Getting Started with the SmartHubs Decision Support Tool:

M2MHub (Mcda2MobilityHub)

A QGIS plug-in using Spatial Multi – Criteria Decision Analysis to find the most desirable areas to install shared mobility hubs

Team members

Dr. Gonçalo Homem de Almeida Correia (Leader) (g.correia@tudelft.nl)	TU Delft
Dr. Anastasia Roukouni	TU Delft
Dr. Miquel Martí Casanovas	UPC
Lara Espíndola Gerhardt	UPC
Dr. Inés Aquilué Junyent	CARNET / UPC
Maarten Verkou	TU Delft

Table of Contents

Introduction

The **Spatial Multi-Criteria Decision Support Tool (DST), M2MHub (Mcda2MobilityHub),** described herein was developed in the context of the project SmartHubs, a two-year project funded by the EIT Urban Mobility – KIC (01/01/2021 – 31/12/2022)

If you would like to have more information regarding the project SmartHubs, please visit: https://smarthubs.eu/

In the first year of the project, the conceptualization of a DST to efficiently prioritise locations of shared mobility hubs in the city took place. The potential users of this DST include local public administrations (municipalities and metropolitan areas) or/and any other entity which is interested in locating shared mobility hubs. The work was led by TU Delft (contributing with the expertise on transport and mobility networks), in collaboration with UPC and CARNET (bringing knowledge about the relation between urban mobility and the spatial configuration of cities). The insights of local administration have been considered during the process by in-depth discussions with representatives of the participating cities in the project (Amsterdam, Eindhoven, Helmond, Barcelona, Lisbon and Setúbal). The perspective of the automotive industry by the participation of ŠKODA AUTO in the regular meetings of the team has also been considered. In the second year of the project, the aforementioned conceptual model was translated into a plug-in for QGIS, the M2MHub.

Flexibility lies in the core of our conceptual model, and this is reflected also at the way the plug-in works – freedom is given to the user to adjust the weights of the criteria used in the spatial multi-criteria decision analysis (MCDA), change their direction, or/and add new ones, based on the different strategies and goals of different users as well as on the special local circumstances of each case study. Moreover, the users will be able to choose between a vector or a raster approach for the input and output layers, which increases significantly the potential to use all available data they have, without being restricted by a specific data format. The intention was to build a tool that is user-friendly and simple to use, while at the same time remaining dynamic and able to adapt to the fast-changing rhythm of modern urban life and needs of citizens and emerging mobility trends.

The output of the model is a heat map that shows the desirability index for locating shared mobility hubs in different areas of a city, based on the criteria and weights used (which reflect the objectives and wishes of the users). It is worth mentioning that, as with every MCDA, the result is never an absolute answer (a hard "yes" or "no" in terms of the locations to build a hub in this case) – the objective is always to assist decision – makers in taking more well-informed decisions by helping them to visualize different tailored-made scenarios according to their own goals.

This guide to the plug-in is divided into two main parts. In the first part, it provides some background information regarding the methodological approach followed in the conceptualization of the model so that the user is aware of the methodological decision behind the tool. The second part of the guide is a step-by-step explanation of how to install the plug-in followed by guidance on how to use its different functions. In the Appendix, instructions on how to convert vector data to raster are included.

It is worth mentioning that prior knowledge of working in a GIS environment, although not being mandatory, it will certainly facilitate the usage and improve the experience of the potential user.

1. Methodological approach

The methodological approach that was used comprises a thorough and in-depth literature review, the selection of the most relevant indicators that resulted from it, and the development of a Spatial Muti-Criteria Framework using a combination of Multi - Criteria Decision Analysis (MCDA) techniques and Geographical Information Systems (GIS) technology. The final output is the production of heatmaps that illustrate the degree of desirability for locating shared mobility hubs in different areas of the city.

The following diagram (Figure 1) presents the methodological approach followed for the conceptualization of the model step-by-step.

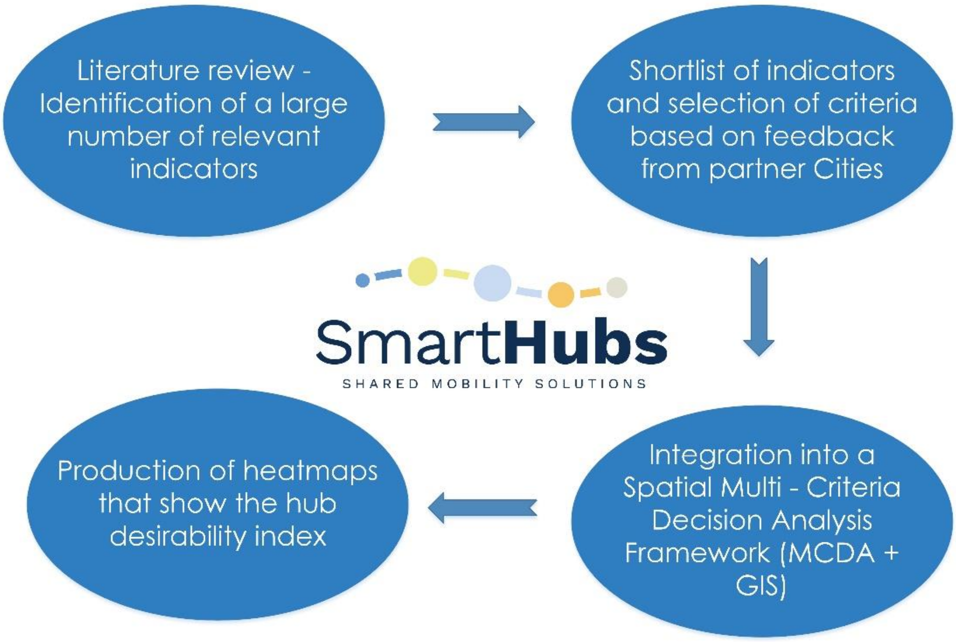


Figure 1. Methodological approach followed for the conceptualization of the tool

For more information regarding the conceptual framework and the methodological approach followed, please see:

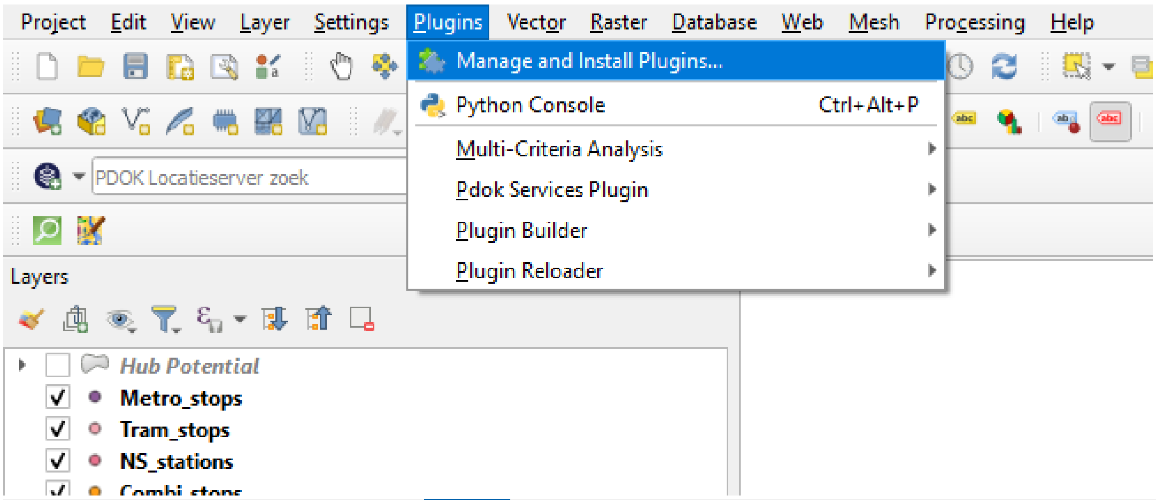
Aquilué Junyent, Inés; Martí Casanovas, Miquel; Roukouni, Anastasia; Moreno Sanz, Joan; Roca Blanch, Estanislao; Correia, Gonçalo Homem de Almeida (2024). **Planning shared mobility hubs in European cities: A methodological framework using MCDA and GIS applied to Barcelona.** *Sustainable Cities and Society* 105377, In Press. Online accessible from: https://www.sciencedirect.com/science/article/pii/S2210670724002051

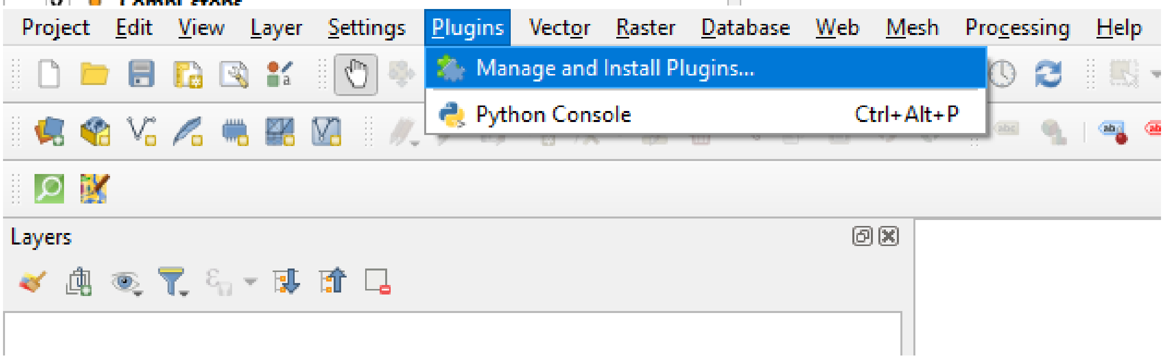
The following section will guide you step-by-step on how to install and use the **M2MHub** plug-in in QGIS.

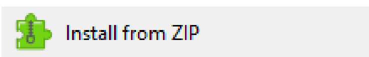
2. The QGIS plug-in of the SmartHubs Spatial Multi-criteria Decision Support Tool (M2MHub)

2.1. Installation (Windows)

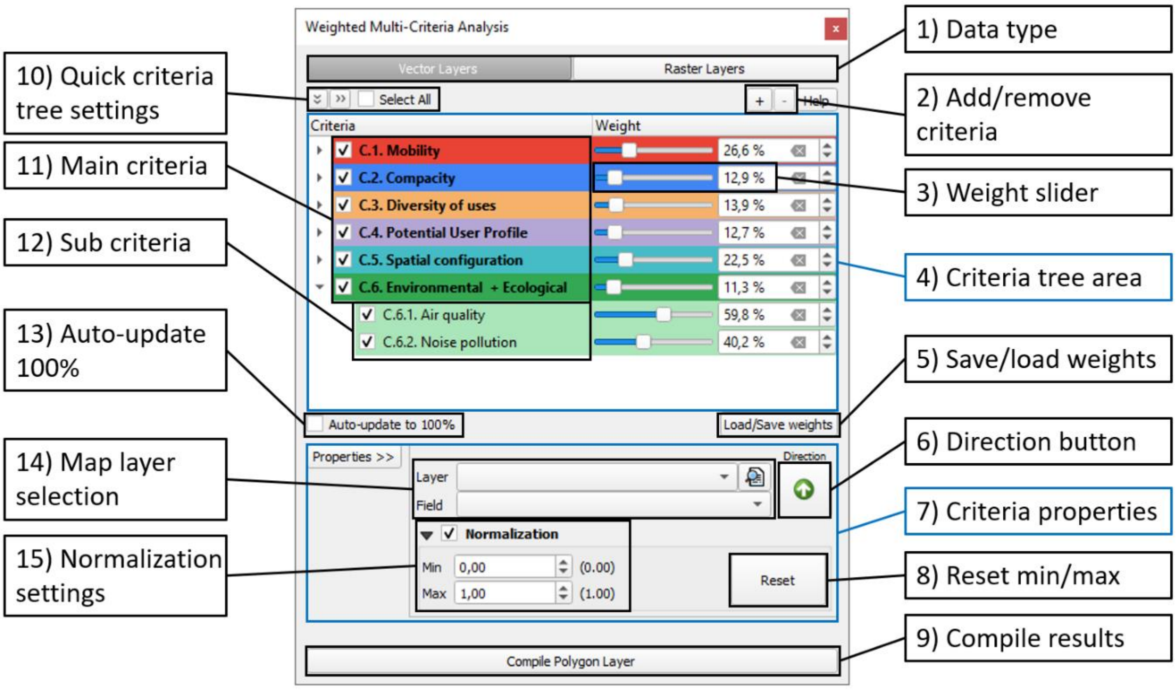
1. Make sure the zip-file "smarthubs_decision_support_tool.zip", can be found on your computer
2. Open QGIS. Any version after 3.0 should work. If you do not have it already on your pc, download and install the latest version of QGIS (3.24.3) here: https://qgis.org/downloads/QGIS-OSGeo4W-3.24.3-1.msi
3. Go to the 'Plugins' tab [Manage and Install Plugins…]





4. Go to  and browse the .zip file that you saved in step 1
5. A security warning will appear. You can ignore it and continue the installation.

2.2. Tool Overview



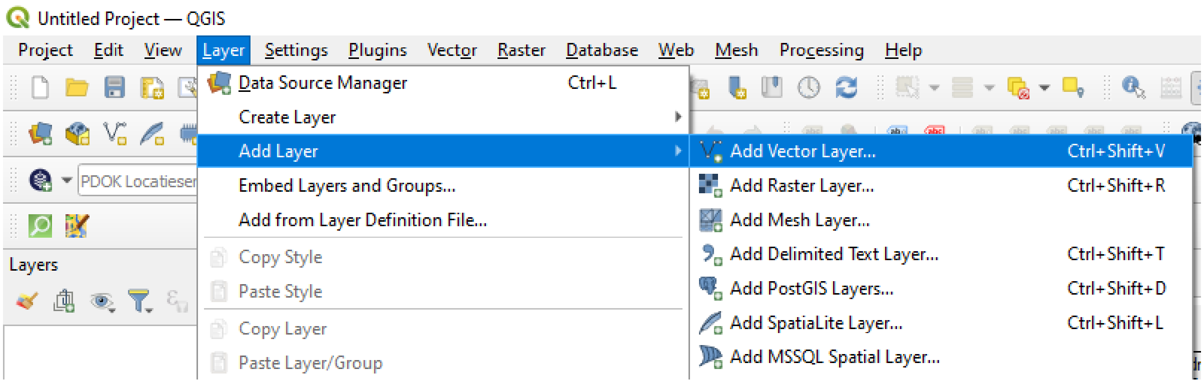
The functionality of the main buttons and fields is described below (per number). It can be slightly different depending on the version of QGIS you are using. The remaining sections in this part explain in more detail the required steps to create a hub desirability map.

1) Choose between "Vector Layers" or "Raster Layers" as the type of input data layers that will be used for the analysis. You can read more about the definitions of vector and raster data on the QGIS website. But in a nutshell, with raster you will be able to combine data that is not easy to represent in polygons, such as buffer zones around the bus stops.
2) Add or remove criteria from the criteria tree area (4)
3) Use the slider or accompanied value to change the weight for the corresponding main or sub-criterion.
4) This area shows all criteria as a tree, where the first level comprises the main criteria (11) and the second level the sub-criteria (12).
5) This button opens a new window where all slider settings can be loaded or saved for later use.
6) The relation between the data and the final desirability to place hubs can be switched from upwards to downwards, where upwards means that higher values of the indicator result in higher desirability and vice versa (for more information on the direction see Section 1.4 of this guide).
7) The "Criteria properties <<<" button expands this section where criterion-specific settings can be changed of the currently selected sub-criterion. It can again be minimized with the "Properties" button
8) The minimum and maximum value of the normalization settings (15) can be reset to the lowest and highest value of the input data.
9) This button will compile the hub desirability map. But before doing so it will open the "Overview Criteria Properties" window to ensure all criteria settings are set.
10) Collapse/expand all sub-criteria in the criteria tree area (4).
11) By default, there are 6 main criteria and their combined weight should add up to 100%. Increasing the weight slider (3) will result in a decrease in all other main criteria weights.

12) Each main criterion has a set of sub-criteria and their combined weight should add up to 100%. Increasing the weight slider (3) will result in a decrease of the other sub-criteria weights below that main criterion (11). Note that the weight percentage of each sub – criterion, represents its part of the main criterion, not its contribution in the overall objective (hub location). For instance, if Mobility has a weight of 23% and Trip density a weight of 55%, that means that Trip density will count as the 55% of this 23% in the final analysis.
13) When this setting is checked, the weights of all main and sub-criteria are changed to ensure their total adds up to 100%. Increasing a weight slider now will automatically decrease the weight of the other criteria.
14) Select a layer from the drop-down menu that should be linked to the current criterion. In the case of vector layers (1) a field also needs to be selected if there is more than one numeric attribute.
15) When checked, the "Min" and "Max" values will be used to normalize the input data. Unchecking "Normalization" will use the values from the input data directly.

2.3. Load input layers

All input maps should be added to QGIS. In most cases, data are provided as "Vector layers", which can be added from the "Layer" tab [Layer] > [Add Layer] > [Add Vector Layer]. Other input layers, such as "Raster Layers" can be added likewise. If you have no input layers available, you can make use of the demo input layers of Amsterdam, following the step-by-step guide in Appendix A. If you have vector layers available, that you like to have converted to raster layers, Appendix B can help for basic vector data.



2.4. Link input layers to subcriteria

If a sub criterion has a weight, the tool needs to know which data to use to perform the analysis. So, the input layers in QGIS need to be linked to the appropriate criteria. There is a built-in automatic matching approach invoked upon start-up of the plugin, or it can be done manually. Each criterion must be represented by a single layer. In the case of working with vector layers, they must have the same geometry, e.g. same zoning, but when working with raster layers they can have different geometry (shapes).

2.4.1. Automatic approach

Whenever the plugin is loaded, it searches for matching name pairs between the input layers and the sub-criteria. This means that all the layers should be named accordingly beforehand, which can be done by right-clicking the layer in the "Layers" panel and using [Rename Layer]. The indexing, for example C.1.1., can be omitted and the name comparison is not casesensitive. If the naming of a layer is changed after start-up, matching layers can be found by clicking the "search matching layer" button next to the layer selection in the criteria properties area.

2.4.2. Manual approach

An input layer can be linked manually by first selecting the sub criterion in the criteria tree and then selecting the desired layer in the criteria properties area. Note that the layer can only be a vector or raster depending on the mode. In the case of a vector, a corresponding field also needs to be selected if there is more than one numeric attribute. If there is only one field with numeric values then this is automatically selected upon changing the layer.

2.5. Change sub-criteria properties

There are some criterion specific properties that can be changed by first selecting the criterion in the criteria tree area, then the criteria properties area needs to be expanded to see the normalization settings and direction button.

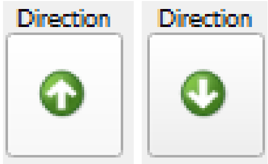
2.5.1. Normalization

The input data needs to be normalized before applying the weights to enable aggregation of criteria. This can be done in the normalization settings of the criteria properties area. By default, the minimum and maximum value of the data are used to normalize the attribute for all features linearly from 0 to 1. In the example below, the minimum and maximum value of the data are 0.00 and 297.53, respectively. The values can be set to any value, as long as the maximum value is higher. The "Reset" button will snap the values back the min/max values of the data, which will remain visible at all time in between brackets, next to the value boxes.

The normalization process can be disabled by unchecking the box in front of "Normalization. This will treat the input as already normalized for that criterion only. This is especially helpful if the data is normalized, but the features with value 1.0 have been removed in one map, but are still present in another.

2.5.2. Direction

When linking data to a criterion in this multi-criteria analysis, by default, a higher value in the input data will lead to a higher desirability to place a hub in that area. In some cases, one might want to reverse the direction of this relation, for example if transport equity is prioritized over transport demand, then the direction of the sub-criterion C.1.1. (Trip density) could be reversed, as the objective would be to build hubs in areas which currently produce and attract a lower number of trips (usually areas that do not have good connectivity or accessibility) to improve the situation there That would mean that a lower value of trip density would result to a higher desirability index. This can be done by pressing the upwards arrow in the criteria properties area.



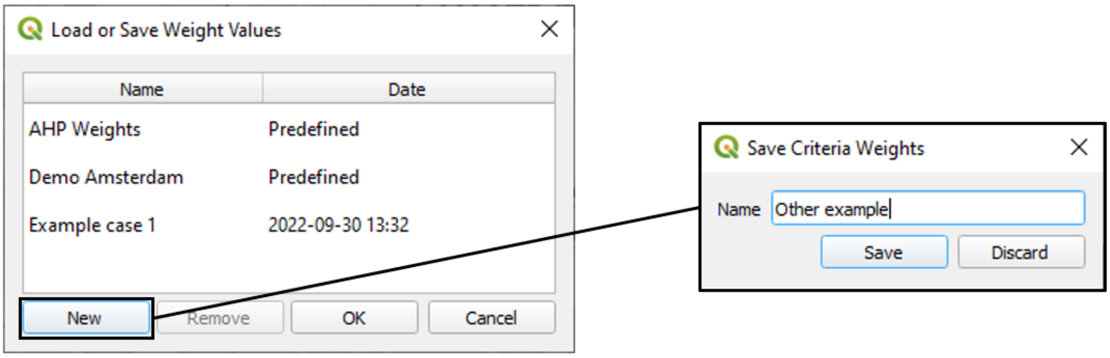
2.6. Set criteria weights

As explained in Part I (Section 1.5), the default weights have been determined by experts using the Analytic Hierarchy Process. The user can change the weights as desired by using the sliders next to the criteria, but this will mean the total sum of the weights is no longer 100%. To prevent this, the "auto-update to 100%" box can be enabled and if a slider is changed now, it will proportionally increase/decrease the other nonzero weights. Note, if a main criterion weight is changed, only all other main criteria will change and if a sub criterion weight is changed, only all other sub criteria below the current main criteria will be changed.

2.6.1. Save/load weight values

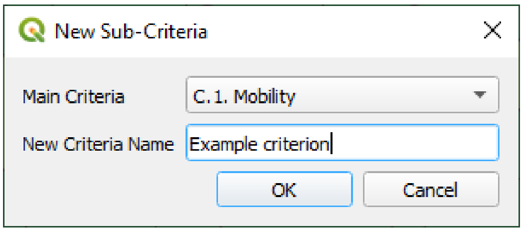
By pressing the "Load/Save weights" button, a window will pop-up showing previously saved weight settings, as can be seen in the screenshot below. Pressing the first option "AHP Weights", will enable all criteria in the criteria tree and set the weights to the predetermined default values for hub type A. The "Demo Amsterdam" case is a set of predefined weights to set slider values for when using the demo layers, see Appendix A.

Finally, there is the option to save a new case with the "New" button which will prompt a window to name the current weight values of all sliders. After saving, it will appear in the list accompanied by the date. These custom cases can later be removed by first selecting it from the list.



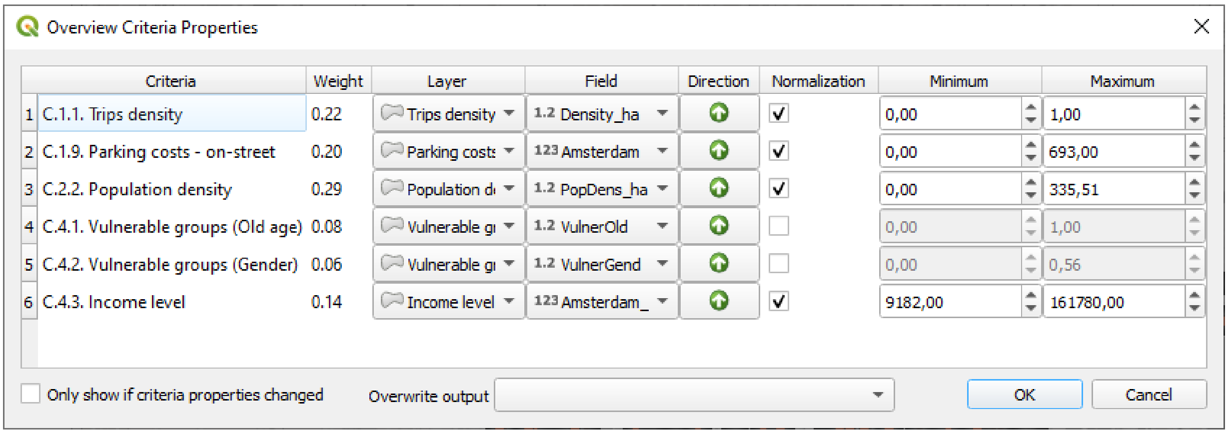
2.6.2. Add custom criteria

As mentioned earlier, the preset criteria in the tree have been carefully selected during the first year of this project. But to ensure the tool stays flexible, the possibility to add custom sub-criteria has been created. When pressing the + button above the criteria tree, the "New Sub-Criteria" window pops up, as shown below. The "Main Criteria" needs to be selected from the list and a unique name needs to be filled in, after which the new criterion will be added to the criteria tree with a weight of zero. If the weights are saved now, this new criterion is saved along with it. The criterion can be removed by selecting it and pressing the - button or by loading weight values of a case that does not have the newly added criterion.



2.7. Compile an output map

The compile results button either has the text "Compile Polygon Layer" or "Compile Heatmap", depending on the mode being set to "Vector Layer" or "Raster Layer", respectively. Clicking it for the first time will prompt the "Overview Criteria Properties" window similar to the one below.



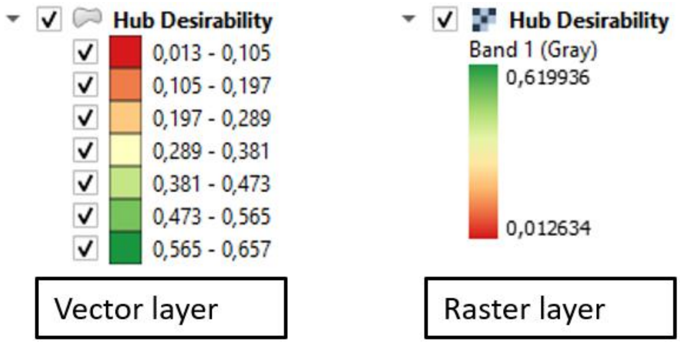
This overview shows all criteria properties for the sub criteria that are checked and have a nonzero weight. The second column shows the overall weight, after taking into account the weight of the main criteria. The remaining columns are similar to the properties in the criteria properties area. Changes here will only be used after pressing "OK" and "Cancel" will revert the settings to before clicking the compile button. Make sure there is a layer for each field.

2.7.1. Extra output settings

Below the table, there is a checkbox which can be enabled to prevent this window from popping up as long as no criteria properties are changed. This can be helpful when the user only makes changes to the weights and wants to see the final result without the overview popping up every time. Furthermore, the output can be overwritten on the previously created output map, by selecting one of the earlier created maps from the dropdown menu.

2.7.2. Output map layer

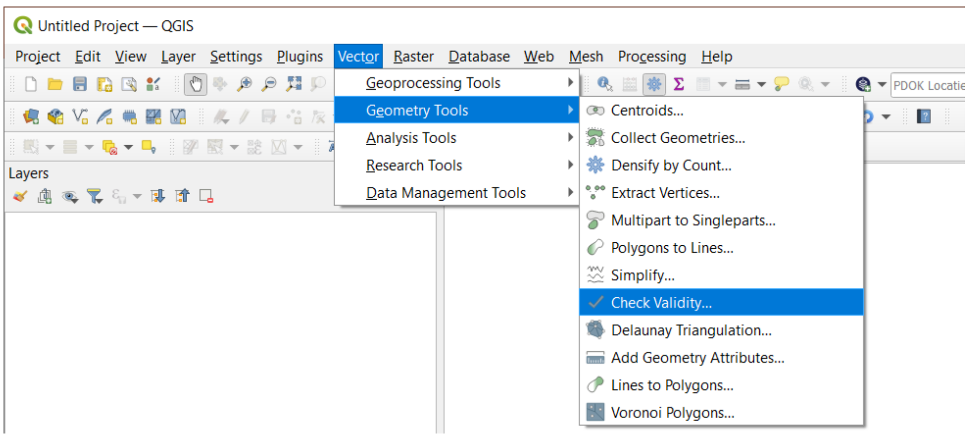
After pressing "OK" a new layer is created at the top of the layer tree in QGIS with the name "Hub Desirability". A red-yellow-green (RdYlGn) colormap is used to display the values from zero to the highest computed desirability. If vector layers were used as an input, then the output is a vector as well and the gradual categorization will create 7 discrete classes with equal interval by default. In the case of raster layers, a singleband pseudocolor render type is used with linear interpolation in the red-yellow-green colormap. Note, the maps are a temporary layer and need to be saved to prevent QGIS from discarding them after closing.



2.7.3. Invalid geometries

In the vector approach the "Union" algorithm from the [Vector overlay] Processing Toolbox in QGIS. In the case of polygons, it checks overlaps between shapes and creates separate features for overlapping and non-overlapping parts. The algorithm will not work with invalid geometries, prompting the error message "Feature (#) has invalid geometry…". The current version of the tool does not skip invalid geometries, so the invalid feature has to be found and removed.

One method to achieve this is with the "Check Validity" from the [Vector] > [Geometry Tools], as can be seen in the screenshot below. This algorithm will create three new layers, named "Valid output", "Invalid output" and "Error output". The latter two can be removed after inspection and "Valid output" can be renamed after which the user can continue with the plugin.



Appendix: Converting Vector to Raster layers

If the tool is used in raster mode, all vector layers need to be converted to raster. This can mostly be done with built-in QGIS tools. Which can be accessed from the "Processing" panel [Processing] > [Toolbox]. Depending on the geometry type and needs of the user, the conversion can have different steps. Below is the strategy for two common types of vector data.

Polygons:

1. Use "Rasterize (vector to raster)" from the GDAL Toolbox [GDAL] > [Vector conversion] > [Rasterize (vector to raster)]
2. Choose your Input layer and Field to use for a burn-in value
3. Use Georeferenced units and set the horizontal and vertical resolution, which is 100 meters in the example.
4. Assign a specified no data value. This has to be non-zero. If you type "nan" here it will change to 1e9 upon running the tool.

Points to heat map:

1. Use "Heatmap (Kernel Density Estimation)" from the Interpolation Toolbox [Interpolation] > [Heatmap (Kernel Density Estimation)].
2. Choose your Point layer.
3. Set a Radius, 400 meter in example.
4. Define the output raster size. Choosing more rows and columns or smaller pixel sizes will increase the resolution of the raster at the cost of increased computation time. For most purposes, 1000 columns/rows of the output raster will be sufficient.