Guide for the LiDAR Building Extraction Tool

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Lidar Building Extraction Tutorial

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Introduction

Light Detection and Ranging (LiDAR) is an active optical remote sensing technology that collects 3-dimensional (3D) point clouds of the Earth's surface. This technology is used for a wide range of applications, including but not limited to high-spatial resolution topographic mapping, 3D surface modeling, infrastructure asset management, and biomass studies. Due to the current impetus to acquire nationwide LiDAR data at the Quality Level 2 (QL2) or better (i.e., horizontal spatial resolutions of at least 1m), this once exotic dataset is becoming ubiquitous.

LiDAR data provides not only a detailed topographic surface but also a point cloud, which includes elevation information on above ground features such as buildings and vegetation. At present, the typical LiDAR dataset is delivered in an American Society for Photogrammetry and Remote Sensing (ASPRS) LAS v.1.4 format. These datasets have minimal classification, typically ground, bridge deck and water features are classified. Additional processing can extract other features from the LAS data.

The LiDAR Building Extraction Toolbox developed by the Earth Data Analysis Center (EDAC) at the University of New Mexico (UNM) is (Figure 1) designed to help the users extract the building footprint information from LiDAR LAS 1.4 files.

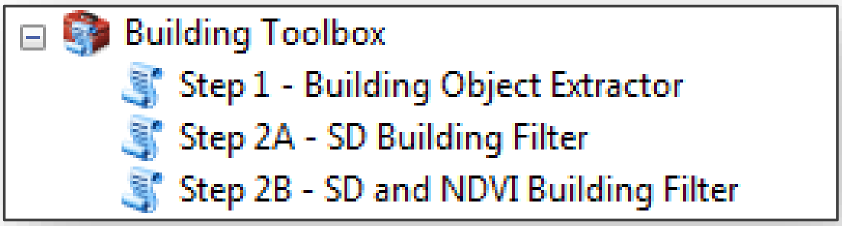

Figure 1: LiDAR Building Extraction Toolbox

EDAC has produced a series of videos that will step a user through the process of configuring the relevant software and creating spatially accurate GIS datasets using the LiDAR Building Extraction Toolbox and QL2 Lidar data.

The Lidar Building Footprint Extraction Tool videos are available on the [EDAC LiDAR Building Footprint Extraction Tool Playlist page].

Part 1 Introduction to LiDAR
Part 2 Tool Download and Setup
Part 3 Building Object Extractor
Part 4 SD Building Filter
Part 5 NDVI Building Filter
Part 6 Final Products

Tool Requirements

1. Software - ESRI ArcMap or ArcGIS Pro

The toolbox is designed to work with ESRI ArcGIS version 10.4; use with version 10.5 or higher requires that the 3D Analyst and Spatial Analyst extensions are turned on. Additionally, the toolbox works with ArcGIS Pro.

2. Lidar LAS and Bare Earth DEM files

The toolbox requires both the LAS files (format version 1.4) and bare earth digital elevation model (DEM) (as an .img, .tif, or ESRI Grid format) files to be stored in separate folders and share the same naming convention. Figures 2 and 3 illustrate how the files should be stored for use with this tool.

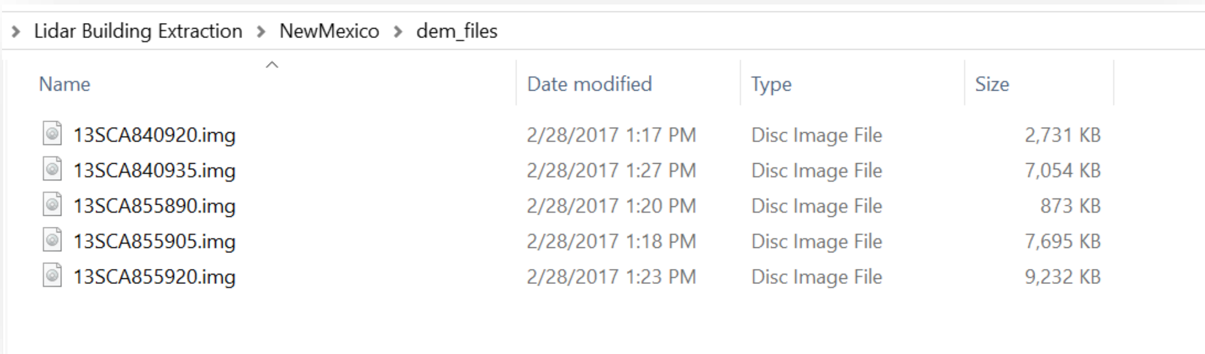

Figure 2: LiDAR Building Extraction Toolbox – DEM File Structure and Naming Convention.

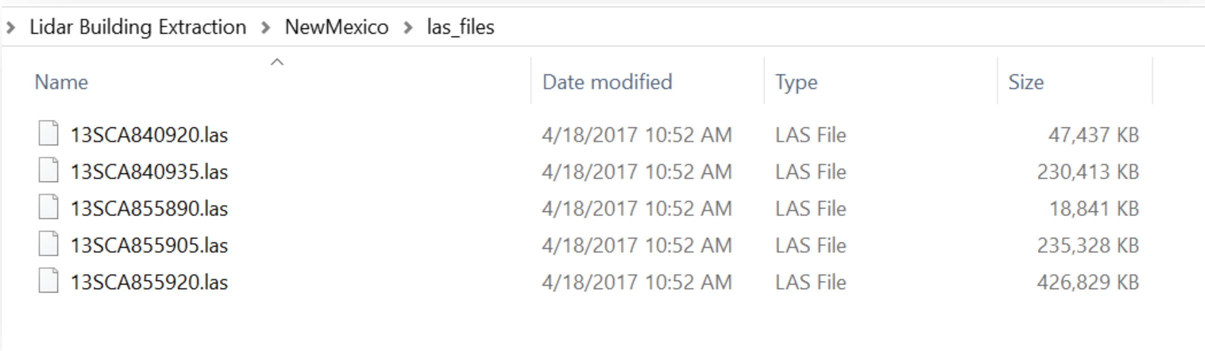

Figure 3: LiDAR Building Extraction Toolbox - LAS File Structure and Naming Convention.

The Building Object Extractor tool receives these input files and a user-defined minimum building height above ground value and outputs building raster objects. These objects are then filtered using: (1) the rooftop height standard deviation alone through the Standard

Deviation (SD) Building Filter; or (2) in combination with rooftop Normalized Difference Vegetation Index (NDVI) values, through the NDVI Building Filter. The second option requires a derived NDVI image that has equivalent spatial resolution as the input LiDAR data. The results from these filters are then converted to vector polygons, which are filtered based on a minimum roof area and have cleaned up edges, resulting in final building footprint polygons.

3. Optional Data – NDVI Data

NDVI data may be available for use in local areas. If NDVI data is not available from the local GIS data clearinghouse or the local government GIS Department, it can be calculated utilizing the National Agriculture Imagery Program (NAIP) four-band (RGB and Near-infrared) imagery. The process of calculating NDVI is explained here.

Building Toolbox Initial Set-Up

These tools assume that the user has the LAS files and the bare earth DEMs for the area of interest separated into two folders (as shown in Figures 2 and 3.) *NOTE: files in both folders should have the same naming format.* The toolbox was designed for LAS files that have an ASPRS format version of 1.4. The bare earth DEMs can be in .img, .tif, or ESRI Grid format.

The toolbox leverages existing tools in the ESRI geoprocessing universe and has retained their full functionality, and ESRI Help documentation provides further information about the use of these tools. For the purpose of this guide, ESRI ArcMap version 10.5.1 is used.

1. Download Toolbox

The YouTube video showing how to download and setup this toolbox (see Figure 4) is located on the EDAC LiDAR Building Footprint Extraction Tool Playlist.

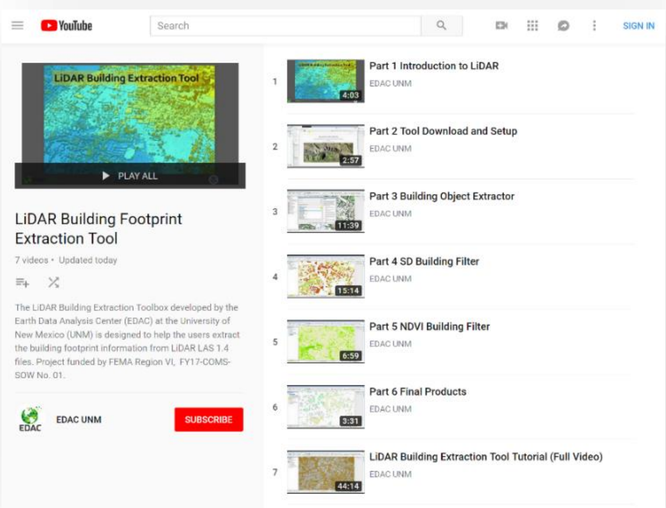

Figure 4 – EDAC YouTube Lidar Building Footprint Extraction Tool playlist.

Download the Building Extraction toolbox from EDAC's GitHub website. You do not need to sign up for an account or login to use GitHub. Click the green download button to download a zip file of the toolbox, as shown in Figure 5.

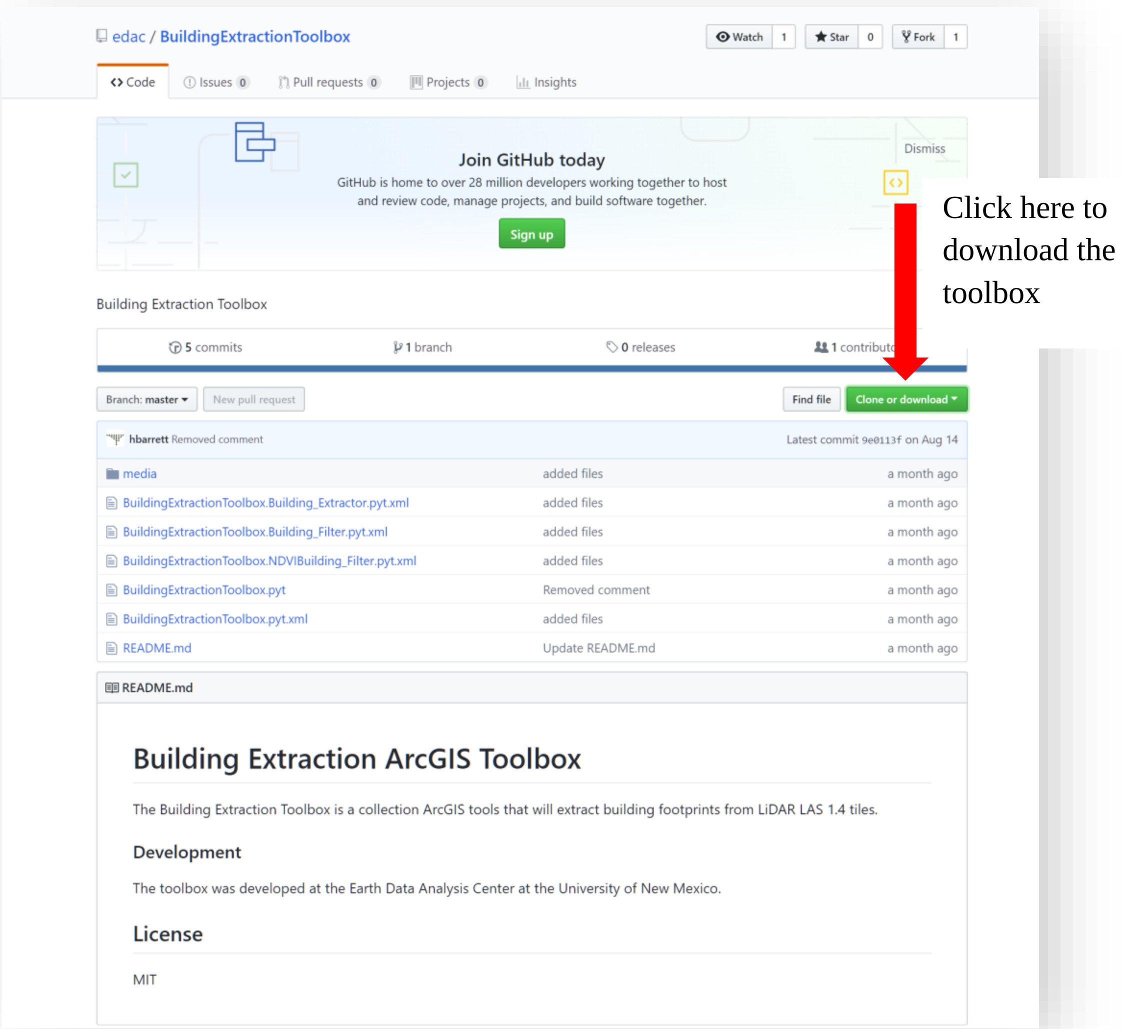

Figure 5 – EDAC GitHub page with Toolbox files.

2. *Toolbox Installation*

Once the downloaded zip file is placed in the correct user folder, the file should be unzipped using WinZip, 7-zip, or another file utility program.

To install the Toolbox, open an ArcMap session and open the ArcToolbox window. First, right-click on the **ArcToolbox** header to select **Add Toolbox;** second, browse to the folder location of the **BuildingExtractionToolbox.pyt** toolbox; and lastly, select the file and click Open. The **Building Toolbox** will be added to the ArcToolbox window (Figures 6 and 7).

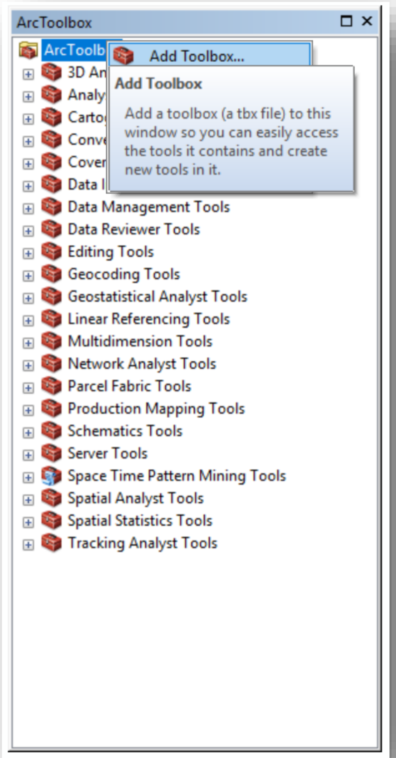

Figure 6 – Adding Building Extraction Toolbox to the ESRI Tool bar.

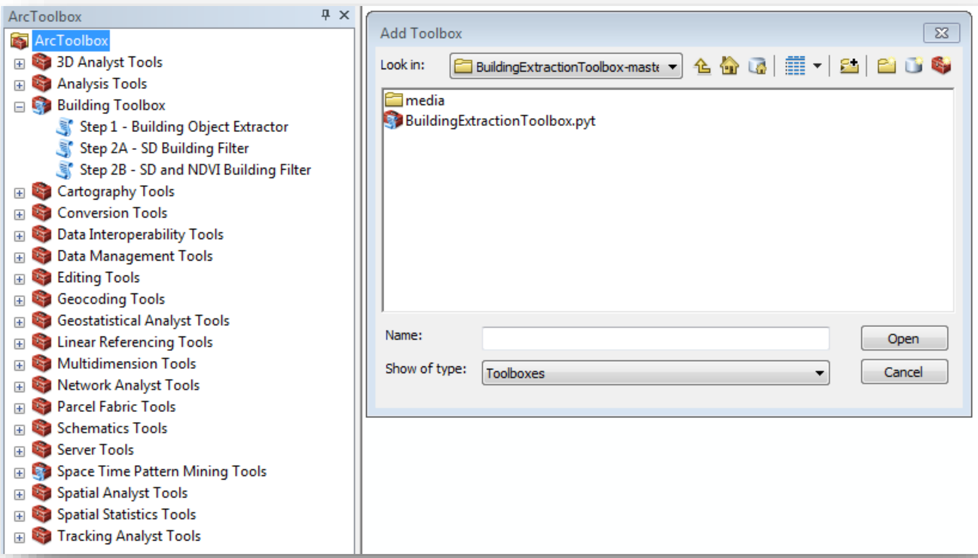

Figure 7 – Adding Building Extraction Toolbox to the ESRI Tool bar.

Building Toolbox Step 1 – Building Object Extractor

The **Building Object Extractor** tool creates raster building objects from the LiDAR data (Figure 8). The Building Object Extractor video demonstrates this part of the process.

1. Data Inputs

The initial questions prompt the user to identify the directories that house the LAS tiles (**LAS Input Directory**) and the bare earth DEMs (**DEM Input Directory**). The tool requires that both the LAS tiles (v. 1.4) and bare earth DEM (as an. img, .tif or ESRI Grid format) are in separate folders and share the same naming convention. The tool also prompts the users to identify the folder location for output products (**Output Directory**).

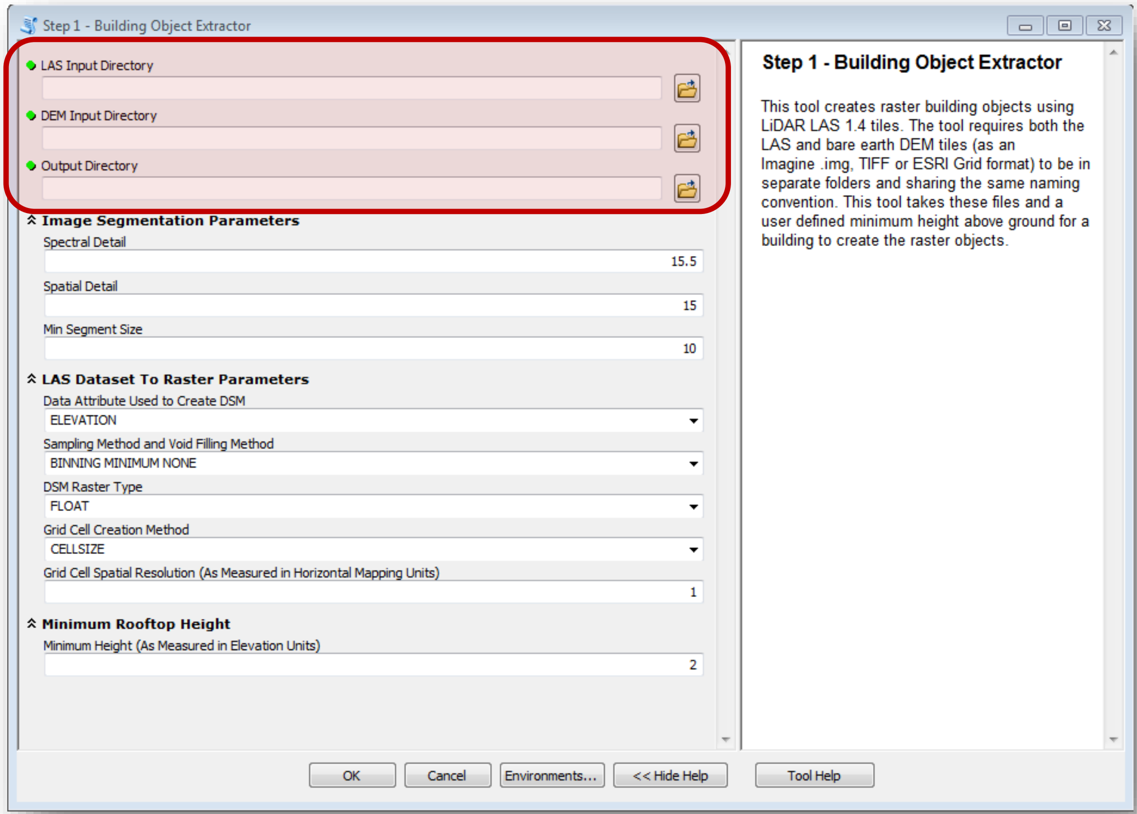

Figure 8 - The Building Object Extractor tool dialog box with the initial questions highlighted in red.

2. Image Segmentation Parameters

The **Image Segmentation Parameters** option allows the user to specify the extent to which results are segmented (Figure 9).

- The **Spectral Detail** parameter sets the level of importance given to the spectral differences of features in the imagery, valid values range from 1.0 to 20.0. Higher values are appropriate when the features are spectrally similar, whereas smaller values create smoother outputs.

Note that if the output scene is too generalized the value should be raised and if it is too segmented then the value should be lowered.

- The **Spatial Detail** parameter sets the level of importance given to the proximity between features in the imagery, values range from 1.0 to 20.0. A higher value is appropriate when the features are spatially interrelated. As with the **Spectral Detail**, smaller values will create smoother outputs, but if the output scene is too generalized then the value should be raised. If it is too segmented then the value should be lowered.

- The **Min Segment Size** parameter defines the minimum size, in grid cells, for an object during processing.

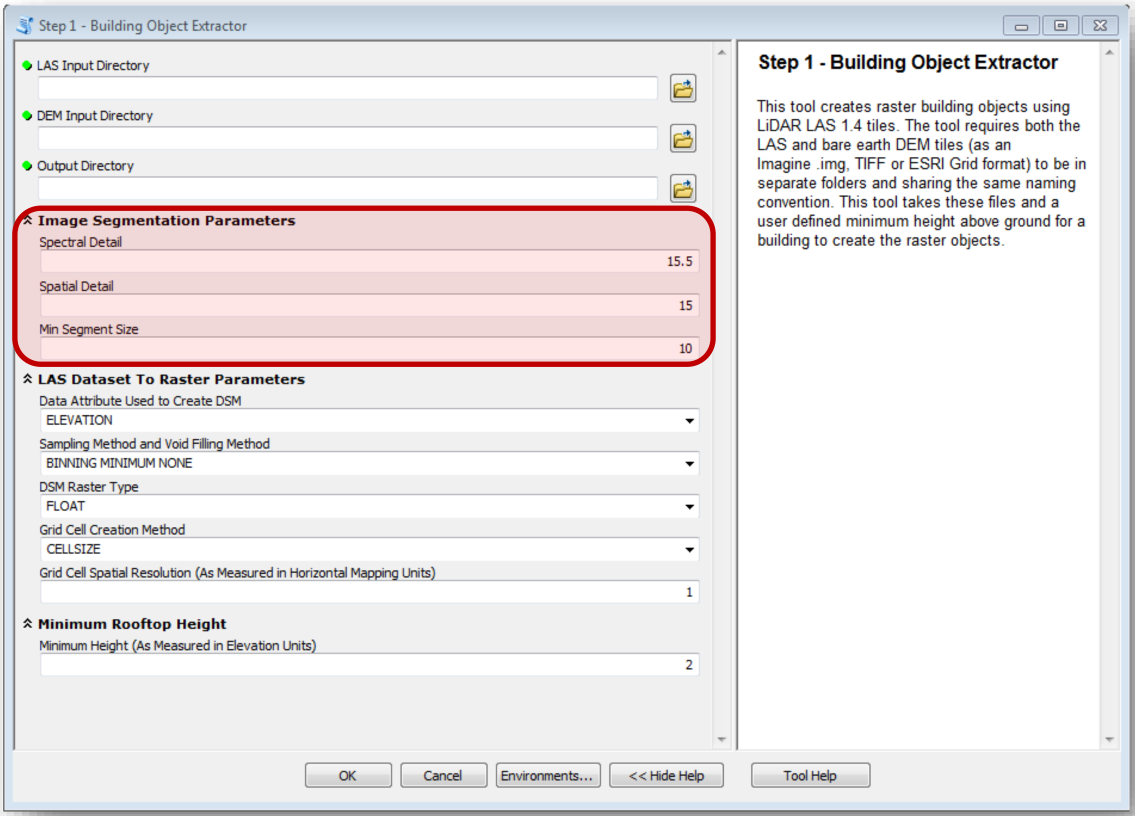

Figure 9 - The Building Object Extractor tool dialog box with the Image Segmentation Parameters highlighted in red.

3. *LAS Dataset to Raster Parameters*

The options listed in the **LAS Dataset to Raster Parameters** (Figures 10 and 11) prompt the user to define how the LAS files and bare earth DEM are to be used to create the Digital Surface Model (DSM).

- The **Data Attribute Used to Create DSM** option allows the user to choose the LiDAR data attribute that will be used to create the output raster, although for DSMs the **ELEVATION** attribute is the default. The two other choices under this option – the **INTENSITY** option (uses intensity information from LiDAR files to create a raster) and the **RGB** option (uses RGB values from LiDAR points to create 3-band imagery) – create raster images but not DSMs.

- Under the **Sampling Method and Void Filling Method** option, the user defines the interpolation technique that will be used to determine the cell values of the output DSM. The binning interpolation approach provides a **Cell Assignment Method** for determining how each output cell will use the points that fall within its extent. The **MINIMUM** choice is the default; as it assigns the minimum value from the points that fall within the cell, and helps it avoid pulling elevation information from other non-building objects, as they should always have the lowest elevation value. There is also the **AVERAGE** choice (which assigns the mean value of the points that fall within the cell), the **MAXIMUM** choice (assigns the maximum value of the points within the cell), the **IDW** choice (uses the Inverse Distance Weighted interpolation to determine the cell value), and the **NEAREST** choice (uses Nearest Neighbor assignment to determine the cell value). The user must also determine a void filling method for cells that do not contain any LAS points; the **NONE** choice, which assigns the NoData value to any empty cell, is the default. Other choices include the **SIMPLE** choice (averages the values from data cells immediately surrounding an empty cell to eliminate small voids), the **LINEAR** choice (triangulates across empty areas and uses linear interpolation on the triangulated value to determine the cell values), and the **NATURAL NEIGHBORS** choice (uses natural neighbor interpolation to determine the cell values).

- The **DSM Raster Type** option determines the data type of the output DSM. The **FLOAT** choice is the default for the output DSM, will create a 32-bit floating point raster that supports values ranging from -3.402823466e + 38 to 3.402823466e + 38, and preserves the original Z-value level of detail. The other option, **INT**, creates an output DSM with an appropriate integer bit depth, rounds the Z-values to the nearest whole number, and writes an integer to each raster cell value.

- The **Grid Cell Creation Method** option allows the user to specify the preferred method for interpreting sampling values in order to define the spatial resolution of the output DSM. The **CELLSIZE** choice is the default and defines the building raster that will be created based on a regular cell size. The other choice, **OBSERVATIONS**, defines the number of cells that are to be used to determine the value of the grid cell.

- The **Grid Cell Resolution (As Measured in Horizontal Mapping Units)** option allows the user to specify a value that defines the spatial resolution of the output DSM (in map unit distance values). For example, a value of 1 for a dataset defined in meters will create an output DSM spatial resolution of 1m.

Using the default choices shown in Figure 11 will convert the LAS point cloud into an ESRI LAS dataset (**.lasd)** files for each tile. From this **.lasd** file, the LAS points that are unclassified (Figure 12) and have the lowest value within each cell are then used to create a DSM with NoData values assigned to cells without any such points. The bare earth DEM tiles are then subtracted from these DSM tiles, resulting in height DSMs; these height values are measured in the same units as the elevation data.

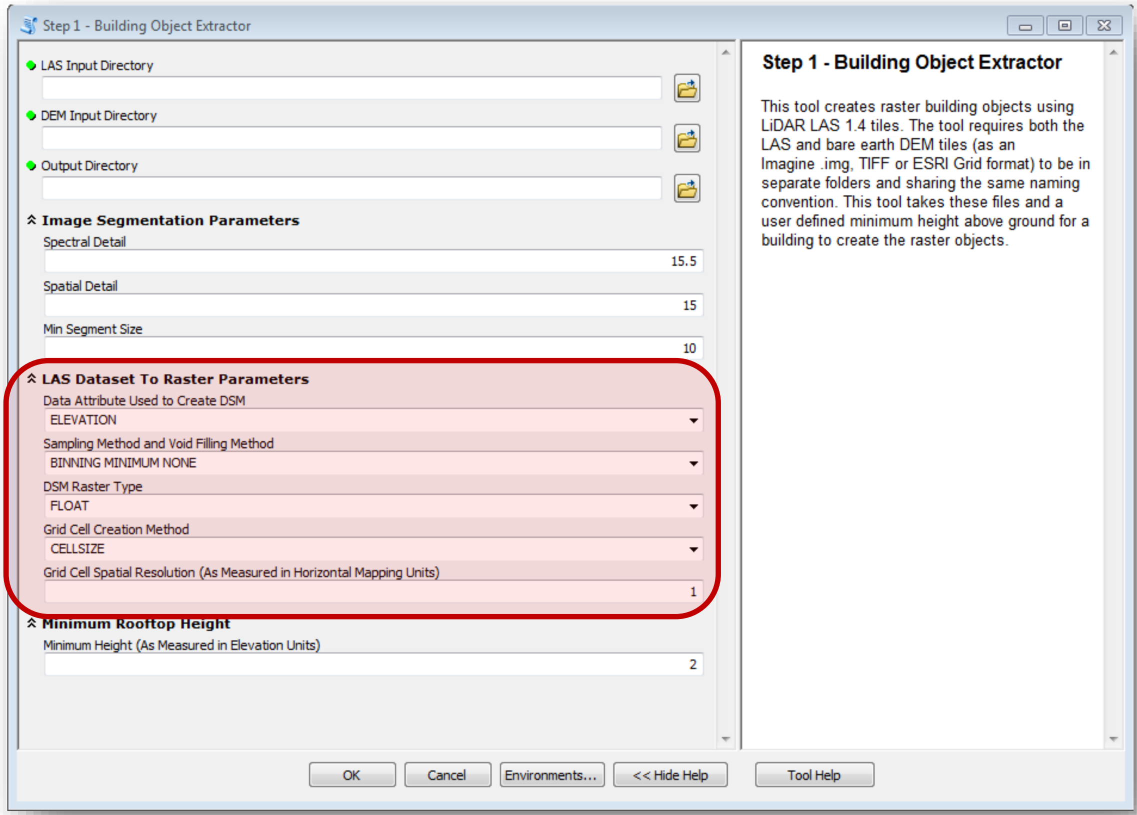

Figure 10 - The Building Object Extractor tool dialog box with the LAS Dataset to Raster Parameters highlighted in red.

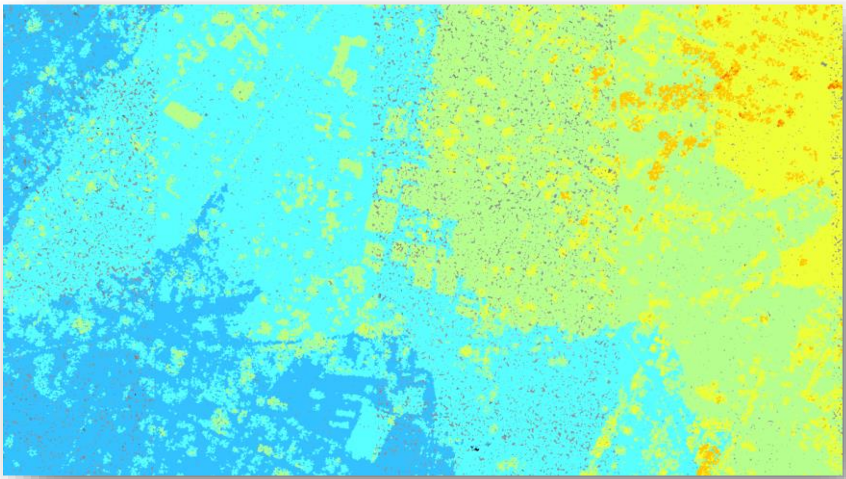

Figure 11 – LiDAR point cloud color-ramped by elevation from blue (lowest) to red (highest).

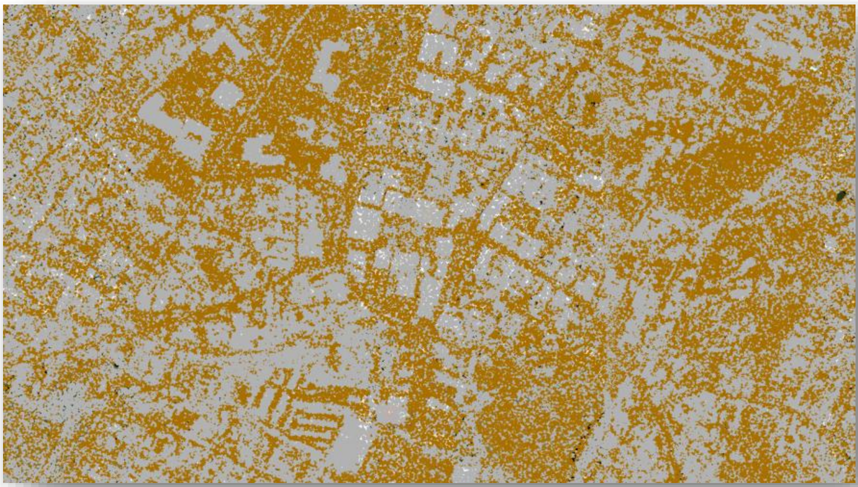

Figure 12 – The LiDAR point cloud with the unclassified LAS points in gray and the ground-classified points in brown.

4. Minimum Rooftop Height

The height DSM contains the building footprints and extensive extraneous feature information. The **Minimum Rooftop Height** option allows the users to define a minimum height that all rooftops should be above (Figure 13) and values below this threshold will be changed to a value of NoData.

- **Minimum Rooftop Height** should be determined for the area of interest and entered in this field.

After the image segmentation is finished, the process will collect the standard deviation of each raster object's height. The user can now go one of two ways. If the user does not have a NDVI image to help mask out vegetation then Step 2A will finish the building footprint processing using the height standard deviation as the only filter. If the user does have a NDVI then Step 2B will use both NDVI and the height standard deviation as a filter to derive the final products.

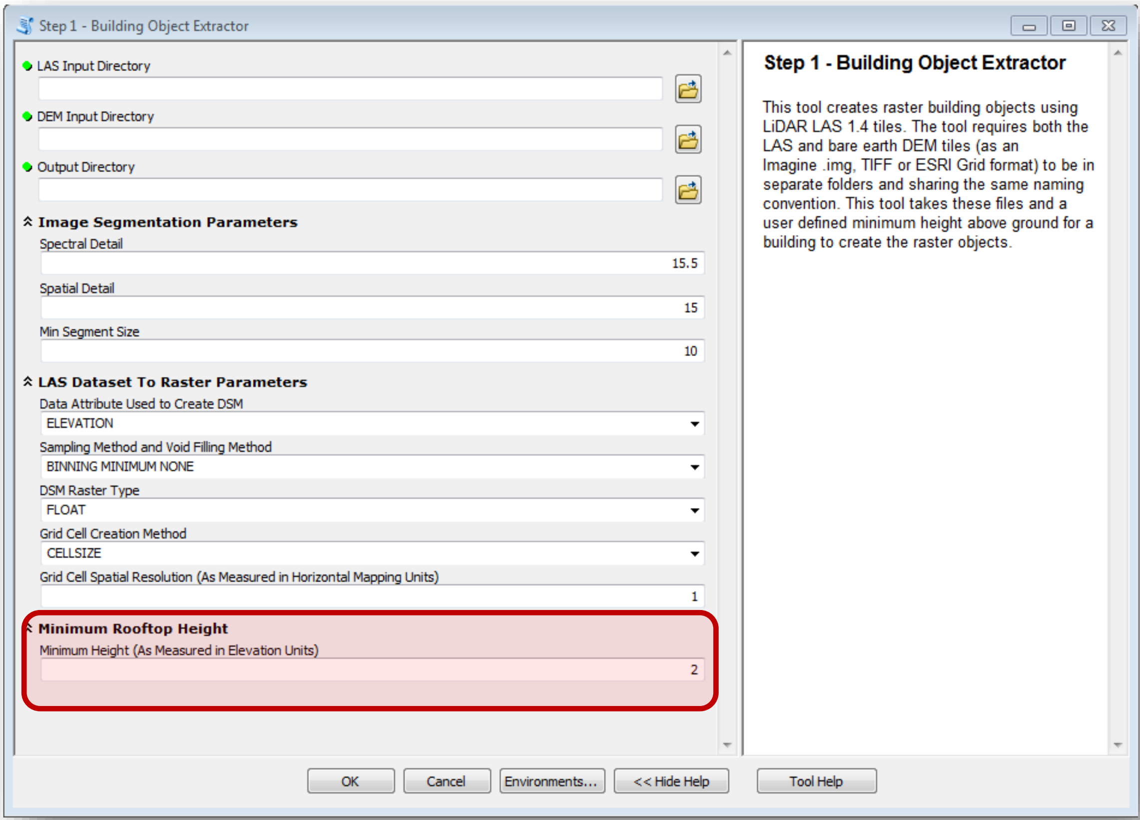

Figure 13 – The Building Object Extractor tool dialog box with the Minimum Rooftop Height highlighted in red.

Step 2A – SD Building Filter Tool Inputs

After completing Step 1, the user can proceed two different ways, one using NDVI to assist with building footprint delineation or two proceeding with footprint extraction without NDVI.

For the user without a NDVI, Step 2A (Figure 14) will create the building footprints based only on the raster objects' height standard deviation. The theory with this part of the process is that despite rooftop slope variations, from flat to high, they typically have a smooth change in elevation, and thus a low standard deviation, whereas vegetation canopies are more chaotic and have a higher standard deviation (Figure 15).

The SD Building Filter video shows this part of the process.

1. Data Inputs

This tool's dialog box has the same initial options as the Building Object Extractor dialog box with the addition of the Threshold option. This is the standard deviation threshold above which all raster objects are assumed to be vegetation, and output values are changed to the NoData. The default value is 1.5, but the user can examine standard deviation values for raster objects in the previous output directory and assess if this value needs to change.

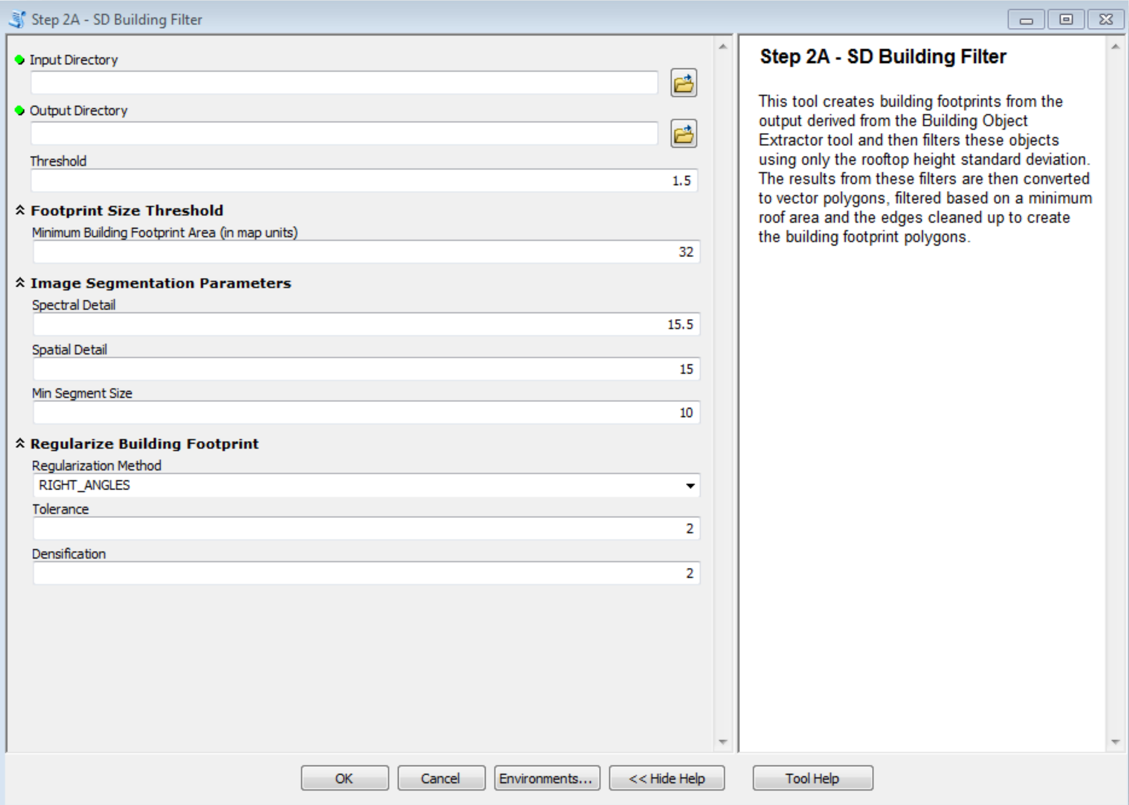

Figure 14 – The SD Building Filter dialog box.

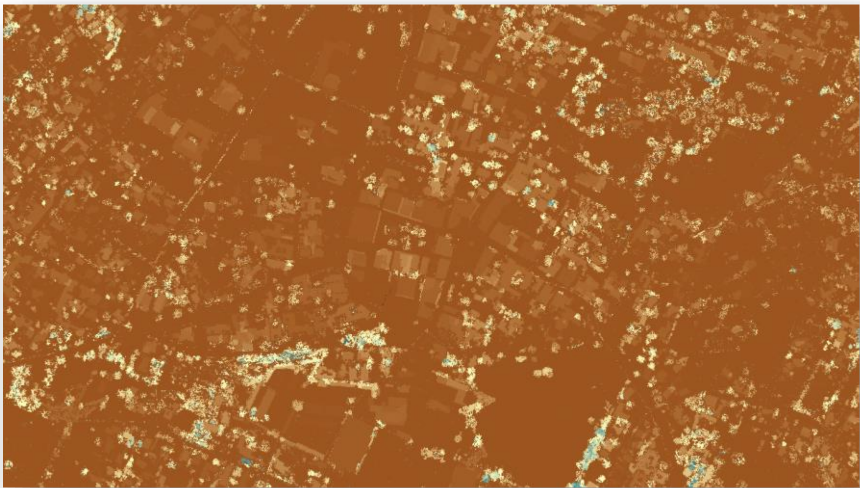

Figure 15 – Raster objects color-ramped with the lowest rooftop height standard deviations in brown and the highest in green.

The process relies on user-defined variables to remove all raster objects with standard deviation values above the threshold value.

The **Footprint Size Threshold** (Figure 16) should be used to define a minimum size value in square area measurement units to filter out smaller structures and other extraneous objects that should not be considered. For example, if the base units of the data are in meters, then this Footprint Size Threshold value will be in square meters. The final building footprints will be copied as feature classes for each tile in a geodatabase found in the output directory.

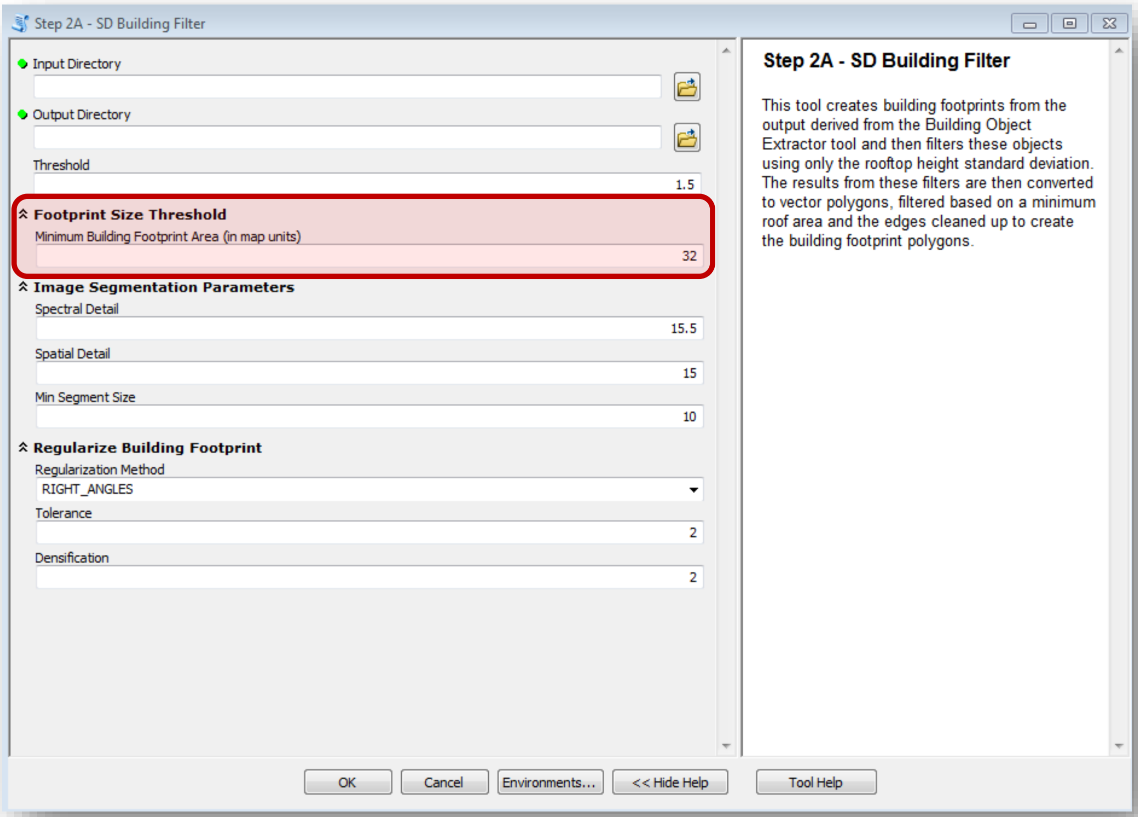

Figure 16 – The SD Building Filter dialog box with the Footprint Size Threshold option highlighted in red.

2. Image Segmentation Parameters

The objects then go through another image segmentation process that works exactly as defined in the previous section. This image segmentation process converts the raster objects to a vector feature class within a geodatabase, dissolving the boundaries between any adjoining raster objects.

3. Regularize Building Footprints

At this point in the process, the objects contain jagged edges due to the vectorized grid cell boundaries. Therefore, these objects must go through a regularization process (Figure 17) to smooth out edges.

- The default **Regularization Method** choice is **RIGHT_ANGLES**, which enforces right angles on all breaks from linear edges based on the user-defined **Tolerance** and **Densification** values. The other choices are **RIGHT_ANGLES_AND_DIAGONALS**, which also allow for diagonalization of breaks, using **ANY_ANGLE** (does not enforce a right angle rule and is good for areas with irregular shaped structures) and **CIRCLE** (enforces a circular interpretation as to the boundaries and is good for areas with structures such as grain silos or water tanks).

- The **Tolerance** option defines the distance that the regularized footprint can deviate from the boundary of the originating feature.

- The **Densification** option defines the sampling interval that will be used to evaluate whether the regularized feature will be straight or bent and must be equal to or less than the **Tolerance** value. If the output polygons appear too blocky then these values should be lowered. If the output polygons still retain too many of jagged edges then these values should be increased.

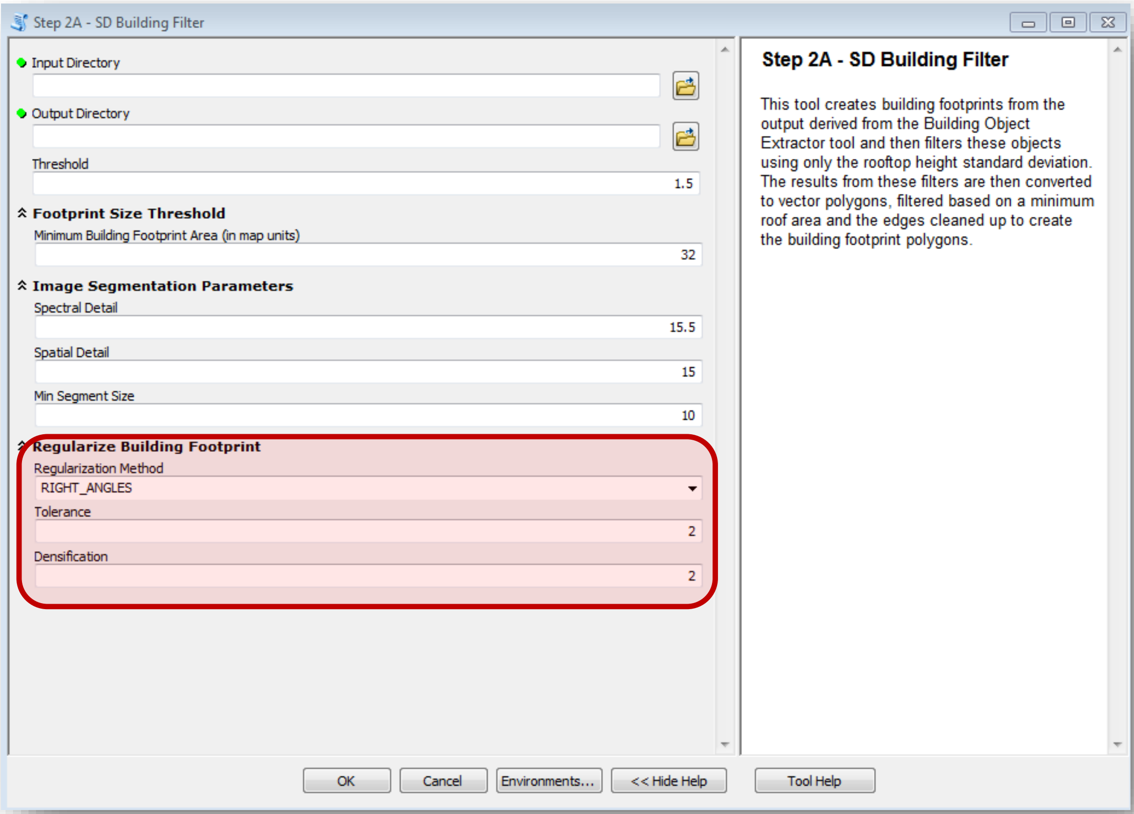

Figure 17 – The SD Building Filter dialog box with the Regularize Building Footprint option highlighted in red.

Step 2B – SD and NDVI Building Filter Tool Inputs

The Step 2B tool functions identically to the Step 2A tool, but if the user has a NDVI image from either aerial or satellite imagery, then Step 2B provides an additional method for cleaning up building footprints. The NDVI image should cover the whole project area and be acquired at a similar spatial resolution and time as the LiDAR data. This tool relies on the following NDVI formula that creates an 8-bit image [Eq. 1], although it is possible that other NDVI-based formulas would work.

$$(((NIR - Red)/(NIR + Red)) + 1) * 100 \quad [Eq. 1]$$

In this equation the value "1" is added to the output to change the normal results which are typically decimal values ranging from -1 to 1, where the value of 0 is the inflection point between non-vegetated and vegetated cover. This change results in an output ranging from 0 to 2, with 1 being the new inflection point. This image is then multiplied by 100 and saved as an 8-bit integer based image ranging from 0 to 200, where values around 100 are the new inflection point and values greater than that are increasingly indicative of greater vegetative vigor.

The NDVI Building Filter video demonstrates this part of the process.

1. Data Inputs

This tool's dialog box has the same initial options as the Building Object Extractor and SD Building Filter Tool.

2. NDVI File and Threshold

In Step 2B, users are prompted to define two additional options (Figure 18) – the NDVI file and the NDVI threshold. This allows the process to further filter raster objects based on user-defined threshold NDVI values. The theory here is that the higher the average NDVI value, the more likely that the object is actually vegetative canopy (Figure 19).

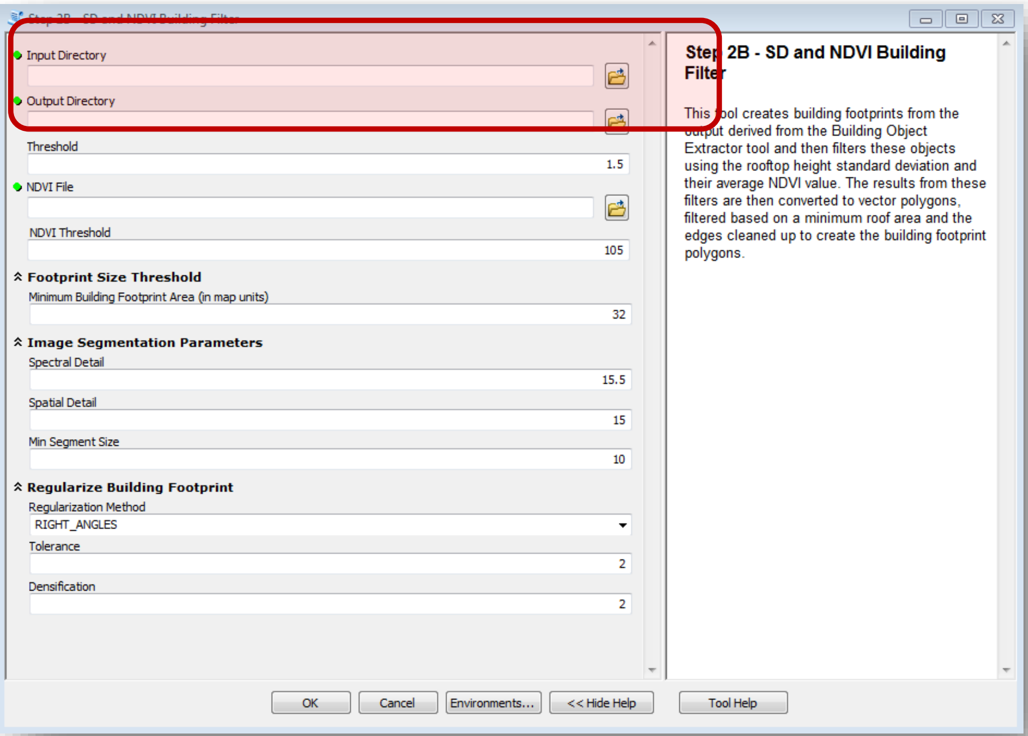

Figure 18 – The SD and NDVI Building Filter tool dialog box with the NDVI options highlighted in red.

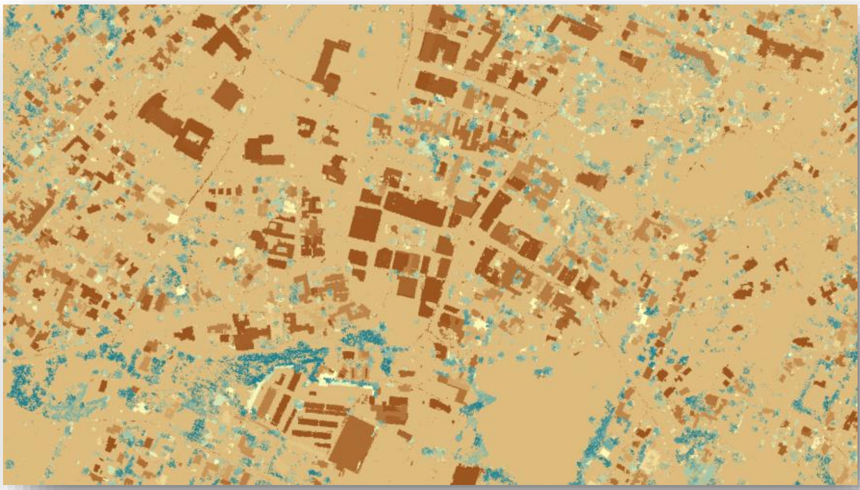

Figure 19 – Raster objects color-ramped based on their average NDVI values with the objects with the lowest values in brown and the highest values in green.

3. Image Segmentation Parameters and Regularize Building Footprints

These are the same as in the Step 2A tool, see explanation above.

Final Building Footprint Creation

Step 2A or Step 2B will both produce building footprints as separate feature class files for each tile in the **FinalBldgs** geodatabase located in the user-defined output directory (Figure 20). Final quality assurance and quality control (QA/QC) requires the editing of building footprints to correct for missing building features or the removal of extraneous features. The last video, Final Products covers the final tool outputs and potential additional data processing steps.

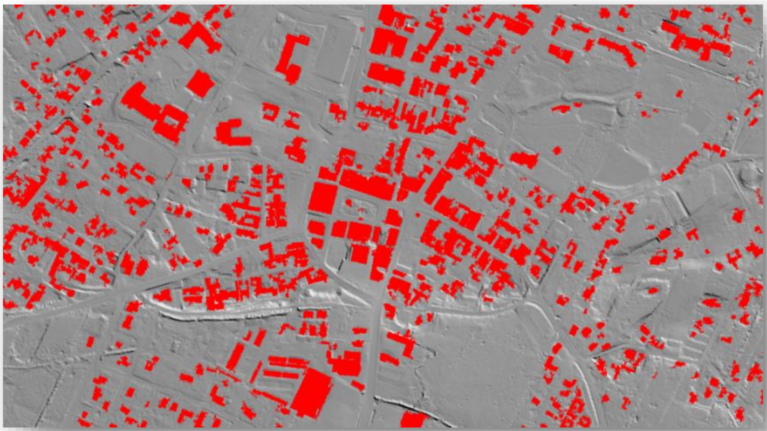

Figure 20 - Final building footprint polygons created by the toolbox.