest to the panoramic photographer, and that is its very high dynamic range. Digital camera sensors (and traditional color transparency film) have a more limited capability than negative film when it comes to compressing the range of brightness in a subject in a single exposure. This is especially pertinent for spherical panoramas, which might include the sun in the zenith and deep shadow in the nadir. Photographers using digital cameras have developed a number of strategies for dealing with this problem, including compositing and, more recently, high dynamic range imaging (HDRI) techniques; but these techniques are generally not straightforward to implement. A color negative, it could be argued, is in itself a ready-made high dynamic range image, and while obtaining good scans from color negatives (especially of high-contrast subjects) is not always the easiest of tasks, standard image-editing skills can be used to tease out the desired detail in both highlight and shadow areas (nor will the latter suffer from the noise often evident in digital images).

At the time of writing, there is much discussion of digital preservation strategies, and possible long-term problems with archiving media such as CD and DVD-ROMs. If nothing else, film has certainly proved itself to be a long-lived and compact data storage medium.

There is also that hard-to-define 'look' of film; the grain, the grittiness, that sets it apart from the digital image with its own characteristics (lack of grain, color fringing, shadow noise) all of which give it a recognizable appearance. This is a simple matter of personal preference.

Finally, there is the advantage of being able to revisit and rescan old negatives as better film scanners become available or your scanning skills improve. Whatever the reason, a carefully stored negative still has all that image information locked in its grain structure awaiting reinterpretation. If we regard scanning as a variation on traditional printing, just another way of making a final positive image, then a familiar quotation from the great photographer (and master print-maker) Ansel Adams seems pertinent:

> The negative is comparable to the composer's score and the print to its performance. Each performance differs in subtle ways.[1]
>
> It would not be so easy for the digital photographer to reinterpret a set of JPEG files taken for a stitched panorama. Depending on the original exposures, highlight and shadow details that were not recorded or were clipped are irrecoverable, and other image qualities, such as white balance, can only be modified by so much before the image is adversely affected. Having said that, there is a sort of digital equivalent to the color negative, and that is the RAW file format, a high-bit-depth image[2] that, to some extent at least, does embody some of the qualities of the negative. But not all digital cameras offer RAW as an option, and, because it generates large files, only a minority of photographers at present routinely use it to create source files for their panoramas.
>
> In the film vs. digital debate, it seems clear that at the start of the twenty-first century digital has resoundingly won the day, and for very many good reasons. And yet, and yet... for those few diehards among us still using film, it may be just a little while yet before the darkroom door is closed for the last time.
>
> _____
>
> 1   Ansel Adams, The Print (Ansel Adams Photography, Book 3) (Boston: New York Graphic Society, 1984).
>
> 2   Many digital cameras can also save high-bit-depth images in formats like TIFF. This also allows for more extensive image manipulation in subsequent editing (as compared with 8-bit formats such as JPEG) but is not as versatile as RAW.

Forum has a section on Location and Travel, including discussions on traveling with film. When entering a country it is always a good idea to say that you are traveling as a tourist, avoiding mention that you are traveling for work or study unless you have work or student visas. Immigration customs, police, and other border officials can be unpredictable in some countries. In some cases, bribery is necessary for the project to continue, though is not sanctioned by the writers or distributors of this guide.

BACKING UP DATA

You should make redundant copies of your data anyway, but it is highly desirable to maintain copies of your data on multiple continents when traveling overseas. One excellent option is to send back-up DVDs to a trusted recipient back home during your travels. In that case, it is wise declare a value of US$1 for your data so as to avoid hefty import/export tariffs and questions about conducting work without a work permit.

2.7. LOCAL SITE LIAISON (MR. FIX-IT/FIXER)

The local site liaison, a.k.a the Fixer or Mr. Fix-It, can be an invaluable assistant. This is a local person who knows the proper procedures for getting necessary permissions to shoot, is familiar with local customs, and is familiar with the area. He (or she) can be

especially helpful in a country with a lot of red tape, such as Italy. A Mr. Fix-It can also provide on-going services such as:

- translator
- driver / guide
- information on local customs and food
- help finding the best photo shop for film and development

A good site liaison is generally a local scholar, photographer, filmmaker, or local guide who lives in the area and is hired to deal with logistics on a local level. To find one, contact local academic institutions and post a request for a local liaison to university list servers, or check with local guide companies, travel guides, hotels, movie/film companies, cultural attachés, embassies, state department recommendations, or local press contacts. In some countries (Germany in particular) taxi drivers often are very knowledgeable and can be hired as a guide for the day. Be sure to negotiate compensation in advance. With the right local liaison, the shoot will go smoothly and everyone will be happy.

OTHER PREPARATIONS

Regardless of local help, it still helps to be prepared. Bring a letter of introduction from the commissioner, institution, or university. The letter should be notarized and could even include certifications by "apostille" (a seal attesting that a notary is registered, which is accepted as the recognition of other countries' official documents under the 1961 Hague Convention). Certainly bring along business cards, as well as many copies of all your documents. The more documents you can supply in support of your project the better. Contact the cultural attaché of the country you will be visiting and ask for a letter of support for your project. Bring letters of support, on official letterhead from the head of the university or institution, as well as the commissioner, professor, and project director. Photographers should bring information about their professional credentials.

WHAT TO DO WHEN THE LOCAL SITE LIAISON FAILS

Sometimes, unfortunately, Mr. Fix-It fails. Be sure to have a back-up plan in the form of alternate contacts or a strategy to deal with logistics yourself. If your local liaison came recommended from someone you trust and (even better) has worked with that person before, you can feel more confident. But, even with the best of intentions, your project will not always have the highest priority for your liaison and contacts and there is always the risk of scam or sheer incompetence. For best results, use a liaison who has good credentials and strong recommendations from friends or colleagues who live or work in the area.

2.8. SITE ACCESS AND RESOURCES

Gaining access to a site can occasionally be as simple as providing a wish list to your local site liaison. However, we are not always so lucky and the commissioner and/or photographer must then do much of the legwork. Generally, you must first determine who is in charge of a building and who is authorized to grant these permissions. A good

place to start is by calling the press office, if there is one. Often, this office handles everything, including scheduling the shoot. More obscure sites are not so well organized, in which case some creative thinking about whom to contact and how to get in touch with them will probably be helpful. In Italy, for example, there is an entire bureaucracy established for handling the rights of the cultural property of the state. Each city has its own bureaucracy. Unfortunately, they are usually not very efficient, so the key to success is to be persistent. Authorities often will not respond to paper or electronic correspondence so you will have to phone or visit the office in person, sometimes more than once.

When determining who controls a site, a great place to start searching is the World Wide Web. A website for the site may have phone numbers or the name of a foundation or group that supports the site. The following are some examples of different types of sites and who controls them:

- Religious Site (e.g. church, mosque, temple): depends on who owns the building. Begin with the religious office. In Italy, the building may be controlled by one of the various Soprintendenza (e.g. Soprintendenza Archeologica di Roma; Soprintendenza Beni Ambientali e Architettonici di Roma).
- Public Space (e.g. square, street, park): Contact the city film commission (in Italy, the Soprintendenza di Film) for permits.
- Archaeological Site: If the site is an active dig, contact the archaeologist or institution who is in conducting the research. In Italy, try the Soprintendenza Archeologica for the city where the site is located.
- Museum: Press office for the museum.
- Library: depends on who owns the library (university; religious organization; city); sometimes libraries are owned by non-profit organizations.
- Residence: private individual; foundation or cultural trust (generally a trust will preserve all the buildings of a particular architect, e.g., the Frank Lloyd Wright Preservation Trust).
- Private Company (e.g. bank): contact the public relations office or the office manager for the company.
- Government Building (e.g. City Hall): contact the building management office or visit the tourism office.
- School/University Campus: contact the public relations department or the Office of the Architect.
- Transportation Hub (e.g. airport terminal, train station): contact the press department of the transportation authority, often a division of city government or an independent public authority. Security clearance is likely a requirement for photographers, particularly for airport terminals, and may take an extended period of time to obtain.

Besides the challenge of gaining access, you will have to study and secure required resources for a shoot: power, lighting, storage, transportation, translators, etc.

POWER

Power requirements are often tricky. Older buildings have a limited number of power outlets, and they are often not conveniently located and are not grounded. Old buildings

Brian Donovan: To the Holy Mountain

A vivid example relating to permissions and site access was my 2001 visit to the Orthodox monastery of Hilandar at Mount Athos in Greece. This was part of a research and educational project for the University of Auckland's School of Architecture, whose main focus was the largely Byzantine art and architecture of this monastic complex, little changed since the 14th century, with its origins in the 11th century.

The Athonite monasteries (there are about twenty of them) are located on an otherwise uninhabited peninsula in the Chalkidiki region of north-eastern Greece, and together they form a sort of autonomous territory, with its own borders, customs procedures, and regulations. The job called for me to travel to the Holy Mountain (as it is known) along with a lecturer from the university. To be able to visit at all, we first had to obtain an explicit invitation from the abbot of the monastery, then apply for a special kind of visa (a diamonitirion) from the Athos Visitors Office at Thessaloniki (the nearest Greek city, and usual starting-point for visits to Athos). But not only that — there is one further condition that must be met for admission to the territory: as a result of a medieval edict still in force, only adult males may visit Athos. Women and children are not only excluded from the monasteries, but from the entire peninsula. Here then, was one of our several goals: to use interactive panoramas to provide female students of art and architecture with the 'next best thing' to visiting the monastery. Moving images, in the form of video or film — which might otherwise be regarded as the next best thing to being there — are forbidden at Athos, and the monks took some

tend to have old wiring that cannot handle the high amp requirements of electronic equipment and lights especially (remember, watts = volts x amps). America uses 110 volts, 60 Hz. In Europe and other parts of the world, they use 220-240 volts, 50 Hz. Many power adapters for battery chargers and computers are capable of handling both systems, but check the label before relying on them. Different countries use different shapes for their power outlets. Steve Kropla's Help for World Travelers has information on international electrical settings and telephone connections.

The easiest solution is to buy a travel kit with all the adapters you will ever need, and make sure to bring as many as you think you will need. At any given time you may be running a computer, charging camera batteries, and backing up data to an external hard drive.

LIGHTING
Unlike traditional architectural photographers, panoramic photographers generally prefer to rely on natural lighting. Artificial lighting increases the complexity of a shoot by an order of magnitude, and introduces problems that would otherwise not exist. For example,

convincing that the QuickTime VR panoramas I would produce, based as they are on still images, did not constitute movies.

Then there was the matter of physical access: this involved travel by bus to a village at the edge of the territory, where final border formalities and customs checks took place; then a ferry to a landing place some way down the coast; and finally a truck ride over dirt roads to Hilandar, nestled in a wooded valley and seemingly an awfully long way from anywhere. A week spent living with the monks and photographically documenting the surroundings followed. One further visit in 2003 allowed completion of the work, as it was only on this second visit that we were finally granted access to the monastery's church (katholikon). This reluctance by the monks to grant us full access to all parts of the complex was entirely understandable — not only were we lay outsiders, but we were not Orthodox (the great majority of visitors to the Athos monasteries are Orthodox pilgrims).

This job had a poignant aftermath, when, in March 2004, a devastating fire destroyed about sixty per cent of the monastic complex (**Fig. 13**). A massive

restoration and rebuilding project is underway, but it will just never be the same again. Although mine are by no means the only photographs depicting Hilandar as it was before the fire, they offer — with the relative objectivity that characterizes most 360° panoramas — a unique record of this lost heritage.

Figure 13. Orthodox monastery of Hilandar at Mount Athos before and during the 2004 fire.

a wall with a fresco must maintain a certain temperature range and environment, and the use of bright, hot lights might be prohibited. Also, site managers prefer to keep the equipment used to a minimum so as to avoid preventing the normal flow of visitors. One tripod is normally not a problem, but lighting equipment can present quite an obstacle.

STORAGE OF EQUIPMENT AND CASES
Keep equipment cases out of view of the shot whenever possible, for the sake of both convenience and security. Be sure to find a secure place to store the cases, such as an office, security desk, or the trunk of your car.

ROADS AND TRANSPORTATION TO THE SITE
Many sites are located in cities with a plethora of transportation options. In some cases, it will be easiest to drive to the site, but be aware that parking can be an issue, especially if the site is in a crowded or insecure area. Cabs are a good option but are not always reliable. Subways or trains are often cheap and reliable, but be sure that you will be

able to physically handle the equipment. Also keep in mind that during peak hours the carriage may well be standing room only and there may be a short window of time at your stop with which to force your way through the crowd and off the train (not an easy task with large, heavy cases).

Sites that are not located in major metropolitan areas present a different set of problems. In Europe, the train system is wide-spread and generally good, but there are still many places that are a long and expensive cab rides from the closest train station. In this situation, it may make sense to rent a car.

TRANSLATORS AND CULTURAL LIAISONS
A local site liaison can be very useful in handling logistical issues. This is discussed in depth in section 2.7.

2.9. Budget

There are three tiers of production systems: base, average, platinum. Which you chose depends on the balance between the project's needs and its resources. The commissioner should discuss the differences in quality verses costs with the photographer (see section 2.5 for information about equipment options). It should also be made clear what costs the commissioner will cover and what costs the photographer will cover. For example, is the photographer responsible for getting travel insurance and liability coverage for possible damage to the site?

The commissioner's budget should cover production, post-production and long-term maintenance of the project. It will need to include the following categories:

EQUIPMENT
This covers all the equipment for the shoot, including items such as: camera, remote switch, flash media, lenses and filters, tripod head and legs, laptop computer, stitching software and image editing software, flash media card reader, travel cases and backpacks, power adapters, and external data storage. Normally the photographer owns or has access to most of this equipment and has to purchase only a few items specifically for the project, such as stitching software and the panoramic tripod head. It may also be possible to rent or borrow individual pieces of equipment. Universities may have equipment loan pools or an art department that will loan equipment for special projects.

TRAVEL
This generally includes flights, travel insurance, local transportation, hotels, per diem food costs, communications, guidebooks, and maps.

FEES/LICENSES

While many sites waive fees for educational use of site photographs, many charge a reduced or full fee. This can range from just a few dollars to hundreds of dollars (the average is between US$100 - $300), but in rare cases the fees can range in the thousands. If the photographer is hired as a contractor, then he or she will also be paid an honorarium. The local site liaison will also negotiate a fee, generally a daily rate (see section 2.7). Extra liability insurance for the photographer or the commissioner may also be required, depending on the site and subject. There may also be access fees for entering the site or for using the site at night or when it is closed to the public. Finally, it may be necessary to bribe officials to travel, import equipment, etc.

If legal consultants are required to write up releases and licensing agreements, their fees should be included in this category.

If the project is being funded by federal or non-profit grant agencies or administered by a university or institution, be sure that these costs are covered in the proposed budget and that the institute grant administration procedures will allow the costs to be paid with grant moneys.

POST-PRODUCTION

Unless the project is being run by a university department that can provide post-production facilities and labor, post-production costs will include purchase or use or hardware (computers), software, and labor involved in turning the source images into the final product.

MAINTENANCE OF ARCHIVE

This oft-overlooked item involves the long-term maintenance of the archive. As network infrastructures, operating systems, and viewing platforms and software change, the archive must be adaptable in order to remain accessible and useful. As of this writing, there is no open-source software for viewing digital panoramas and we cannot assume that commercial software manufacturers will continue to distribute and provide support for current versions of viewing software. It is not enough to store your work in a secure and stable environement: it will require further investments of time and effort to remain accessible to future users.