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# Recording the Weathering of Outdoor Stone Monuments Using Reflectance Transformation Imaging (RTI): The Case of the Guild of All Arts (Scarborough, Ontario)

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*Reflectance Transformation Imaging (RTI), developed in 2001 at Hewlett-Packard (HP) Labs, has been available for almost a decade but has been largely overshadowed by the rapid growth of laser and structured-light scanning in many cultural heritage applications. Work by Cultural Heritage Imaging (CHI) in San Francisco and at the University of Minho, Portugal, has done much to promote the technology and to develop a standard workflow. Demonstrated in this technical note is the way RTI can be integrated into the toolkit of the working stone conservator. The case of weathered façades in sandstone and limestone at Guild of All Arts in Scarborough, Ontario will be considered and the potential of RTI to reveal original tool marks on stone as well as spalling, both features that can be difficult to capture reliably outdoors with standard photography. RTI promises, by virtue of its ease-of-use and low-cost, to become a standard tool of documentation among conservation and heritage professionals for before and after-treatment recording.*

*L'imagerie par transformation de la réflectance (ITR, ou RTI en anglais) fut développée en 2001 aux laboratoires de Hewlett-Packard (HP). Bien que cette technologie soit maintenant disponible depuis bientôt dix ans, son application dans le domaine du patrimoine culturel fut éclipsée par celles de l'imagerie par balayage laser et de l'imagerie par lumière structurée, ces dernières ayant connu une croissance très rapide. Les travaux du Cultural Heritage Imaging (CHI) à San Francisco et de l'Université de Minho, au Portugal, ont grandement contribué à faire connaître cette technologie et à développer des processus d'opération standardisés. Cette note technique démontrera comment l'ITR peut être intégrée à la trousse d'outils du restaurateur de pierre. Ce faisant, le cas des façades de la Guild of All Arts (Guilde des artistes et artisans) à Scarborough, faites en grès et calcaire et usées par le temps et les intempéries, sera présenté. Le potentiel de l'ITR de révéler autant les marques d'outils originales que l'usure et les lacunes de la pierre sera mis en évidence; ce sont d'ailleurs des caractéristiques pouvant être difficiles à documenter de façon fiable dans un environnement extérieur à l'aide de la photographie traditionnelle. L'ITR, de par sa facilité d'utilisation et son faible coût, pourrait devenir un outil de documentation standard de l'avant et l'après traitement pour le professionnel de la conservation-restauration du patrimoine culturel.*

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## Introduction

Reflectance Transformation Imaging (RTI), developed little over a decade ago, provides the perfect tool for documenting and monitoring weathering on outdoor monuments. It allows the conservator to accurately monitor minute changes of texture on planar surfaces without the need for expensive structured-light or laser scanning systems.[1] In the present paper a preliminary "proof of concept" for using RTI in stone conservation is outlined, based on a test case, the outdoor monuments at the Guild of All Arts in Scarborough, Ontario. The monuments at the Guild were selected for two reasons. First, many of the architectural artifacts at the Guild have benefitted from conservation treatments over the last several years – many performed by one of the authors – and much more remains to be done. The RTI documentation of these monuments is a natural outgrowth of ongoing efforts to document and conserve these pieces of Toronto history. Second, the architectural features deposited at the Guild, weathered from decades of exposure to the elements, are easily accessible from ground-level. Were they *in situ* in their original buildings this initial study of RTI's use would have presented considerable additional challenges.

## The Guild of All Arts

### *Background*

The Guild is a publicly owned, densely forested site on the Scarborough Bluffs in the east end of the Greater Toronto area, providing magnificent views of Lake Ontario and a key public access point to the lake shore and waterfront trail (191 Guildwood Parkway, Scarborough**)**. This site has a remarkable history as a Canadian arts and crafts colony and has been designated under the Ontario Heritage Act because of its significant contribution to Toronto's heritage. The property contains formal gardens, sculpture and many interesting and beautiful architectural fragments. There is also a significant art collection and archival material related to the Guild of All Arts that is now owned by the City.[2]

The Guild Inn was built in 1914 as a white stucco, Arts and Crafts style mansion originally surrounded by over 400 acres of gardens and woodlands. The residence was built for Col. Harold C. Bickford, a decorated war hero. When Rosa Breithaupt Hewetson purchased the property in 1932, shortly before her marriage to Spencer Clark, the socially conscious couple decided to model their new property as the Canadian equivalent of Roycroft in East Aurora, New York, considered to be the centre of the Arts and Craft movement at the time. The site provided a home and forum for artists and artisans, where their work was created and collected for the enjoyment of many. Many of the artists were contemporaries or students of members of the Group of Seven, and the influence can be seen in the work they produced.

During the Second World War, the Canadian Government requisitioned the property and turned it into a training base for the Women's Royal Naval Service (WRENS). The hotel also served as a military hospital for victims of shellshock, with the craft facilities providing therapeutic rehabilitation for the service personnel undergoing treatment there.

The Clarks returned to the property in 1947. For the next 35 years, the Clarks built a reputation as patrons of the arts and preservationists, amassing a huge art collection and preserving architectural fragments from dozens of demolished buildings. Most acquisitions seem to have been acquired from wrecking companies with exception of the Bank of Montreal panels, which were donated directly by the bank. The onsite construction was lead by Arthur Hibberd. The property and the architectural fragments were sold to the Toronto and Region Conservation Authority in 1978 to be maintained as a public park. Spencer Clark continued to run the hotel until 1983, when a Board of Management was formed to oversee operations. At amalgamation, the Board was disbanded and the City’s Culture Division took over responsibility for the sculpture and architectural fragments, while the Parks and Recreation Division oversees the surrounding parkland. The hotel continued to operate under contract management until it closed in 2002 when it was considered no longer viable without a major capital infusion.

### The Temple Building

The Temple Building was the Head Quarters of the Independent Order of Foresters from 1895 to 1970 (**Figure 1a**). It was the first high rise building using steel frame construction to be designed by a Canadian. At ten stories high it was the tallest building in the British Empire. The architect was the well-known George Gouinlock whose library was donated to the Guild of All Arts. The two carved red sandstone relief panels “TEMPLE BUILDING” along with five relief stones which framed the two windows above it were removed from above the entrance of the building and relocated to the grounds of Guildwood Park in 1975 (**Figure 1b**). The stones were placed on top of a cast concrete footing and three rows of brick were used to elevate the stones from the concrete and provide structural stability behind the thinner stones.

### The Bank of Montreal

In 1937 the architectural firm of Chapman, Oxley and Facey were commissioned to design the Bank of Montreal Building.[3] Construction was halted in 1939 on account of the Second World War. Owing to the illness of Alfred Chapman, Marani and Morris redesigned and completed the Building in 1948 (**Figure 2a**). Six animal and twelve human panels were created by six of Canada’s foremost sculptors to adorn the entryways (**Figures 2b** and **2c**): Emanuel Hann, Arctic and North West Territories; Elizabeth Wyn Wood, Saskatchewan and Manitoba; Frances Loring, Ontario and Quebec; Florence Wyle, New Brunswick and Prince Edward Island; Donald Stewart, Nova Scotia and Newfoundland; Jacobine Jones, Alberta and B.C. The panels were carved by the stone carvers Peter and Louis Temporale of Fort Credit, Ontario.

The animal and human panels were moved to the Guild of All Arts and erected into freestanding structures in 1975. Four of the human panels representing Ontario, Quebec, British Columbia and Nova Scotia were used to create a freestanding monolith, with a finial atop taken from the stone pillar at the entrance to Victoria Park in Niagara Falls, Ontario (**Figure 2d**). Each representation of a province or territory was carved on two light-grey limestone panels with Ontario facing northwest in its current location near the front entrance to the Guildwood Park. The structure was placed on concrete pad on top of three cast concrete steps. Bronze inscription plaques were embedded into the last step.

## RTI Technology

At present, Reflectance Transformation Imaging (RTI) relies on the underlying algorithm of Polynomial Texture Mapping (PTM).[4] In layman’s terms, the technique uses a series of images of an object, each taken with a directional light-source in a different position, to calculate the *surface normal* for each pixel in the image, that is to say, the vector at right angles to the surface at that particular point. In other words, the algorithm compares the way the light reflects off the surface for each pixel from every light position. While the detailed mathematics of the program need not concern most end-users, a familiarity with the concepts helps to explain when and where the technique can be applied, and just why RTI may fail if care is not taken to control certain parameters during the capture process. Once this information has been captured, however, it allows the end-user to manipulate the light-position around an object and to enhance the surface of the object using the additional information provided by the surface normals (e.g., Specular Enhancement and Diffuse Gain). A superb guide to the RTI process, both the field capture routine and the processing, has been kindly posted by Cultural Heritage Imaging on their website.[5] What follows is largely derived from this document with additions/adjustment made through our own experience.

One of the most significant advances in RTI since its development in 2001 came with the advent of Highlight-Based RTI.[6] Developed at the University of Minho, Portugal, Highlight-Based RTI replaces a fixed array of lights and instead uses the ingenious trick of placing a shiny, reflective black or red sphere in a fixed position in each frame of the RTI capture. When a mobile flash-unit is moved to different positions at a fixed distance from the object, the flash casts a bright highlight in the sphere. Software detects the sphere, ascertains its diameter in


**Figure 1a**. The Temple Building, Bay and Richmond (N.W. Corner). Photo courtesy of City of Toronto, Cultural Services, The Guild Collection.

pixels, and then also detects the bright highlight in the sphere for each photo (**Figure 3**).

It must be stated at the outset that the texture map created by RTI does not replace the sort of highly accurate spatial information created during laser scanning, or other range-based scanning techniques. Instead, RTI generates only the direction of the surface normal for each pixel in the photograph. While these surface normals alone do not at present permit the measurement of distances in the z-plane, they are required if light is to be reflected off a surface in any 3D visualization software. Studies have shown that the surface normals generated through range-based techniques can be up to 30 degrees off from the true

**Figure 1b**. Temple Building in situ in the Guild shortly after its erection in 1975 (Acc. # 1978.1.150). Photo courtesy of City of Toronto, Cultural Services, The Guild Collection.

**Figure 2a**. Bank of Montreal, 1948 – 1972, King and Bay Streets (N.W. Corner), Toronto. Photo courtesy of City of Toronto, Cultural Services, The Guild Collection.

vector.[7] RTI produces a far more accurate estimation of the surface normal and, as a consequence, a much more natural visualization of a surface. RTI cannot, however, produce meaningful data about complex three-dimensional objects such as statues. Thus the technique is ideally suited to the documentation of stone façades which are typically planar and actually creates a better representation of fine textural variations than more expensive range-based systems. That said, if, for instance, one wanted to create a three-dimensional simulacrum of an object, or parts of it, using rapid-prototyping, range-based scanning would be necessary. Consequently, we see these two technologies as complementary, not competing.

A significant advantage of RTI is the relatively inexpensive and readily available equipment required to create highly-accurate texture maps of planar surfaces. At the same time, highlight-based RTI remains an "artisanal" recording technique that requires of the user considerable care in field set-up and knowledge of technical photography. Because no integrated highlight-based RTI set-ups are commercially available as yet, a thorough understanding of the equipment required for RTI capture is indispensible. Much time can be saved by ensuring that the proper equipment has been selected and checked before any field work. The equipment list, along with remarks and estimated prices, have been presented in summary form as **Table I**.

**Figure 2b** and **2c**. Detail of the panels on the entrances to the Bank of Montreal. Photo courtesy of City of Toronto, Cultural Services, The Guild Collection.

**Figure 2d**. Monolith of the Bank of Montreal panels with the Ontario panel (right) in situ at the Guild.

**Figure 3**. Highlight detected by a small red cross on a billiard ball in the RTI Builder software.


**Figure 4**. Complete Nikon D700 camera with a 50mm lens and flash and shutter remotes mounted on a ball-head.

**The Capture Process at the Guild**

With the use of a shutter remote, a line guide and "in camera" shooting, we have found that RTI capture can be accomplished by only two people, one holding the light, the other the string and shutter remote while directing the shots, in as little as 15 minutes.

Very careful preparation and planning, however, is necessary before setting up any RTI capture, as well as considerable care during the capture. The camera and tripod cannot be touched once the capture sequence has begun for fear of putting the camera out of position.

*Set-up*

Any RTI capture must begin by the recording of the basic measurements expected in any documentary photography. One


**Figure 5**. Guide-rod inserted into the umbrella-holder of the flash.

**Table I. List of Equipment Needed for RTI Photography**

| Equipment | Requirements | Comments | Cost |
|---|---|---|---|
| Camera | • digital single-lens reflex (DSLR)<br>• full manual capability<br>• capable of being fully controlled by a USB connection from a laptop ("tethered shooting")<br>• bodies that are metal and environmentally sealed | The authors prefer rugged professional-level cameras although many "prosumer" models match the image quality of professional models. Although both full frame (FX) and non-full frame (DX) cameras have been used in our RTI work, no appreciable difference has yet been observed in the quality of RTIs. The authors have used both the Nikon D700 (**Figure 4**) and D300s. | ~$1,800 (camera and lens) |
| Camera lens | • prime lenses preferred over zoom lenses for their optical clarity<br>• 50mm or equivalent (**Figure 4**) | In outdoor use, the authors strongly prefer 50mm or equivalent lenses for their 1:1 reproduction ratio. This focal length also produces minimal lens distortion toward the outside of the frame where the balls are placed. | |
| Flash unit | • sufficiently powerful to illuminate in excess of the ambient light<br>• can sustain repeated use at high power<br>• must work in any orientation | We have found that the AlienBees ® B1600 (640 true watt/seconds of power) with 6 f-stops and a maximum 2-seconds of recycle, designed and manufactured by Paul C. Buff Inc. of Nashville, was the best option on the market (**Figure 5**). | ~$600 |
| A portable battery for the flash unit | • indispensable if no power outlet or portable generator is available | The Vagabond II ® Portable Power System by Paul C. Buff, which includes both a 12 volt battery inverter in a compact nylon shoulder bag, has worked best with our choice of flash unit. | ~$200 |
| Wireless flash trigger | • the flash trigger should have sufficiently strong radio-frequency signal to trigger the light in all positions | The PocketWizard ® series of flash remotes is now available (MiniTT1 # 801-143 and FlexTT5 # 801-153). At the Guild we used the less expensive Opus OPL-WTS 4. We prefer the Paul C. Buff remote trigger solution at present because it is cheaper than the PocketWizard but is more reliable than the Opus system. | ~$100 |
| Wireless shutter remote | • the shutter remote should have a sufficiently strong signal to trigger the camera from several metres away | While some cameras have inexpensive infrared shutter releases, we have found that they do not usually have long range and must often be pointed directly at the camera. | $20-80 |
| A length of string | • coloured nylon mason's line is ideal<br>• the string should not stretch under normal circumstances and must be firmly attached<br>• must be least three times the length of the diagonal of the frame | It can be helpful to have the string on a small spool for quick changes of length between shoots. | ~$5 |
| Tripod | • a sturdy aluminum tripod | Although there are many lightweight tripods on the market, we find older aluminum tripods are more resistant to vibration. Any camera movement can spoil the resulting RTI. | ~$200 |
| Two snooker balls | • should be solid black or red in colour (**Figure 3**) | Both red and black balls can be used with the software, although experience has shown that solid black balls slightly outperform red balls for automatic detection within the software. | ~$30 |
| RTI Builder & Viewer Software | • available from the CHI website and the HP Labs PTM download section | The installation of the RTI Viewer software for both Mac and PC is uncomplicated, but the installation of the RTI Builder requires care as the software must have the directory path of the HP PTM fitter software. | free |

must take accurate measurements from the camera to the object, the height of the camera from the ground, and the dimensions of the object itself. While one billiard ball is sufficient for highlight-based RTI, the "best practice" is to use two in case for any reason the highlights are obscured on one of the balls, such as by the sun. The balls must be placed outside of the area of interest and so as not to cast shadows on this area. The balls can be easily cropped out of the final RTI. The balls must also be in the same focal plane as the objects so that they are not blurred. Photographic gray cards behind each ball greatly assist the software in detecting the edge of the spheres without any operator intervention, as well as giving a measure for white-balance corrections. At the Guild we drilled and tapped two black billiard balls and mounted them using 1/8 inch screws on light-stands. A simpler option is placing the balls on firm holders such as large hexagonal nuts so that they are firmly mounted.

We strongly advocate that a spirit-level adapted to mounting a DSLR hot-shoe be used to ensure that the camera is perfectly aligned on either a vertical or horizontal plane. While it may be intuitive to mount the camera parallel to the object, we believe that aligning the camera by a spirit-level, independent of the object, allows for the RTI to be repeated under similar conditions in the future, which is highly desirable in conservation recording.

Since the diffraction limit of the lens generally requires an aperture of between $f/5.6$ and $f/11$ to maintain maximum sharpness, the exposure setting must be made to fit this aperture window. A further limit is imposed by the speed of the remote flash trigger and the flash itself. In the case of the set-up outlined above, the fastest exposure possible is 1/320 of a second before the shutter goes out of synchronization with the flash. In outdoor settings, however, bright ambient light often requires higher shutter speeds when the aperture is limited to $f/11$. In this case, the use of neutral density (ND) filters (available by special order from most photography stores) can slow the shutter speed by uniformly limiting the light entering the camera without any changes in hue or colour. ND filters can return the aperture and shutter speed to the optimum range, even when the flash has been set to very high power to overcome high ambient light levels.

Focusing and exposure settings are established in much the same way as normal digital photography with a couple of important exceptions. Because all the individual shots used to make up a single RTI must be taken with exactly the same settings, it is important to switch lenses to manual following automatic focusing so as not to change focus settings in any way during the capture sequence. Exposure must be checked at both the lowest and highest light positions with the same settings. Perfect exposure at all light positions is not possible. Rather, over-exposure when the light is in its highest position will have to be accepted to get decent exposure at other light positions. Generally speaking, large LCD viewers on most camera bodies as well as their histogram functions are more than adequate for determining proper exposure. A laptop is generally not needed.

One unique and original accessory added by our team to the RTI capture process is a straight metal rod about 60 cm long and 5 mm in diameter attached to the flash-unit's umbrella holder (**Figure 5**). To this metal rod we attach a metal fishing lead with aluminum tape, and to this lead the mason's line. This rod allows the holder of the light to quickly and accurately aim the light directly at the centre of the object. The fishing lead, in our experience, is necessary because the heat of the light can cause the mason's line to burn and break in a matter of minutes.

### *Capture Routine*

While camera operation controlled by a laptop–so-called "tethered" shooting–has been preferred in the past, we have found that this system is best confined to indoor work. The time delay for images to be downloaded through a USB cable to a laptop, as well as the inconvenience of bringing a laptop into the field, have led us to prefer "in camera" operation to tethered shooting in most cases.

With the use of "in-camera" shooting and a remote shutter release, only two operators are required for an RTI capture (**Figure 6a**). The first operator stands next to the object and holds the mason's line in one hand and the remote shutter release in the other. The second holds the monopod with the flash at a distance fixed by the length of the mason's line. When the light has been properly positioned and the line aligns with the metal rod inserted into the light, the line is removed and shutter is triggered remotely. It is of crucial importance that the length of the line be at minimum three times the total diagonal distance of the object in the field of view, often up to four or five metres at the Guild. The underlying Polynomial Texture Mapping software assumes that in each shot the light is at a fixed distance from the centre of the object. If care is not taken to ensure that the light is at a fixed distance each time and at an adequate distance, the quality of the RTI is severely compromised.

This process is then repeated until a good distribution of light positions around the object has been obtained (**Figure 6b**). Generally speaking, between 16 to 80 images uniformly distributed around a notional hemisphere around the object is adequate. What counts as a "good distribution" however lacks clear, quantitative definition at present. By keeping the Light Position file–the list of light position vectors generated by the RTI software–it is hoped that in the future a scoring system could be developed to determine how evenly the lights are distributed. Unfortunately, in outdoor work some light positions cannot be reached because they are too high, or the ground prevents the shots from going low enough. The RTI algorithm, however, is tolerant of a certain amount of missing data. The effects of changing light distributions on the final RTI, and optimal light distributions, has been usefully studied.[8]

### *Post-Processing*

If tethered-shooting has been used, the images can be downloaded directly into a working folder to be used by the RTI software. In cases where large numbers of objects are being shot, we now prefer to keep all the images stored on the camera's CF card and then to transfer them for processing later. The fastest way to accomplish the transfer is by a dedicated CF-card reader installed into the PCI-express port of a laptop.

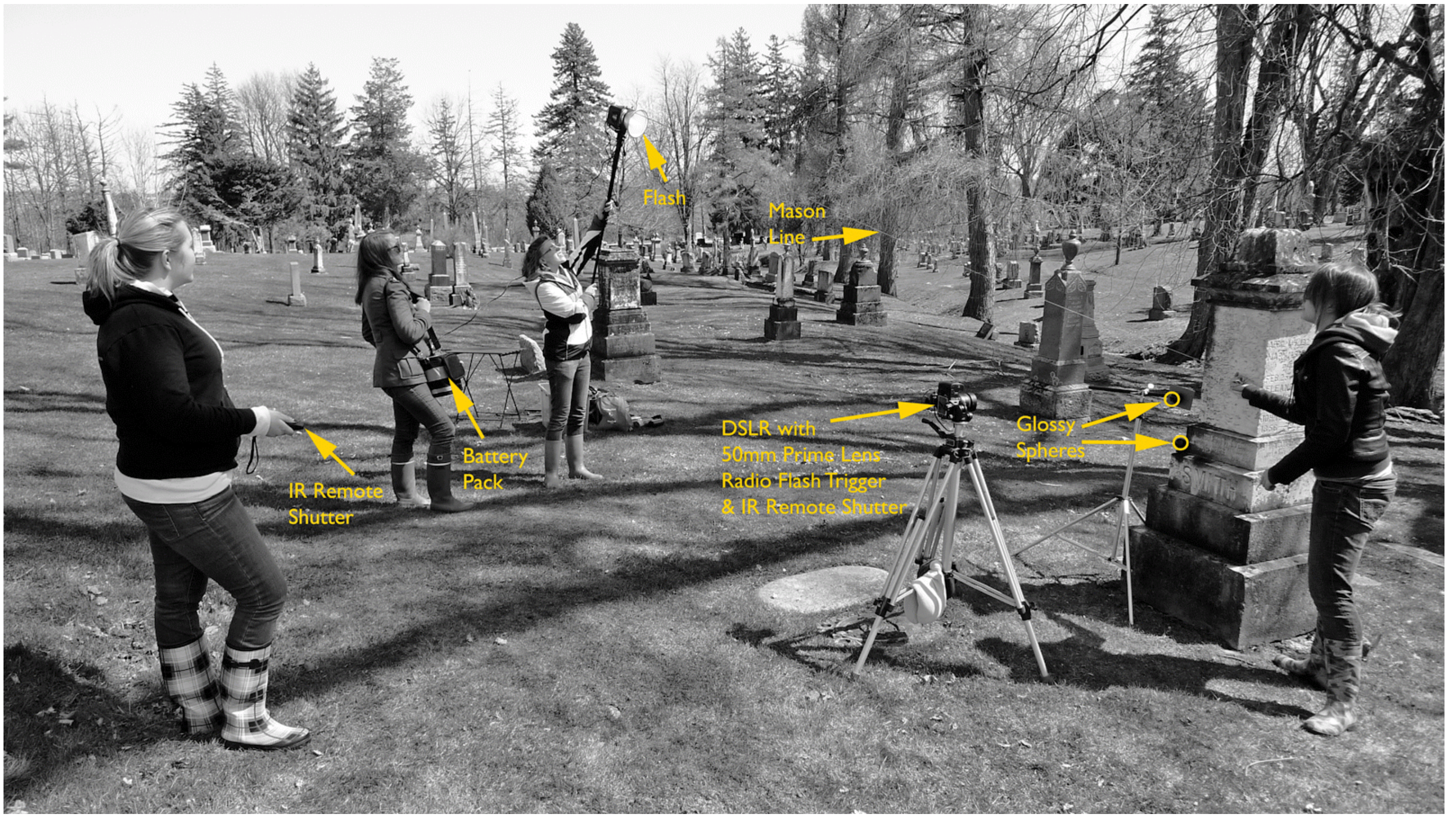


**Figure 6a**. RTI field set-up in action in the Cataraqui Cemetery, Kingston, Ontario with a group of students learning the technique. The RTI equipment is labelled.

**Figure 6b**. RTI field set-up in action in the Cataraqui Cemetery, Kingston, Ontario. The ideal light distribution has been superimposed.

We prefer minimal post-processing and convert the native Nikon RAW format, .nef, to .jpg, the file format required by the RTI builder. For long-term archival storage, the proprietary Nikon .nef files should be converted to a lossless file format such as TIFF, or ideally in the open RAW format DNG (Digital Negative). Various options for conversion are available, but we prefer Adobe Camera Raw plug-in that works with Adobe Photoshop and Bridge in CS5. In rare cases where white-balance is clearly off or colour correction is needed, we use an X-Rite ColorChecker® Passport that functions through the ColorChecker® Passport software or application specific plug-ins. In general, however, we remain concerned that white-balance and colour correction in post-processing may change the luminosity values needed for proper RTI building and introduce non-reproducible variables. Proper photographic technique in the field, however, will make such corrections unnecessary.

To check that the finished RTI properly represents the surface normals of the object, we load the texture map into the original HP PTMViewer application and output it with the "Display Normal Visualization" function. Unfortunately, this option is only available on the original HP viewer, not the newer RTIViewer (v.1.0.2) now available through CHI. Generally we look for a dominance of the colour blue, which represents normals pointing towards the camera, as we would expect for a planar surface (**Figures 7e** and **8e**). The RTIViewer allows for the easy creation of snapshots of various light-positions where different features are visible.[9] These snapshots can be saved and printed separately to include within a particular monuments print dossier. The RTI and all the files used to create it should be saved on archival CD/DVD-ROM disks just as is done for all other photographic documentation.

**Results**

Most of the façades that were transported and re-erected as free standing structures, lawn decoration or were left in piles awaiting uses on the grounds of the Guild were sandstone, limestone or marble. Very few were of granite or metal. The sedimentary and metamorphic stones, particularly the porous sandstone, limestone and marbles used in older structures, are susceptible to both chemical alteration and disintegration, with dissolution and erosion increasing dramatically as rain and snow becomes more acidic, as in polluted urban environments.[10] In addition, these stones were originally specified and used to form the façade of a building. The structure they were part of carried the structural load and provided some shelter from the elements. These fragments were separated from the structure in order to save them from demolition and complete loss; they survived, although they were exposed to environmental extremes that has led to a loss of surface detail documented each year.

*Temple Building*

The stones are at ground level near the front entrance of the Guildwood Park (**Figure 7a**) and are a favorite background for many wedding parties as well as a climbing challenge for the younger visitors. Since the relocation, much of the very soft and friable red sandstone (especially the lower portions of the Temple Building stones near the concrete) has suffered rapid and drastic deterioration (**Figure 7b**). The photographic evidence suggests that the otherwise soft stone was partially protected while it was part of the building, but in its re-incarnated state the stones have been exposed to organic, physical and chemical deterioration within an accelerated pattern. Since the sandstone is naturally so porous, it is susceptible to excessive weathering and spalling. The Specular Enhancement of the RTI (**Figure 7c**) shows much more clearly than the natural-light photograph (**Figure 7b**) how little of the original surface remains, and the extent of the spalling. Another still image of the Specular Enhancement shows how other features become visible by changing the light-position (**Figure 7d**). In particular, it can be observed that on the "E" and the "M", the original finished surface of the letters, including a slight groove at their edges, is still observable on the top, while on the bottom of each letter this original surface has eroded entirely. In subsequent monitoring, the specular enhancement could be used to verify where new areas have spalled. In natural light photography, internal shadowing within the photograph can create problems for determining just what has been lost. Confirming exactly what has been lost over time and what has been repaired, is also of paramount importance to the working stone conservator in dealing with clients.

The Surface Normal Visualization of the section imaged of the Temple Building inscription (**Figure 7e**) shows some of the limitations on large-scale RTI captures, however. While much of the stone is blue in colour, the area to the bottom right is reddish. The presence of red on areas that we know are roughly parallel to the image plane of the camera indicates that an insufficient sample of light positions was taken and distortions have crept into the RTI. In this case, the low position of the stones meant that too few lower light positions could be taken. Again, the

**Figure 7a**. Overview of the Temple Building photographed with natural light before the capture sequence.

**Figure 7b**. Close-up of the Temple Building inscription, in natural light. **7c**. Specular Enhancement of the RTI. **7d**. Specular Enhancement of the RTI using a different light position than in **7c**. **7e**. Surface Normal Visualization of the RTI.

surface normal visualization provides a good guide to just what areas of the RTI can be reliably used. A smaller field of view, perhaps as small as single letters on the lower level, will have to be used to record more accurate RTIs of these features.

*Bank of Montreal – Ontario Panel Structure*

Columns and square slabs of a slightly darker limestone were used to form the corners and roof of the Bank of Montreal four panel structure. The surrounding area is below grade and standing water pools around the structure for better part of the year (**Figure 2d**). The two limestone slabs forming the panel that represents Ontario were chosen for RTI (**Figure 8a**) since the stone has been exposed to all three forms of deterioration: organic, physical and chemical. There is ample evidence, specific not only to this panel, of physical damage that likely occurred during the demolition of the building and the re-erection process (various losses at the edges and protruding low relief carved elements). There is one repair that has been made to the upper slab with a dissimilar limestone. The overall surface has been affected by a wide range of microscopic and larger lichen with evidential staining of the very lowest and upper portions of the limestone. Of particular concern is the spalling of stone that is taking place right below the left-proper knee of the male figure. Both Specular Enhancement and Detail Enhancement of the RTI (**Figures 8c** and **8d**) show where the original tool-marks are still visible and where spalling is taking place (particularly clear in **Figure 8d**). These tool-marks will provide important land-marks in the future for judging the extent of weathering on the surface. As these marks become even fainter, RTI will exceed the capabilities of conventional raking light photography.


**Figure 8a**. Overview of the Ontario panel photographed with natural light before the capture sequence.

**Figure 8b**. Detail the lower right of the Ontario panel photographed with natural light.

**Figure 8d**. RTI Detail Enhancement of the foot of the Ontario panel.

## Conclusion

In addition to the panels from the Bank of Montreal and the Temple Building stones, RTI was used to conduct a preliminary survey of other artwork at the Guild: a marble statue by Marshal Wood, 1875 (part of Imperial Bank of Canada 1928 -1972), limestone reliefs and entrance elements from the façade of Bank of Nova Scotia, an Ionic marble column from the Bank of Nova Scotia (before and after treatment), a terra cotta Music Scroll from Music Hall, earthenware finials from Gibson House Entrance, and decorations from Bank of Montreal Wall. We hope that all monuments and endangered structures within the Guildwood Park will be properly documented and recorded in an attempt to monitor and control their deterioration. RTI offers a manageable qualitative means to perform the necessary monitoring.

Most conservation studios and/or archaeological groups have a reliable DSLR with prime lenses to allow the proper documentation of finds and artifacts. In most cases these professionals also have access to a computer in order to process, use and print the digital images. In order to adopt RTI, the additional equipment needed include: reliable flash with portable power source (if embarking on outdoor RTI capture), black reflective sphere and small miscellaneous items as previously

**Figure 8c**. RTI Specular Enhancement of the left proper leg of the Ontario panel.

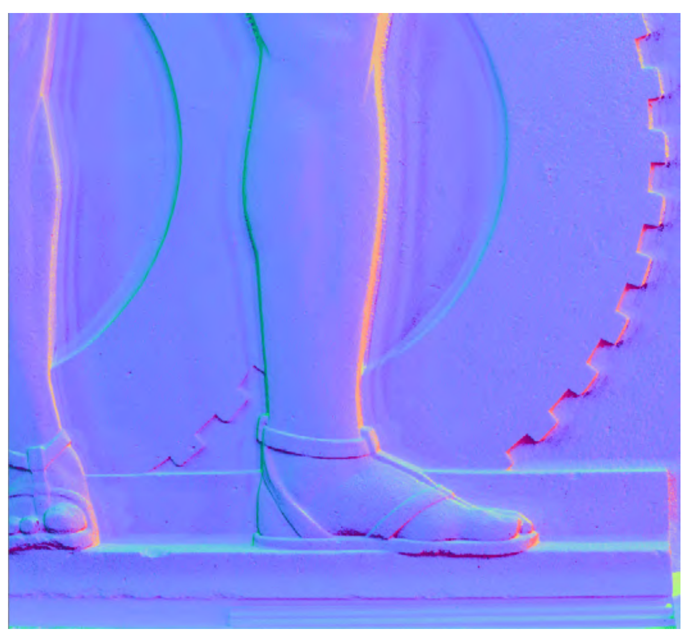

**Figure 8e**. RTI Surface Normal Visualization of the Ontario panel.

mentioned (remote triggers and controls), all likely totaling less than $1,000 (see **Table I**). Even with the addition of new camera and prime lens, the initial investment to adopt RTI is less than $2,500 with free RTI PC and MAC compatible software available on line. Compared to an entry-level range-based system starting at $17,500 (hardware and software), RTI is far more appealing and user friendly.

While the data used to produce the RTI can be stored using an archival file standard, much work remains to be done on developing quantitative standards for measuring the quality of a highlight-based RTI capture. It is the authors' belief, however, that the data already gathered in the RTI process, particularly the Light Position file–the list of normal vectors describing each light position–can be used in the future to provide an estimator of quality using techniques in Directional Statistics, notwithstanding the fact that the light positions used in each highlight capture will vary because the flash is handheld.[11] There is good reason, therefore, for working stone conservators to integrate RTI into their workflow without hesitation.

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**Materials and Suppliers**

Most photographic equipment, including camera bodies, lenses and remotes, was purchased at: Camera Kingston, 114 Princess Street, Kingston, ON, K7L 1A7 (613) 549-3747; Henry's, 616 Gardiners Road, Kingston, ON, K7M 3X9 (613) 389-9864; or Vistek Camera, 496 Queen Street East, Toronto, ON, M5A 4G8 (416) 365-1777.

The reflective black billiard balls were purchased at St. Lawrence Pools, 525 Days Road, Kingston, ON, K7M 3R8 (613) 389-5510.

Our flash equipment and battery packs were purchased from AlienBees, a Division of Paul C. Buff Inc., 2725 Bransford Avenue, Nashville, Tennessee 37204, USA, 1-800-443-5542.

The latest RTI software was acquired, free of charge, from Cultural Heritage Imaging, 2325 3rd Street, Suite #323, San Francisco, CA 94107, (415) 558-8672, info@c-h-i.org.

The mason's line and fishing lead were both purchased from Canadian Tire, 2560 Princess Street, Kingston, ON, K7P 2S8 (613) 384-0011.

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