Scale Bars for Photogrammetry: User Guide

To enable the measurement of an object or a site in 3D, you place scale bars on, around, or next to the imaging subject. When you process your series of images to create a 3D model, the processing software — CHI uses Agisoft Metashape Pro — finds the exact center of the targets on the scale bars in the set of photos. You then enter the precalibrated distance between the targets on the scale bar to set the scale of the project. Once the scale is set, you can get a highly accurate measurement of any feature of the imaging subject.

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About the Scale Bars

Your set of professionally calibrated scale bars from Cultural Heritage Imaging is uniquely suited to today's practice of close-range photogrammetry.

The 12 scale bars in the set are flat, lightweight, linear bars. These are calibrated scale bars with printed targets separated by a known distance. There are three each of four sizes/styles, 9 coded, 3 non-coded.

The scale bars are:

- Designed by senior photogrammetry experts at the US Bureau of Land Management for highly accurate measurement and scientific imaging in photogrammetry projects.

- Individually calibrated by CHI staff to a precision of 1/10mm or better accuracy.

- Printed on 4mm ALUPANEL®, a tough, durable composite material consisting of 2 aluminum sheets bonded on either side to a solid polyethylene core.

- Not subject to delamination or warping, optimized for long-term outdoor use, water- and environment-resistant.

- Made with a grayscale background with many detailed features to enable the generation of a measurable 3D model of the entire scale bar.

We recommend that you protect the scale bars by storing them in the heavy plastic bags they come in. If needed, clean them with a damp cloth.

Target Types

There are two basic types of scale bar target, *coded* and *non-coded*.

- Coded scale bars targets

  Three sizes of the scale bars have 12-bit coded targets. The coded targets are automatically detectable by several photogrammetry software packages, including Agisoft Metashape Pro, and automatically named (represented by numbers). The numbers of the coded targets are different on all the bars in a set, and CHI offers 5 different sets, each with unique coded targets. This is useful if more than one set of scale bars is needed in a project. The coded target design ensures that the processing software can recognize each target as unique and not confuse them with other targets within the same 3D project.

- Non-coded targets come in the cross-type style:

  Non-coded, cross-type targets (alternating quadrants of black and white within a circular boundary) are found on the small, 5cm scale bars. The cross design allows some software packages (including Agisoft Metashape Pro) to detect them automatically as targets, placing a marker at the center of the circle where the black and white sections intersect.

Scale Bars Specifications

The scale bars are calibrated by CHI staff to a precision of 1/10mm or better, with the actual calibrated measurement between each target written on the scale bar.

Half-meter Scale Bars (3)

Include 3 coded targets. Centers of each target are approximately 25cm apart, with a total distance from targets at each end of 1/2 meter (or 50cm). The bar's overall dimensions are 60cm long x 6cm wide.

Quarter-meter Scale Bars (3)

Include 2 coded targets. Centers of each target are approximately 25cm apart. The bar's overall dimensions are 35cm long x 6cm wide.

5cm coded Scale Bars (3)

Include 2 smaller coded targets. Centers of each target are approximately 5cm apart. The bar's overall dimensions are 10cm long x 6cm wide. The smaller target diameters can be helpful when documenting smaller subjects.

5cm non-coded Scale Bars (3)

Include 2 non-coded cross-type targets. Centers of each target are approximately 5cm apart. The bar's overall dimensions are 10cm long x 6cm wide. Scale bars with non-coded targets can be useful when imaging small subjects.

How to Use the Scale Bars

To support highly accurate measurement of 3D data of an object or a site, it is essential for photogrammetry practitioners to learn the correct placement and use of calibrated scale bars.

Placing the Scale Bars

As you prepare to image a subject, you start by placing the scale bars on, around, or next to the subject or site. You should consider the scale bars to be part of the "area of interest" for your photogrammetry project, and make sure that your overlapping image set extends at least two images beyond the position of the scale bars.

Place the bars such that the targets can be clearly seen in multiple overlapping images. When overlapping photos are taken of the scene or object, the targets on the bars become *markers*. The markers serve as reference points for scale definition, and also help the processing tool to align the images accurately.

The scale bars do not need to appear in every photo. They should be well covered by overlapping photos with good geometry so their calibrated values can be used to provide accurate scale for the whole photogrammetry project.

Important Note: Do not move the scale bars during photogrammetric image capture of your project. If a scale bar is accidentally bumped or moved, remove it from the scene. Do not attempt to place it back in the scene, as it will not be in exactly the same place. To be used accurately, the scale bars must be in a constant location relative to your subject while they are being imaged. Once included in a proper set of photos they may be completely removed from the scene.

The following figures show some ways of placing scale bars.

Figure 1: On the left, three coded marker 25cm scale bars in place around a smaller subject. In the middle, three coded 5cm scale bars around a subject. On the right, three non-coded cross-style 5cm scale bars are placed around the subject. In the Metashape Pro software, there is a limit of a 30-pixel radius (60-pixel diameter) to detect the coded markers. Using smaller size targets, such as the 5cm coded bars, or placing the non-coded cross style markers around the subject eliminates this problem when using high-resolution cameras and smaller subjects.

When placing scale bars on the ground (figure 2), outside the primary subject area, you must take additional overlapping photos that include the scale bars in order to use them for accurate measurement in your project. These additional images should include photos that are aimed directly over the scale bars. If you only take photos of a vertical subject when the

scale bars are horizontal on the ground, then the scale bar targets will be oblique in your images, and they may not be detected, or they may be detected with high errors. Make sure to take overlapping images pointing the camera down at the horizontal scale bars and then take overlapping, "bridging" rows of photos, moving and tilting your camera no more than 15 degrees for each row until you are aiming directly at the vertical subject. The bridging rows of photos ensure that the horizontal scale bars and the vertical subject photos will align together.

In larger projects, place the scale bars on each side of the subject so that you can control the scale across the entire project.

For some subjects, it may be convenient to place the scale bars over the subject, but you may not want to have scale bars in your final model. In this case you can take images with the scale bars over the subject area. Then, remove the scale bars and take photos of that area again. Align all photos together. When processing your project, you can include the scale bar images during alignment and optimization of camera calibration and pose estimation (when you set scale), then "disable" (in Metashape software) the scale bar images before building your dense cloud, mesh, or other products. The scale bars will have done their job of scaling the subject or scene but will not appear in your final model.

Figure 2: Scale bars in place around petroglyphs in Hawaii. On the right, three scale bars placed around the base of a painted wooden sculpture. As noted above, with this configuration you must take additional photos to get good scale bar data (See above paragraph about placing scale bars on the ground for more details)

How Many Scale Bars to Use in Your Project

While photogrammetry software can add scale to your project with a single scale bar, it is advisable to place a minimum of three scale bars in your project to provide additional statistical confidence. We recommend four. Two bars provide a basic check, and three or more add confidence and statistical reassurance.

Using four bars is ideal, especially for larger projects and outdoor environments, because it is all too easy for a scale bar to be moved by the wind, kicked, picked up by a curious child,

or otherwise displaced during capture. If this happens, the project will still have the statistical integrity provided by three scale bars.

The fourth scale bare can also serve as an additional test of the project's measurement integrity. Three scale bars can be input into the system to set the scale and the fourth bar's length can then be estimated by the photogrammetry software. Comparing this estimate to the calibrated scale bar distance will provide additional proof of the project's level of measurement precision.

Figure 3: Three scale bars in place along a large outdoor sculpture. It is safe to place the scale bars against this concrete material. The scale bars were photographed, then removed from the scene, and the whole sculpture was imaged (inset photo). After scale had been set for the subject (see processing section below) then the images that include the scale bars were "disabled" in the project, so that they did not appear in the final model. (Sculpture: Ledelle Moe, *Collapse I*, 2000, concrete and steel, H. 9 x W. 34 x D. 12 ft. at North Carolina Museum of Art, outdoor sculpture garden. Inset image credit: Chris Ciccone)

Processing Data with Scale Bars

There are a number of software packages available for processing your 3D project. The scale bars in your set can be used with any of several software packages, though not all packages will automatically detect both types of targets in these scale bars.

Cultural Heritage Imaging (CHI) uses Agisoft Metashape Pro, and these instructions are based on the 1.7 version of that software. The scale bar processing workflow in Agisoft Metashape Pro Version 1.7 includes these basic steps:

- Set the scale bar accuracy.

- Detect the targets on the scale bars in the image set to generate markers in each photo that includes scale bars.

- Create scale bar objects between the related markers.

- Add the calibrated scale bar distance data between the related markers to the scale bar objects.

Each of these steps is described further below. More information on placing markers and creating scale bars can be found in the *Agisoft Metashape User Manual, Professional Edition, Version 1.7,* Chapter 4, "Referencing."

Set the Scale Bar Accuracy

The scale bars from Cultural Heritage Imaging are calibrated to 1/10mm accuracy or better. The scale bars include scribed data to 1/100mm. The extra information is to eliminate rounding errors when using longer scale bars, such as the half-meter bars. You should set the **Scale bar accuracy (m)** to 0.0001 (the default value is 0.001).
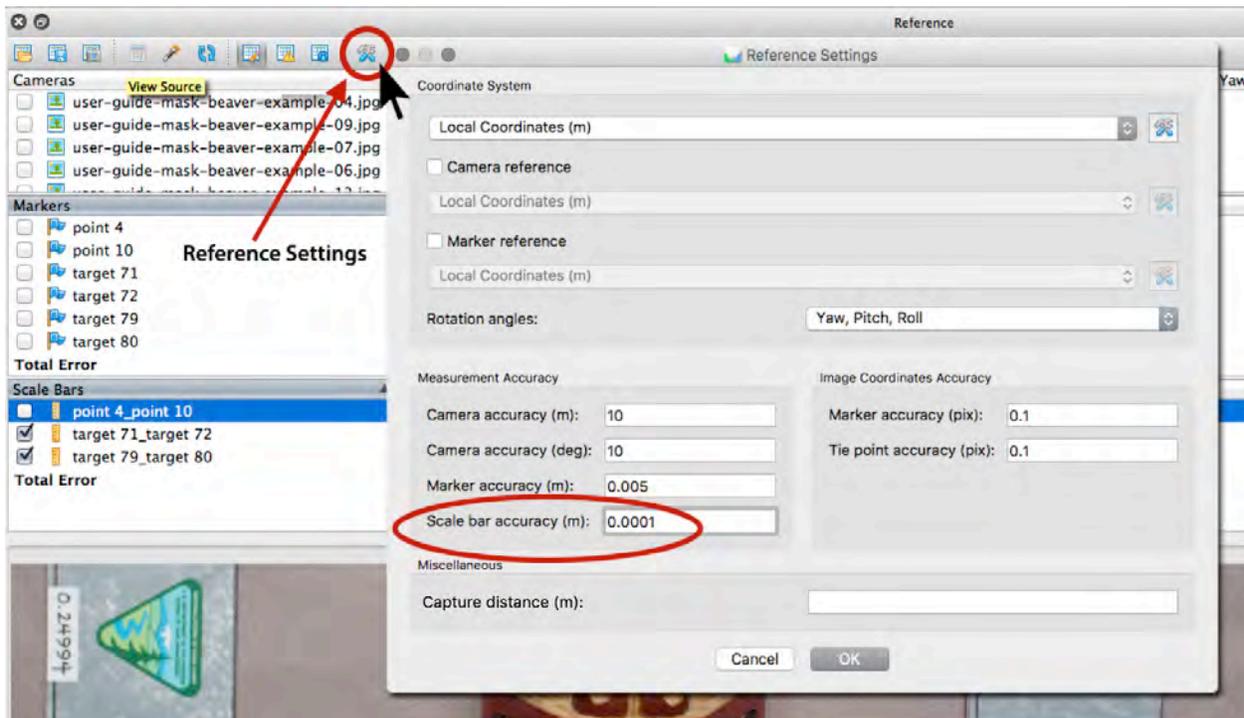

Figure 4: Set scale bar accuracy.

Detecting Markers

After aligning photos and optimizing your project, use the **Detect Markers** dialog to detect the targets on the scale bars, and use them to automatically generate markers. Make sure the **Reference Settings** pane is visible and choose **Tools > Markers > Detect Markers** (Figure 5).
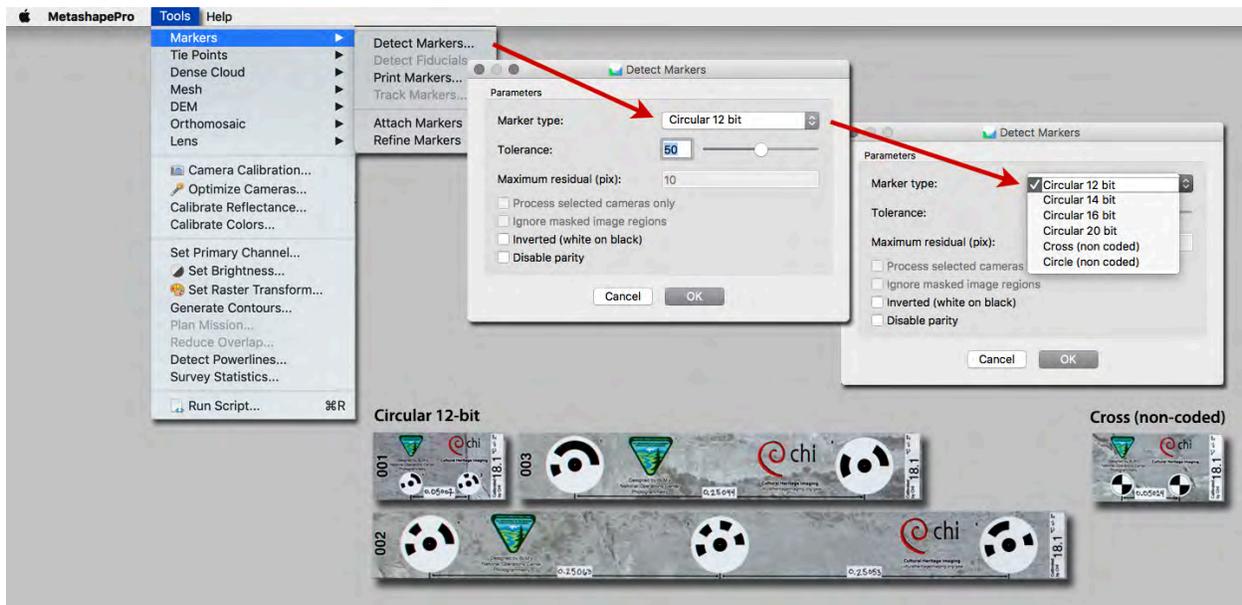
Figure 5: Detect markers for scale bars.

TIP: We suggest that you start with a tolerance of 50, and make it higher if not all targets are detected.

Figure 5 also shows the different kinds of markers on the scale bars.

The scale bars from CHI include three kinds of marker targets supported by Metashape, as shown in Figure 5. CHI uses marker targets that are circular 12-bit coded, circle non-coded or non-coded cross.

An advantage of coded targets is that they are always named consistently. Coded targets are named "target xx," where xx is the number of the coded target, printed on the scale bar. Non-coded targets are named sequentially in the order the software identifies them, and labeled "point xx," but the numbering is not reproducible in different projects.

TIP: If you are using both circular coded and circular non-coded targets, you should detect the coded markers (the circular 12-bit marker in this example) before you detect any non-coded circular markers. This is because the center of the 12-bit coded marker is a circle, and it will be detected as a non-coded circle if there is not already a marker present from detecting the coded markers. Then when coded markers are detected, you may have duplication of markers in the center circle of the coded markers.
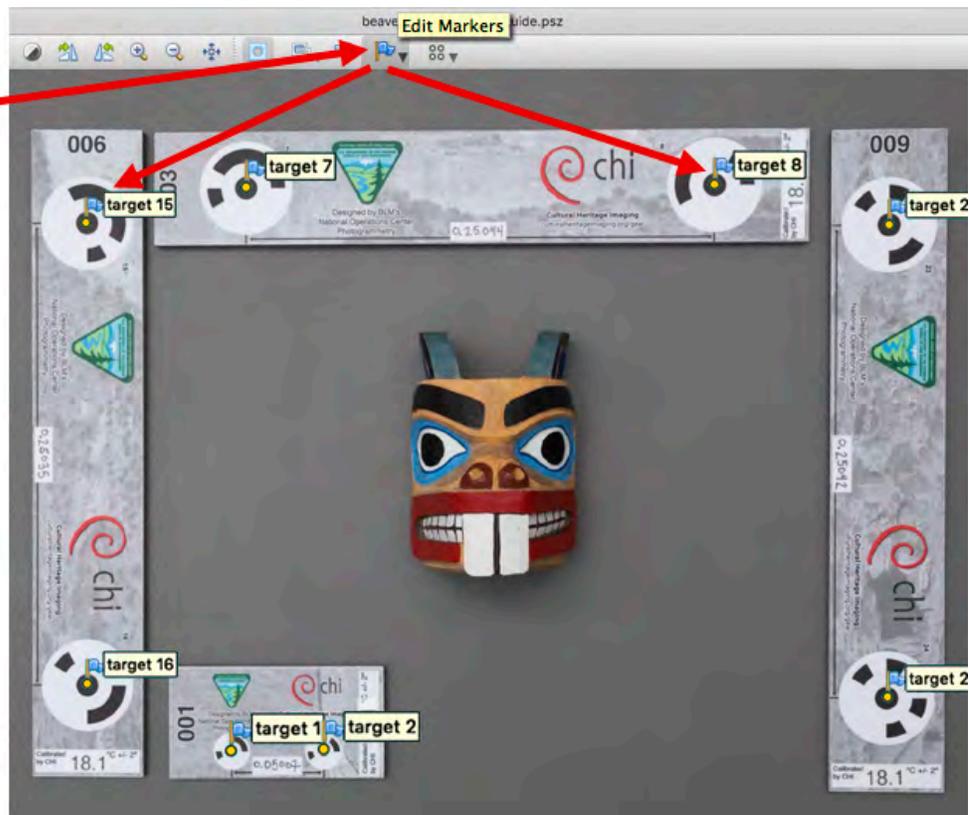

Figure 6: Detected coded targets.

TIP: If you are photographing close to a smaller subject with a high-resolution camera, and the software does not detect the coded markers, it may be that there are too many pixels across the marker in your images. The limit in Metashape Pro v. 1.7 is a 30-pixel radius from the center of the target to the edge of the target (60-pixel diameter). In this case you can detect non-coded circles, and check the box for "Inverted", to detect the inner circle of the coded marker as a non-coded circle.

The markers on coded and non-coded circular targets are placed with high precision because the center of the circle can be detected algorithmically.

The centers of non-coded, cross-type targets with calibrated distances, as well as the corners of the small scales made up of black and white squares, are placed with high precision because the center point of the cross can be detected algorithmically by the software.

Although you will rarely use the scales made up of black and white squares for setting scale in your project, you may retain any detected scale markers if they have low error. They mark additional known points that can aid the software in the photo alignment and camera calibration.

To see the markers that are generated in each image, click the **Edit Markers** icon in the top toolbar (the blue flag). Each marker is labeled as a target or point, with an index number.

For more information on markers, see the Agisoft Metashape Pro user's manual, Chapter 4, "Referencing."

Examining and Editing Markers

After you detect the markers, you can see information about each marker in the Markers area of the **Reference** pane, as shown in Figure 7.
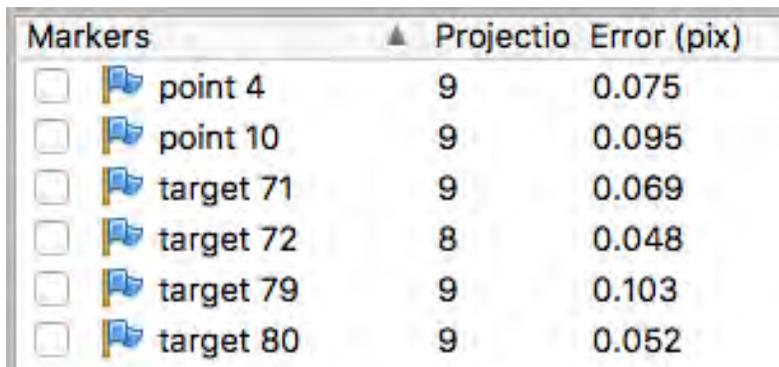
Markers ▲	Projectio	Error (pix)
🏳 point 4	9	0.075
🏳 point 10	9	0.095
🏳 target 71	9	0.069
🏳 target 72	8	0.048
🏳 target 79	9	0.103
🏳 target 80	9	0.052

Figure 7: The Markers area of the Reference pane after markers have been detected.

- The **Error (pix)** value is the estimated error in units of pixels for that marker's placement. You should check these values to evaluate the quality of the automatic marker detection.

- The **Projections** value is the number of photos in which the marker was detected. We recommend a minimum of three projections for any marker that is used to set scale for the project.

Check the Error for Each Marker

You can sort by error to find the most extreme marker errors in your project. You can review the markers on a photo, remove them, or change their positions.

If you intend to use a marker to set scale, we recommend that you remove projections on photos with the most error, or remove projections until the marker error is below 0.4 pixels. (See "Creating Scale Bar Objects" below for instructions)

In Metashape Pro, it is possible to see information about all the images that have a projection for any given marker, and to see the error in pixels for each projection on each photo. To view this information, right-click on a marker in the workspace or in the **Reference** pane, and choose **Show Info...** from the menu.
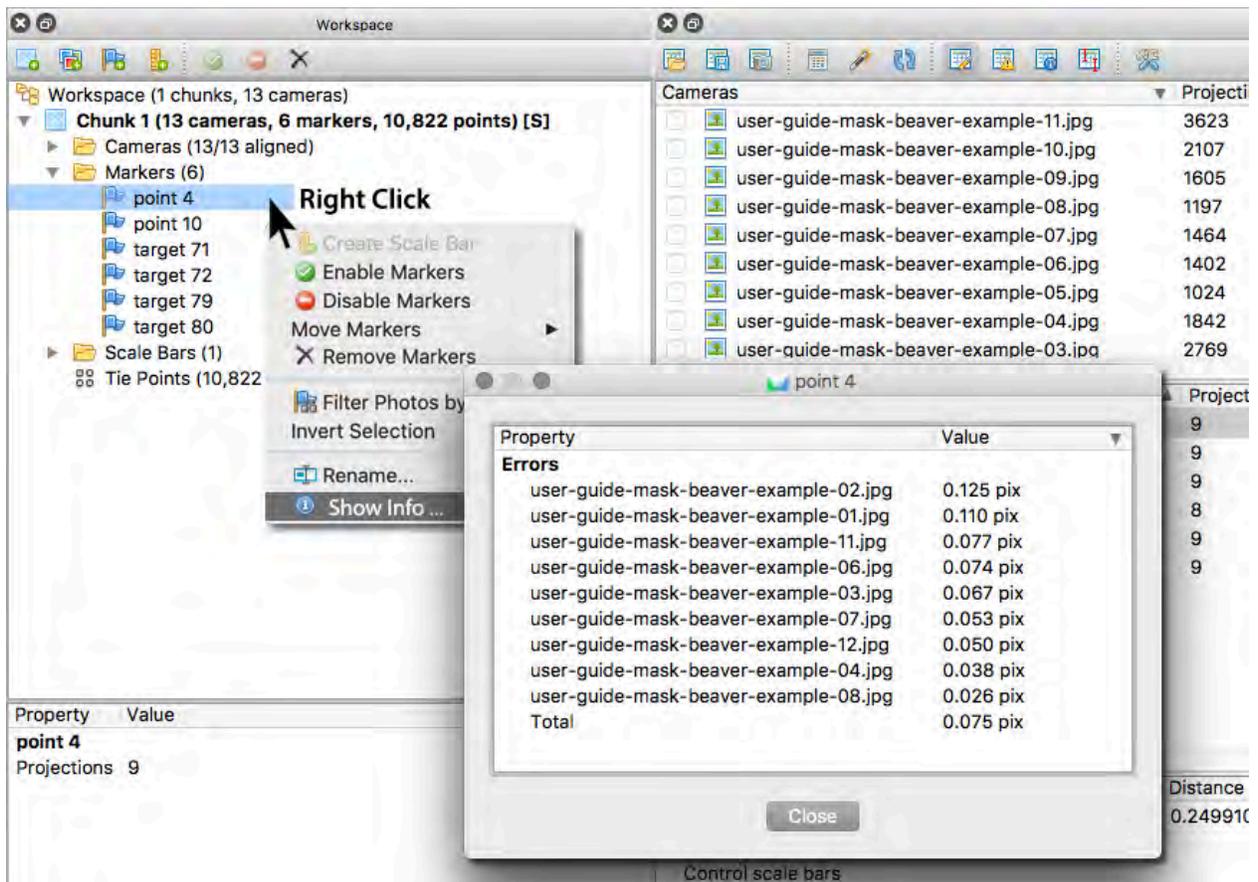
Figure 8: "Show Info…" box for a marker.

You can sort the "Value" column for pixel errors in the **Show Info…** dialog box. You can remove the marker from photos that have high pixel error. You can double-click on an image name in the **Show Info…** dialog box and that image will appear in the main window. We recommend that you have a minimum of 3 projections for any marker you plan to use to create scale. (See below on how to add and remove markers.)

TIP: After sorting the pixel errors for each photo with a projection for a marker, you can remove the marker from any photo that has a high pixel error. Removing the marker affects the number of projections for that marker, so be sure to check that you have enough.

You can also find all the images that have projections for a specific marker by right-clicking on that marker and choosing **Filter Photos by Markers**. Then check the marker placement for the images that have a green or blue flag (indicating the marker is being used). To do this, double-click on the image in the **Photos** pane, and then zoom in on the target in the main window area.

When you have made any change to a marker in a photo, click the **Update** icon in the **Reference** pane toolbar to update the pixel error estimate.

Check the number of projections for each marker

Markers should appear in three or more images if you have a good image set with proper overlapping images. If you see fewer than three projections for a marker, you can place the

marker by hand on additional photos. Alternatively, you can choose not to use that marker for creating scale bar objects.

As described above, there are two ways to find the photos that have projections for a given marker. You can use **Filter Photos by Markers** or the **Show Info…** dialog box. You can then remove markers that have high error, or reposition them. If you do not have enough markers, you can place them by hand.

Metashape sometimes detects additional photos that have a marker and shows them with a gray flag, because there is not enough certainty about the position. These potential markers are not used in the project unless you place the marker explicitly in the additional photo or photos, as shown in Figure 9. If you don't have enough projections, one way to add more is by explicitly placing any potential markers in a photo.

The green flag by photo 13 in Figure 9 indicates that the marker for target 72 is being used in this photo. A gray flag indicates that a potential marker was detected, but it is not being used.

To convert a potential marker to a used marker, double-click to select the photo with the gray flag. In the main window area, hover over the base of the flag for the suggested marker until it turns red. You can then right-click to bring up a menu (note that the menu is context-sensitive and changes depending on whether you are hovering over a marker or not). To place the marker, choose **Place Marker** from the right-click menu.
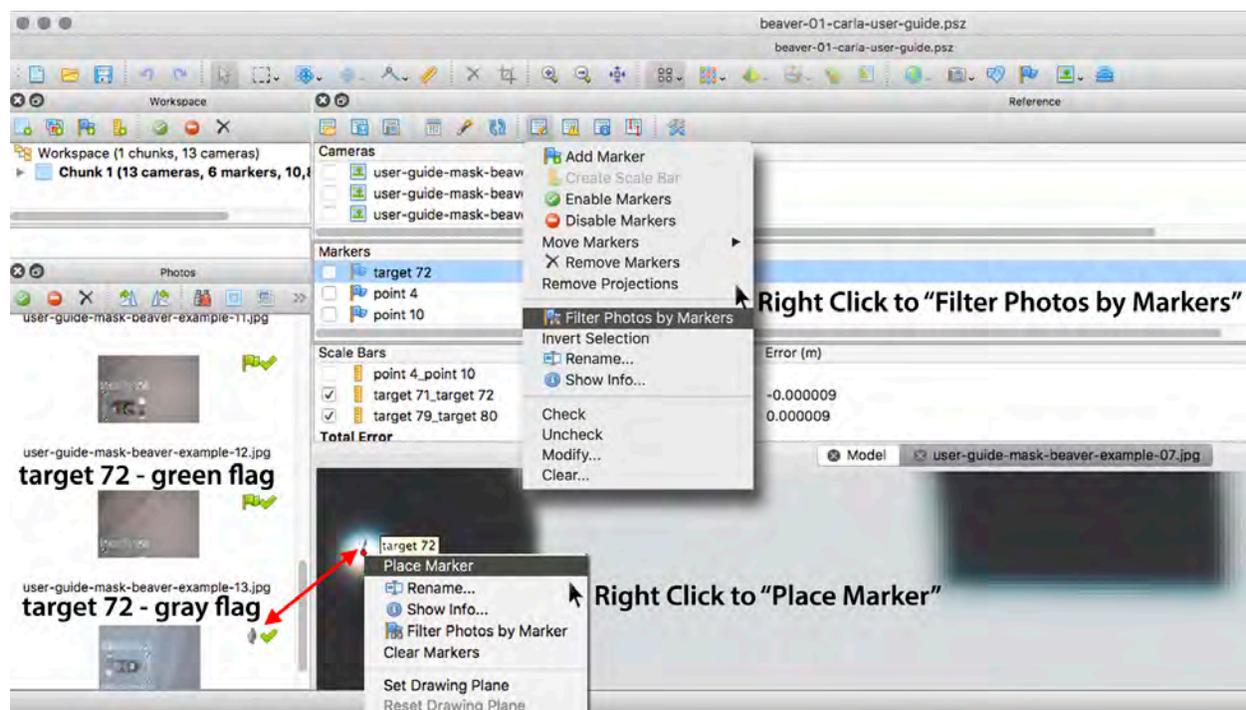

Figure 9: Placing markers by hand.

Creating Scale Bar Objects

The processing software uses a *scale bar object* to represent the physical scale bar that was used to create the markers. You must create these scale bar objects from marker pairs, after all markers have been created.

To create scale bar objects, select two markers in the **Reference** pane; then right-click and choose **Create Scale Bar**.

Each scale bar object you create should correspond to a physical calibrated scale bar that you used when capturing your image set.
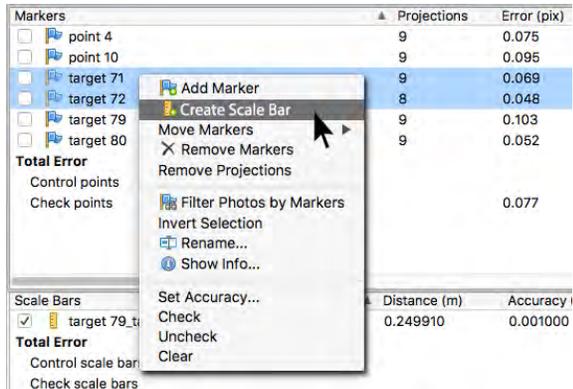

Figure 10: Creating a scale bar from target 71 to target 72.

Adding Scale Bar Distances

Click the **View Source** icon in the **Reference** pane toolbar to view the scale bar objects you have created. Each scale bar object is associated with a **Distance** value that you can set to the exact distance in meters between the two markers on your physical scale bar. This is the information that provides the scale for the whole 3D project.

The **Distance** value for a scale bar object is initially blank. In order to set the scale for the project, you must enter a distance value for one or more scale bar objects. The distance between markers in the scale bar object should match the known distance between targets on the physical scale bar.

To enter a known distance value:

- Select a scale bar object.
- Double-click in the **Distance (m)** column.
- Enter the known distance between targets for the corresponding calibrated scale bar.

TIP: While a project can be scaled using the known distance from a single scale bar, more scale bars are strongly recommended. Two bars provide a basic check, and three or more add confidence and statistical reassurance.

TIP: When you make any changes to markers or scale bar objects, such as manually placing or moving markers or entering scale bar distances, click the **Update** icon to see the effect of those changes on the errors and estimated distances.
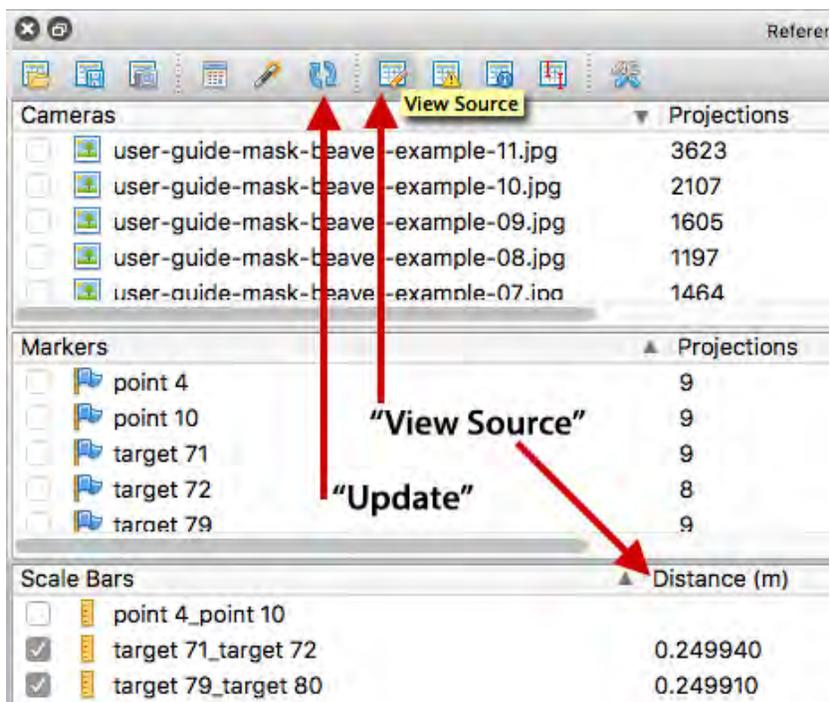

Figure 11: Updating information about markers and scale bars.

Check estimated scale bar distance values

In a well-shot project with crisp photos and proper image overlap, the difference between the estimated distance value for each scale bar object and the known target distance in the corresponding calibrated scale bar should be less than the precision of the scale bar. In the case of the scale bars from CHI, this is 1/10mm (0.0001 meter).

Each time you update the source data, the tool refines the scale of the entire model. It then uses the current scale and project geometry to estimate distances for all defined scale bar objects.

To show the estimated distance values that are based on the current scale, click the **View Estimated** icon in the toolbar.

Figure 12: Show estimated distance between markers in scale bar objects.

In Figure 12, the distance values you entered are replaced by the estimated values based on the current project scale. The tool estimates values for all scale bar objects, based on the current scale it has developed for the model.

- The check marks show those objects for which you have entered distance data. For these objects, the estimated distance value is adjusted to conform with the current scale in the model.

- The unchecked objects have only estimated data, because no data has been explicitly entered for them.

You can evaluate the accuracy of the current scale by seeing how closely the estimated distance values for scale bar objects match the known distances between targets in the physical scale bars that you used to generate the image set.

TIP: Enter known marker distances for all except one of the scale bar objects that correspond to your physical scale bars. This enables you to compare the wholly estimated value with the adjusted values.

Reference Information

Photogrammetry Resources

- **Photogrammetry Information**

There is a photogrammetry page on the CHI website with links to a variety of materials, including an instructional video series entitled *Practical, Scientific Use of Photogrammetry.* CHI hosts free user forums for people working in the field of computational photography, including a forum for photogrammetry.

- **Photogrammetry Training and Consulting**

  Cultural Heritage Imaging offers a [4-day class in photogrammetry](#). This hands-on training session is held 2 or 3 times a year in our studio in San Francisco, or we can make arrangements to conduct the training at your site.

  Cultural Heritage Imaging also offers [consulting](#) in photogrammetry to meet a wide range of needs. We can handle scientific imaging for you, help you plan projects, make equipment recommendations, and more.

How Scale Bars Are Calibrated

The Cultural Heritage Imaging (CHI) calibration process uses photogrammetry. We have "golden master" scale bars that were calibrated multiple times using different cameras and lenses, along with other golden masters calibrated by senior photogrammetrists from the US Bureau of Land Management. We use at least 4 golden master scale bars in the photogrammetry image set when we calibrate new scale bars.

In addition to how we image the scale bars, we also follow an error reduction workflow in the Metashape Pro processing software. We reduce error in the photogrammetry project to a root mean square error of between 0.13 to 0.15 pixels. We use auto-detection in Agisoft Metashape Pro for placing the markers on the scale bar targets. The Metashape auto-detection algorithm places the marker at the least mean squares centroid of the detected target. We manage the process, and, if needed, remove error from the markers, as described above, to achieve an estimated error on the marker placement below 0.15 pixels. We add scale values to the project from our golden master scale bars. In our calibration projects the Metashape estimated error (for all the estimated golden masters distances) is between .000005 and .00008 of a meter (5 to 80 microns).

We believe that our calibrated measurements are accurate to a precision of 1/10mm or better. Our testing shows repeatability closer to 5 hundredths of a millimeter. We scribe the data onto the scale bar to 1/100 of a millimeter so as to prevent rounding errors when adding scale values across the larger scale bars that have 3 or 5 targets.

Thermal Expansion of the Scale Bars

The scale bars are printed on 4mm ALUPANEL®. The manufacturer's published linear thermal expansion is 2.4mm/m at a 100°C temperature difference.

This translates to a linear dimensional change of 0.024mm/meter per degree Celsius (C) or 0.013mm/meter per degree Fahrenheit (F).

The longer coded scale bars are calibrated every 25cm, so the linear expansion for the calibrated data for a temperature change of 1°C = 0.006mm and 1°F = 0.0033mm.

The calibrated scale bars are marked with the temperature at which they were calibrated (generally between 62°–68°F, 16.7°–20°C).

If you want to compensate for linear expansion (for example, if you are using the scale bars outdoors in a wide range of temperatures), you can add or subtract the following amounts for the temperature change from the noted calibration temperature.

Temperature change in **Celsius**	Add or subtract the following amount for a 25cm calibrated distance	Temperature change in **Fahrenheit**	Add or subtract the following amount for a 25cm calibrated distance
+/- 5°C	0.00003	+/- 5°F	0.000017
+/- 10°C	0.00006	+/- 10°F	0.000033
+/- 15°C	0.00009	+/- 15°F	0.00005
+/- 20°C	0.00012	+/- 20°F	0.000067
+/- 25°C	0.00015	+/- 25°F	0.000083
		+/- 30°F	0.0001

You can download a brochure from the ALUPANEL® manufacturer with additional technical information:

https://www.multipaneluk.co.uk/products/sign-display/alupanel/#panel-overview

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Cultural Heritage Imaging Limited Warranty

Cultural Heritage Imaging Incorporated ("CHI") warrants the calibration data on our Calibrated Scale Bars Product to be accurate within 1/10 of one millimeter. We provide the above warranty for 90 days after the shipment of the product. We provide a one-time replacement of any scale bar that does not have this level of calibrated accuracy. The Customer should email scale-bars@c-h-i.org with any questions or concerns about the calibration on their scale bars. CHI will, at its sole discretion, determine if there is a calibration error, and will replace the scale bar or bars at CHI's expense if it is determined there is a calibration error. Note that the scale bars are printed on ALUPANEL® which has linear thermal expansion properties described in the *Scale Bars for Photogrammetry User Guide* (the Guide) which can affect the calibration data. How to compensate for thermal changes is also described in the Guide.

Exclusions and Limitations

Except for the limited warranty set forth above, CHI expressly disclaims any and all other warranties express or implied, including any warranty of quality, merchantability, or fitness for a particular purpose, and you specifically agree that CHI shall not be liable for any special, incidental, indirect, punitive, or consequential damages for breach of any warranty of any type on any CHI product.