



## The Georeferencing of Old Cartography in Geographic Information Systems (GIS): Review, Analysis and Comparative Study of Georeferencing Software

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**Abstract.** Contemporary organizations have faced the growing management of cartographic documentation, some of them of heritage interest. There are numerous institutions that are digitizing, georeferencing and publishing their historical cartography. The motivation of this research is to facilitate the choice of the most appropriate software to perform these tasks. This article carries out the critical review and analysis of four Geographic Information Systems (GIS) of full significance today. After systematizing the general characteristics and modules that must satisfy this type of application, we proceed to the detailed evaluation of the selected Geographic Information Systems, reaching as a result the discussion of the advantages that each one of them provides, of their distinctive characteristics, as well as their professional adequacy.

**Keywords:** Geographic Information System; GIS; Evaluation; Old cartography; Georeferencing.

### [es] La Georreferenciación de Cartografía Antigua en los Sistemas de Información Geográficos (SIG): Revisión, Análisis y Estudio comparativo de Softwares de Georreferenciación

**Resumen.** Las organizaciones contemporáneas se han enfrentado a una gestión creciente de la documentación cartográfica, algunas de ellas de interés patrimonial. Existen numerosas instituciones que están digitalizando, georreferenciando y publicando su cartografía histórica. La motivación de esta investigación es facilitar la elección del software más apropiado para realizar estas tareas. Este artículo lleva a cabo la revisión crítica y el análisis de cuatro Sistemas de Información Geográfica (SIG) de plena importancia en la actualidad. Después de sistematizar las características generales y los módulos que deben satisfacer este tipo de aplicaciones, procedemos a la evaluación detallada de los sistemas de información geográfica seleccionados, llegando a la discusión de las ventajas que ofrece cada uno de ellos, de sus características distintivas, así como de su idoneidad profesional.

**Palabras clave:** Sistemas de Información Geográfica; SIG; Evaluación; Cartografía antigua; Georreferenciación.

**Sumario.** 1. Introduction. 2. Methodology. 3. Results. 4. Discussion and conclusions. 5. Acknowledgements. 6. Agradecimientos. 7. Referencias bibliográficas.

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## 1. Introduction

Ancient cartography is not only a source of passive information, the fixed image of the evolution of a city or a territory or the mere representation of material facts (Calatrava and Morales, 2005). It is, and also represents, a broad metaphor for the material and mental life of human groups (Fimiani, 1985). Maps are not merely descriptive documents of history; they are also an active part of it. Their evolution and diversity exemplify what society has demanded from geographical and spatial representation systems in each historical moment. Their technical improvement, with the incorporation of elements such as the grid or the scale, reflect the modern aspiration to total control of space.

The digital revolution has led cartography to unprecedented levels of consumption (Cascón-Katchadourian; Ruiz-Rodríguez, 2016: 971). This revolution is marked by essential steps, including improvements in the treatment, dissemination and manipulation of cartography. This is due to the restitution by aerial photogrammetry in digitized cartography (Cortés-José, 2001: 39-113), successes achieved with Global Positioning Systems (GPS), and new procedures in composition, cartographic writing and map printing (Espíago, 2001: 183-220). To all this we must add the transformation that has resulted from the appearance of the Internet in both documentation and cartography (Jiménez-Pelayo; Bonachera-Cano, 2001: 223-266), which in turn has seen the appearance in the last decade and a half of global map servers such as Google Maps, Bing Maps, and OpenStreetMap among others.

All these advances have led to the emergence of easily accessible digital programs or platforms to view, compare and edit maps such as OpenLayers (OpenLayers, 2020), Leaflet (Leaflet, 2019), Carto (Carto, 2020) and Maptiler (Cascón-Katchadourian; Ruiz-Rodríguez, 2016). Thanks to these advances and georeferencing, ancient cartography is increasingly consumed today.

Georeferencing consists of determining the position of an element in a spatial coordinate system other than its own. Likewise, according to Dávila; Camacho, “the georeferencing process is determined by a relationship of positions between spatial elements in two coordinate systems, so that, knowing the position in one of the coordinate systems, it is possible obtain the homologous position in the other system.” (2012).

To perform georeferencing with a GIS of an old plan or map, it must start from its previous digitization, and it basically consists of identifying a place that we know is safely shared by both non-georeferenced cartography and georeferenced cartography, indicating to the GIS that both points are in the same coordinates. For this, it is key to be able to select places that have been preserved over time, such as landforms, monuments, streets (Figure 1). This makes it easier to georeference 19th and 20th century plans or maps that are geometrically more accurate (Figure 2)

than the more imprecise and schematic ones from the 16th and 17th centuries (Figure 3).

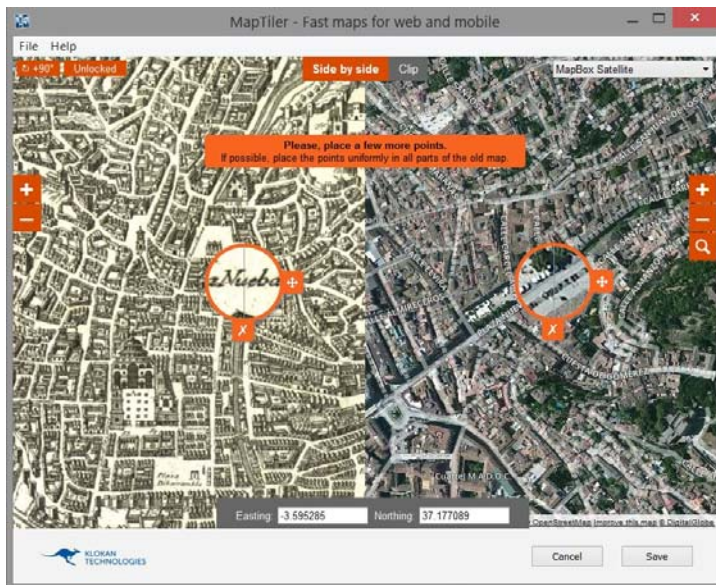


Figure 1. Assign location visually with places that have been preserved over time.  
Source: Maptiler.

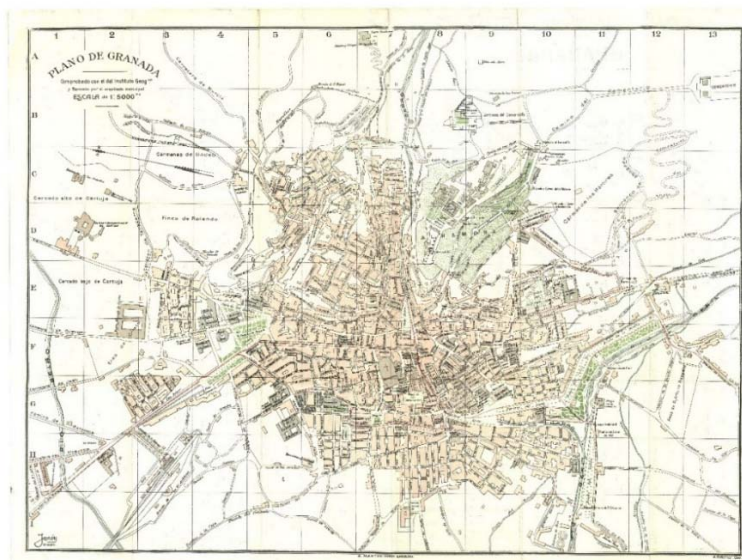


Figure 2. "Plane of Granada". 1914. Colomer. Fenoy. XX century.

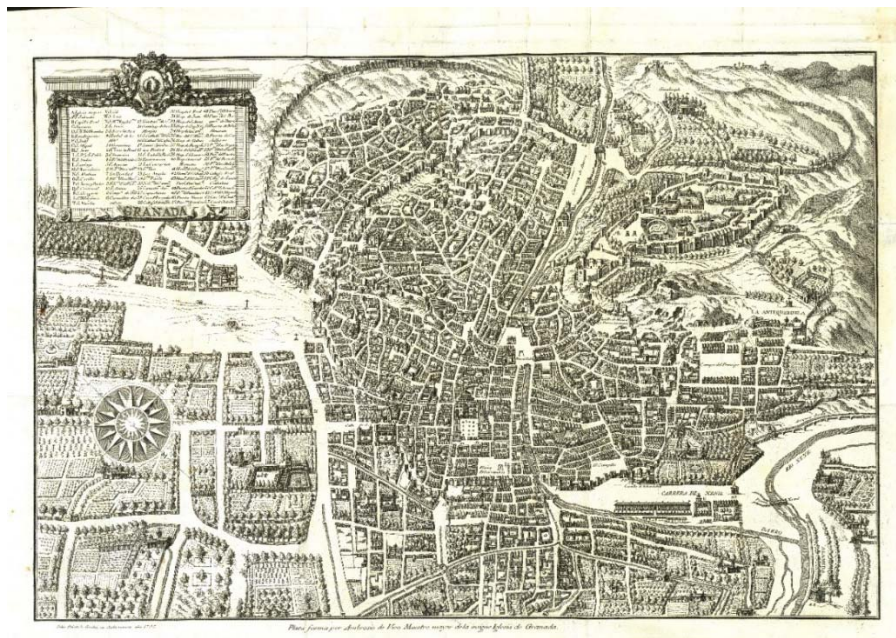


Figure 3. Plane “Plataforma of Ambrosio de Vico” 1590-1595. XVI century.

In general, the steps to follow to perform georeferencing using standard software are:

1. Add the image to be processed.
2. Choose a coordinate system or spatial reference system. If the image already has a coordinate system included as metadata, most software adds the coordinate system automatically. If not, it must be added through an external file or manually chosen from a list for this purpose.
3. Apply georeferencing itself. Again, the programs generally detect that the file comes with information about the geographical position and if so, they automatically capture it. If not, we can add it according to the following options:

a) Assign location visually: Programs usually show a screen divided in half, where on the left side it shows you the image without georeferencing, and on the right side an already georeferenced map of various web services. The mechanics consist of clicking on one map and the other, creating control points, technically similarities of place are established between both maps.

b) Other ways to add the coordinates are for example, “Load from external file” (World File, OziExplorer, MapInfo), this involves introducing the geographic coordinates through external files. Another common option is Bounding box (West South East North). A last option would be manual georeferencing by adding the coordinates.

4. Choose the tile format, the tile scheme, the resampling, the type of transformation and the format in which we want to save the georeferencing obtained.

Georeferencing allows users to locate in a current geographical situation, the old cartography, thus favouring both its contemporary comparison, and the renewal of the vision of the old cartography that remains in the archives, libraries and other cultural centres. At present, there are numerous institutions that are offering old georeferenced maps ready to be compared (Cascón-Katchadourian and others, 2018a; Instituto Geográfico Nacional, 2020a; Instituto Geográfico Nacional, 2020b; Institut National de l'information géographique et forestière, 2020), sometimes even allowing their collaborative georeferencing (British Library, 2020; Institut Cartogràfic i Geològic de Catalunya, 2020; National Library of Scotland, 2017; New York Public Library, 2020).

The specific software that has enabled all these updating processes have been the so-called Geographic Information Systems (GIS), a set of very diverse programs that cover both private desktop solutions such as ArcGIS or Geomedia of Hexagon; free software GIS solutions such as QGIS, gvSIG, Grass, Saga, MapInfo or others; online GIS applications such as Mapbox or Leaflet; and specific programs such as Klokantech's MapTiler or Georeferencer, which allow the georeferencing of cartographic documentation and its conversion into an interactive map layer that can be displayed in many different ways through the Internet.

This article is organized as follows. The Methodology section explains how the sample has been chosen, makes a brief description of the programs chosen, and lists the different fields analysed and evaluated. In the results a comparison is made between the described software tools. Finally, in the discussion and conclusions, a summary table is offered with the total sum of all the modules, the lessons learned from this study are noted and a conclusion is made with some observations.

## 2. Methodology

Due to the wide range of available Geographic Information Systems (GIS), the current research aims to give more precise knowledge of this software to allow a more informed choice. This is achieved with the analysis, comparison and evaluation of a representative sample of software solutions. These solutions may or may not be specifically dedicated to georeferencing or web publication of raster cartography map mosaic (ESRI, 2013a).

From the experience of the authors in the management of ancient cartography through the research project Histocarto at the University of Granada (Cascón-Katchadourian and others, 2019) (Histocarto, 2020), and from the results of precedent investigations where we identify the most significant points of evaluation for this software (Cascón-Katchadourian and others, 2018b), we proceed to the analysis and evaluation of four types of software which have been qualitatively selected. These four

different software are representative of the current existing options for georeferencing ancient planes or maps: QGIS, ArcGIS, gvSIG and Maptiler.

QGIS is an Open Source Geographic Information System (GIS) licensed under the GNU General Public License and is an official project of the Open Source Geospatial Foundation (OSGeo). It has been chosen as the leading open-source GIS desktop, therefore, the most representative of free software. QGIS works like a body to which add-ons are made. Some of these add-ons are official and others are developed by other users who are not official developers. In this case, its official georeferencing complement has been analysed and compared: GDAL Georeferencer.

ArcGIS for Desktop is the quintessential private desktop software, undoubtedly the best known and used of all GIS. ArcGIS is in fact a set of products, rather than just one, that are marketed under that generic name. It has been chosen for its popularity and for our provision of free licenses (v.10.2.2) to be able to be tested at the University of Granada. Georeferencing is done in ArcGIS through the Georeferencing module that comes as standard in ArcMap.

GvSIG is one of the most widely used free software-based GIS software, chosen as a leading example of existing GIS from the public sphere. This project which began in 2002, has been promoted by the Generalitat Valenciana, in particular by its 'Consejería de Infraestructura y Transporte' (Anguix; Díaz, 2008). In gvSIG georeferencing is performed through the Geographic Transformations menu when a raster view is opened, and once inside the georeferencing submenu is selected.

Finally, MapTiler completes the selection of software representative of the existing options. Developed by the Klokantech company which specializes in the development of mapping projects with many institutions, it is chosen as a singular example of those GIS solutions specialized in georeferencing cartographic documentation and turning it into an interactive map layer to be displayed via the Internet.

The evaluation of the four selected software tools has been developed from the following six specific fields of analysis: (1) general features, (2) compliant standards and metadata, (3) inputs and outputs, supported WMS/WMTS services and reference systems, (4) control points (5), raster transformation types and resampling methods, and (6) facility for georeferencing and web publishing.

For the selection and graduation of the evaluation elements the previous article 'Georeferencing and web publication of ancient mapping in geographic information systems: requirements for its evaluation and a case of study' (Cascón-Katchadourian and others, 2018a) was used as a base. Within this article the list of those items that a GIS software must comply with when correctly geo-referencing was exhaustively detailed, as well as the steps and fundamental decisions needed to carry it out satisfactorily.

The segmented results of our analyses are shown below, organized in a specific results table, completed with values 0-1 or 0-3 according to the selected field of analysis. A final cumulative table of scores obtained in the set of six analysed fields is offered and discussed.

### 3. Results

#### 3.1. General characteristics of the product

The general characteristics section includes the analysis of three elements that greatly influence the access of users to each software (price, cross-platform availability, and languages), in an evaluation of 0-3 (Table 1).

A first condition for the use of a specific type of software is its price. In this aspect we award the highest score (3) for free and/or open-source software, and the lowest score (0) for very expensive proprietary software.

A second feature to consider for user access is the number of platforms (operating systems) where the software can be installed. In this case, the highest score (3) is given to availability for four or more operating systems, and the lowest score (0) for a single operating system.

The third and last feature analysed is the languages offered by the software interface. In this case the lowest score (0) is given when it is only available in one or two languages, and progressively higher scores are awarded depending on the number of languages available, and on whether those languages are in the majority.

With these features in mind, both QGIS and gvSIG achieve the highest score by displaying all the features: both are free, open source, can be installed on Windows, Mac and Linux, in addition to having light versions on Android and being available in more than twenty languages, including all the major ones.

Arcgis and Maptiler achieve lower scores, due to both their high prices (more in the case of Arcgis) and their low cross-platform availability: in the case of Arcgis because it can only be installed on Windows without emulators or partitions, and in the case of Maptiler, for not having a light version available for mobiles, and lack of languages (available in English only).

Table 1. Valuation of general characteristics. Source: Own elaboration.

Software	PRICE	MULTIPLATFORM	LANGUAGES	TOTAL
<b>QGIS</b>	3	3	3	<b>9</b>
<b>Arcgis</b>	1	0	3	<b>4</b>
<b>Gvsig</b>	3	3	3	<b>9</b>
<b>Maptiler</b>	2	2	0	<b>4</b>

#### 3.2. Compliant standards and metadata

This section is divided into the evaluation of the descriptive standards (3.2.1), and the OCG standards (3.2.2) that each program meets. The graduation results are as follows: (0-1) either support the standard, in which case the program receives a 1, or do not support it in which case the program receives a 0.

### 3.2.1. Descriptive Standards

The second table shows the comparison of the four different types of software with the main descriptive metadata standards that, according to the authors, should have GIS software. From the perspective of the authors it is believed that a GIS, as an information system, should provide tools for, describing information of a geographical nature. This section positively evaluates that metadata can be viewed, edited, validated, exported and imported.

The first standard of the table is the ISO 19115 metadata. Cartography as geographic information is a documentation with its own characteristics. It has elements such as the scale, the projection, coordinates or a cartographic reference system which require a separate standard for their description. In order to define a structure for describing geographical data, this international standard was created, which provides a model and establishes a common set of terminology, definitions and application procedures for metadata (Sánchez-Maganto and others, 2008).

The second standard to be discussed at is Dublin Core, created in 1995, which is the most widely used meta-information scheme in the world. It is also ISO 15836, and consists of 15 basic elements to describe any information object. These are useful metadata for optimising the search via the Internet of geographical information hosted on the Web (Escriu-Paradell, 2004).

The third standard is the Content Standard for Digital Geospatial Metadata (CSDGM) of the United States Federal Geographic Data Committee (FGDC), a metadata standard for Geographic Information (Sánchez-Maganto and others, 2006). The union and harmonization of this standard and other formal standards gave rise to ISO 19115.

Finally, under the *other* item the software achieves a score of 1 if it supports other types of standards and description standards such as ISAD (G), ISBD, MARC 21, MODS or if it is able to automatically fill in the technical metadata.

In reference to the results in Table 2, nearly all the GIS show weaknesses in this section. Arcgis does not, thanks to the Arccatalog tool for creating and maintaining metadata supports ISO 19115 and FGDC including features such as validation, import and export (Morales, 2014). In addition, Esri Geoportal Server supports a wide variety of standards such as FGDC, INSPIRE, Dublin Core, etc. Finally, QGIS supports metadata through external add-ons such as Metatool (QGIS, 2016), which includes ISO 19115 and FGDC or Qgsprojectmetadata (QGIS, 2018) which support Dublin Core.

Gvsig and Maptiler do not perform well in this sub-section. Maptiler does not work with metadata because it is not specialized in archive description. In the case of Gvsig, although it did have metadata editors in previous versions, these have not been implemented in the core of the product at the time of this analysis (June 2020).



Table 2. Valuation of descriptive standards. Source: Own elaboration.

Software	ISO 19115-19113	DUBLIN CORE	FGDC (CSDGM)	OTHER	TOTAL
<b>QGIS</b>	1	1	1	0	<b>3</b>
<b>Arcgis</b>	1	1	1	1	<b>4</b>
<b>Gvsig</b>	0	0	0	0	<b>0</b>
<b>Maptiler</b>	0	0	0	0	<b>0</b>

### 3.2.2. OGC Standards

The third table shows the standards of the Open Geospatial Consortium (OGC). This consortium consists of companies, organizations, GIS software developers, states and universities. The OGC was founded in 1994 to make geographical information an integral part of the global information infrastructure. To this end, they are responsible for developing interface standards, associated standards and good practice guides aimed at helping to create information systems that can exchange geographic information with other information systems, that is to say, that are interoperable (Open Geospatial Consortium, 2020).

They have developed a large number of standards (Osgeo, 2014) the most important being WMS (Web Map Service), WFS (Web Feature Service), WFS-T (Web Feature Service-Transactional), WCS (Web Coverage Service), WMTS (Web Map Tile Service) (Web Processing Service), SOS (Sensor Observation Service), CSW (Catalogue Service for the Web).

In this section, of the four GIS evaluated, three have obtained the highest score: QGIS, ArcGIS and gvSIG. All meet various consortium standards either through cores or add-ons. As an example, ArcGIS complies with TMS through ‘ArcBruTile’ (GitHub, 2020), SOS through ‘52 norte’ and CSW through an open-source CSW client (ArcGIS Enterprise, 2020).

MapTiler does not support the following standards: WFS-T, WPS, SOS, because they do not fall within the program's role. It supports WMTS and TMS, and the rest are supported as program input files (MapTiler, 2020a).

Table 3. OGC standards valuation. Source: Own elaboration.

Software	WMS	WFS	WFS-T	WCS	WMTS	TMS	WPS	SOS	CSW	TOTAL
<b>QGIS</b>	1	1	1	1	1	1	1	1	1	<b>9</b>
<b>Arcgis</b>	1	1	1	1	1	1	1	1	1	<b>9</b>
<b>Gvsig</b>	1	1	1	1	1	1	1	1	1	<b>9</b>
<b>Maptiler</b>	1	1	0	1	1	1	0	0	1	<b>6</b>

### 3.3. Inputs and outputs, WMS/WMTS services and supported reference systems

In this section, different items that intervene to facilitate georeferencing have been combined in the same table (table 4) with scores of 0-3. High scores are awarded to the larger number of inputs/outputs that are supported, the more WMS/WMTS services which are supported, and the more coordinate systems there are. The ease of use for different types of users will also be awarded a higher score. If these criteria are not met, they receive the lowest score (0).

As for inputs or outputs supported, it evaluates the raster file formats that are opened, visualizes and is able to edit the program. Software interoperability or its ability to exchange information with other programmes is also measured.

Furthermore, it also evaluates the number of file formats in which the program is able to save the georeferenced raster. It should be noted that these rasters have to carry with them the information of the coordinates, of the projection either as metadata within the Geotiff format, or as an auxiliary file that is located in the same folder as the georeferenced file. The more file formats that can be opened or saved the higher the score the software receives in this section.

It is clear that this is an item that has been well solved by the software as each one is awarded the maximum score. QGIS opens 72 categories of raster files, some of them such as the GDAL (GDAL 2020) open approximately ten different file types. The georeferenced file is saved in geotiff and can then be converted to one of the above 72 categories. Arcgis (ESRI, 2019a), gvSIG (2017) and Maptiler (2019a) support a large number of raster files and allow these files to be saved once georeferenced in multiple formats. In the cases of Arcgis and gvSIG in some formats the georeferencing information goes in the file header (ERDAS IMAGINE, BSQ, BIL, BIP, Geotiff and grids). In other formats a georeferencing file with the same name as the georeferenced file is added by adding a W (ESRI, 2019b). Maptiler is oriented to the web publishing of files, so it creates a 'folder'. This is a folder structure which contains an html document. It also allows Mbtiles or Geopackage or includes it within the cloud either directly or from a mobile device.

As far as the WMS (Web Map Service) service is concerned, it is understood that this service facilitates georeferencing, particularly for information professionals who do not have access to digitised reference mapping to support the process. In this item it is evaluated whether the GIS comes with a complement that makes maps available for streaming, usually with the standard of the OCG (Open Geospatial Consortium) called WMS, although other services such as WMTS and TMS will also be evaluated. It also values the number of commercial maps it uses, such as Google Maps, Bing Maps, Map Quest, OSM/Stamen, Apple Maps, Mapbox, Mapquest, Strava, Tianditu. It also allows users to access WMS servers manually by adding the URL.

In this analysis QGIS stands out with the maximum score over the other 3 types of software that receive 2 points (Table 4). Each software has the option to manually enter the URL. QGIS comes in first place due to the complements it contains to facilitate this work, such as Open Layers Plugin or the most

recommendable Quick Maps Services (Nextgis, 2015). It stands out for the large number of reference cartography available, for its fluidity compared to Arcgis (Arc Bru Tile) and for the ease of adding different layers that are automatically incorporated into the proposed area. Both Arcgis and gvSIG have a series of default suppliers in their cores, however these have fewer external map services, especially gvSIG. On the other hand, the latter is more fluid than Arcgis, so both have the same score.

Maptiler works in a different way, by georeferencing an image, the screen is directly divided into two and in one of them Google Maps Streets appears. The user is able to choose between 5 options, the aforementioned one from Google and its Roadmap, Satellite and Terrain versions and an Open Street Map version. Although the number of options is limited, the ones available are fundamental. It is also more intuitive than the others.

Finally, when a raster is georeferenced, it has to be given a reference system for destination coordinates; normally the reference system of the supporting raster has to be introduced. It is agreed that it should have as many as possible and that the search system for them is simple and efficient.

Similarly to the previous item, all analysed GIS get a good score here, although gvSIG is somewhat behind. All offer an infinite number of coordinate systems and possess the most common. Likewise, the most used or recent coordinate systems stand out from the rest. Although QGIS, Arcgis and Maptiler have the highest scores, the latter is more intuitive, offering various types of searches according to country, code and coordinate system or by EPSG/ESRI offline database or UTM. The other two GIS are also very complete allowing for textual searches and browsing. In the latter the coordinate systems are sorted by folders and the user is able to choose from a list. It is this last option that gvSIG does not possess so it is awarded a score of 2.

Table 4. Inputs and outputs, WMS/WMTS services and supported reference systems.  
Source: Own elaboration.

<b>Software</b>	<b>Inputs/outputs supported</b>	<b>WMS/WMTS Services</b>	<b>Coordinate system</b>	<b>Total</b>
<b>Qgis</b>	3	3	3	<b>9</b>
<b>ArcGIS</b>	3	2	3	<b>8</b>
<b>GvGIS</b>	3	2	2	<b>7</b>
<b>MapTiler</b>	3	2	3	<b>8</b>

### 3.4. Points of control

Subsection georeferencing by coordinates or relying on maps is a fundamental point because a GIS must allow both options for its users. Georeferencing is carried out using two procedures: 1. By entering the coordinates manually; typically with coordinates X and Y in degrees, minutes and seconds, or with coordinates projected in metres. 2. Relying on a map or with reference cartography, that is to

say, with the support of a map that is georeferenced; this technique consists of clicking on the raster to be georeferenced and on the georeferenced raster and establishing control points for the same geographic location.

All GIS allow both possibilities, which are perfectly integrated, to serve different users. In fact, it is the first thing that the software requests when the process is started. Maptiler is the most complete in this aspect, allowing multiple options for georeferencing (see figure 4). All allow the entry of control points that have been previously saved.

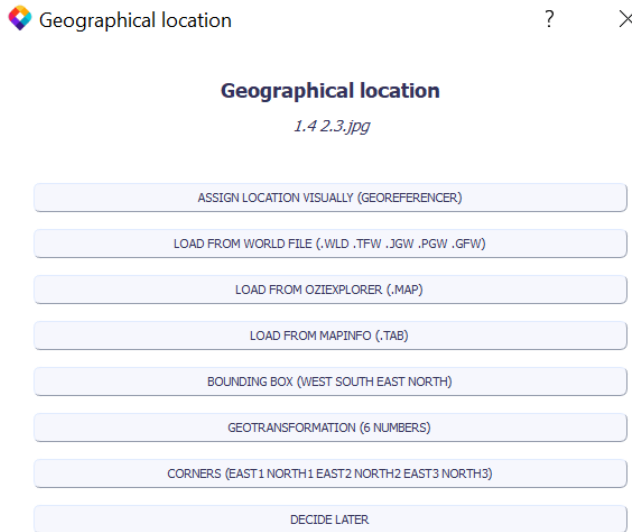


Figure 4. Georeferencing options. Source: Maptiler

The item 'Possibility of saving the control points' evaluates the possibility of saving the control points that have been generated by georeferencing a raster, to be accessed at a later date. Among other things, it is useful for saving time in contexts where georeferencing is being tested. For example, to discover the type of transformation and type of resampling that give better results with this raster and to discover how many control points should be entered, 10 or 15. To test all these possibilities it is very useful not to have to re-enter the control points and to be able to add those that had previously been saved.

All evaluated programs allow saving control points except Maptiler which allows saving the project (not strictly points) but only in the pro version, which is the most expensive, therefore it has been given a score of 0. Each program saves points as an external file, but with a different file format; QGIS as GCP file (.points), Arcgis as world (.wld) and GVSIG as a metadata file attached to the raster but it also allows exporting in CSV format. Therefore, these saved points can only be opened in the same software, except the Arcgis format that Maptiler opens.

The last item in this section is called ‘Automatic calculation of the next point’. This is a very useful tool in the georeferencing process, since it saves a lot of time, initiating only when georeferencing occurs with a supporting map. Once three of the control points are linked between the two maps, the fourth point is introduced in either one of the maps and the program automatically points out where it should go by triangulation on the other map. Logically, this tool must be accompanied by the possibility of modifying that point.

This item is not implemented in desktop GIS software, it is only included in Maptiler. QGIS and gvSIG do not include it and Arcgis allows automatic georeferencing of the dataset raster with a reference dataset raster, without introducing any checkpoints. However, this tool is intended for aerial and satellite images, and does not work well with scanned maps or historical data (ESRI, 2019c).

Table 5. Valuation of control points. Source: Own elaboration.

Software	Georeferencing coordinates or relying on maps	Possibility of saving control points	Automatic calculation next point	TOTAL
<b>QGIS</b>	1	1	0	<b>2</b>
<b>ArcGIS</b>	1	1	0	<b>2</b>
<b>GvSIG</b>	1	1	0	<b>2</b>
<b>MapTiler</b>	1	0	1	<b>2</b>

### 3.5. Types of transformation of the raster and methods of resampling

#### 3.5.1. Types of Raster Transformation

In the georeferencing process, once the control points have been assigned, it is time to choose the type of raster transformation to be performed before running georeferencing. This subsection assesses the types of transformation that the software has, and whether or not it has the fundamentals to offer solutions to users with different types of documentation (ESRI, 2013b). This table (Table 6) has no gradation, either it has the type of transformation analysed in which case it is given a 1 or it does not, in which case it is given a 0.

With the exception of gvSIG, the rest of the GIS have scored full marks in this subheading, which is a result of the importance given to the types of raster transformation. Each GIS names each type of transformation differently, there is no uniformity, even the same type of transformation has different names in each software.

In spite of this, as reflected in the table (table 6), in the first column all the analysed GIS possess the Polynomial transformation (with its different versions 0, 1, 2, 3), surprisingly, Maptiler only offers the Third Polynomial (unless it adapts the order of the polynomial according to the control points being introduced) (Maptiler, 2020b). In the case of Thin Plate Spline in the second column, Gvsig is the only software which does not possess it. In the third column, the remaining types of processing considered to be the most relevant have been added. Possessing

one of these types is awarded a 1. In addition to the 2 previous types QGIS, the most comprehensive software in this aspect, offers Linear, Herlmet and Project transformations (QGIS, 2020a). Arcgis offers Adjustment or Projective transformation (ESRI, 2013b) while Maptiler offers Scaled, Similarity and Affinity transformations. Gvsig offers only two types of transformation; the Polynomial and the Afin, adding some confusion to the sub-paragraph since affinity is also called First Order Polynomial (Gvsig, 2020).

Table 6. Valuation of the types of processing of the raster. Source: own production.

Software	Polinomial	Thin Plate Spline	Projective, linear, similarity	TOTAL
QGIS	1	1	1	3
ArcGIS	1	1	1	3
GvSIG	1	0	1	1
MapTiler	1	1	1	3

### 3.5.2. Available resampling methods

When georeferencing is carried out, the geometry of the raster image is usually modified. Vector elastic deformations are produced, projections changed, translations and rotations included, etc. As a result, it is very rare for the cell centres of the input raster to coincide with those of the output, so resampling must be carried out (ESRI, 2013b).

Each resampling method is chosen for its appropriateness for a particular task. The three most commonly used are (ESRI, 2013b): Nearest Neighbour, Bilinear Interpolation and Cubic Convolution (Getreuer, 2011). The first usually generates a sawtooth effect on the lines, the second blurs the contrasts and the third is the best for historical mapping (Dávila; Camacho, 2012). It is assessed to have these three or others less commonly used such as Majority, which tends to provide smoother results than Nearest Neighbour; Cubic Spline, which is usually used for the adjustment of a curve with continuous derivatives from a discrete set of data (Escudero; others, 2016); Lanczos, which is useful for graphics (Turkowski; Apple Computer, 1990), and others such as Reverse Distance (Gabri, 2018), Average or Mode.

Again, all the analysed GIS obtain good scores (table 7), only gvSIG does not get the maximum score by not possessing the Cubic Convolution which is the most interesting for this study, although it does possess one of the 'other' methods of resampling: Reverse Distance.

The remaining Software have the three main resampling methods and Arcgis adds as extras Majority; QGIS Cubic Spline and Lanczos; and Maptiler is the most complete as it includes Cubic Spline, Average and Mode.

Table 7. Valuation of available resampling methods. Source: Own elaboration.

Software	Nearest Neighbour	Bilinear Interpolation	Cubic Convolution	Others	TOTAL
QGIS	1	1	1	1	4
ArcGIS	1	1	1	1	4
GvSIG	1	1	0	1	3
MapTiler	1	1	1	1	4

### 3.6. Facility for georeferencing and web publishing

In this section, different items that allow such graduation have been combined in the same table (table 7) with scores of 0-3. Two of them refer to web publishing and one to georeferencing. All three are related to how intuitive or easy it is to carry out these processes. A higher score (3) will be awarded the more different types of web publishing the software offers and the easier and more intuitive the processes. Otherwise, the score will be lower (0).

The first item evaluates the ‘Types of Web Publishing’ which offer GIS to users. It is therefore appreciated at this point that the program offers various ways to publish on the web, provided that they offer different solutions for different users' needs. It could be when working in the cloud, that the program creates a local folder structure to upload to the server, etc.

This item is well addressed by all the GIS analysed. The highest score is obtained by Maptiler, both for the different types of outputs it generates, and for the multiple options it offers to each type of user (Figure 5). Maptiler has its cloud version called Maptiler Cloud but the free version only allows uploads in Mbtiles and with a limit of 100 megabytes (Maptiler, 2020c).

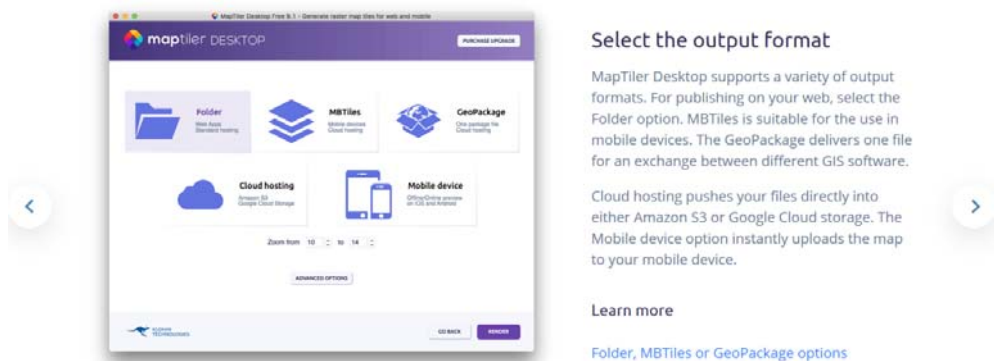


Figure 5. Types of output that Maptiler allows. Source: Maptiler.

The rest of GIS receive the same score, but for different reasons. QGIS offers multiple options: QGIS Server (QGIS, 2020b), QGIS Cloud (QGIS Cloud, 2020), and various program add-ons such as Qgis2leaf, open layer geo that allow you to

publish as a leaflet (Leaflet, 2019). Although it gives many options for different users, there are very few to publish raster, and they are only oriented to vector layers (Mappinggis, 2019).

A similar situation can be seen with Arcgis. It offers two fundamental types of publishing documentation; Arcgis Enterprise, which is the evolution of Arcgis for Server (ESRI, 2019d) and Arcgis Online that runs on a cloud infrastructure managed by Esri in a Software as a Service (Saas) model. The latter has limitations on uploading raster data.

Finally, the gvSIG Online platform for the implementation of Spatial Data Infrastructures (SDI) possesses the following positive points; it allows the sharing of geographic information in the cloud, it is based on standards (WMS, WFS, etc.) for generating maps and applications thanks to its system management tools, and it works with Geotiff. However, it lacks the ability to generate the folder structure to upload to your server as does Maptiler and connections with others complements like QGIS.

The item 'Georeferencing facility. Intuitive' groups those issues that make the process of working with a GIS simpler, more comfortable and more intuitive:

- Easy to activate the georeferencing plugin (if not active with the standard package) and access it from the main software interface.
- Allow georeferencing by coordinates written manually or with a reference map.
- If working with a reference map, make it easy to add to the georeferencing process.
- If working with reference map, both the image to be georeferenced and the supporting georeferenced image are in the same visual panel, not shown separately and layers must be turned on and off.
- When adding control points, which can be inserted and zoomed at the same time, users do not have to choose the zoom tool or mark point, with the consequent loss of time.
- Automatic calculation of the fourth point and following, as seen above.
- It has supporting documentation that explains the process of georeferencing step by step, websites, videos, etc.

In our analysis Maptiler obtains the highest score (Table 8), while the other GIS tie with two valuation points. We conclude that the four GIS analysed are globally intuitive and easy to use even though georeferencing is a complex process.

Maptiler is a program specializing in georeferencing, therefore, there is nothing to activate. Users are simply given the option 'Standard tiles', add the image to georeferencing and the software asks if we want to georeference visually or enter the control points manually or by file. The screen is automatically split in two and a commercial map is displayed as a reference map, although other maps can be chosen. The control points are introduced with a single click while you can zoom in with the mouse or pad. It automatically calculates the 4 points and the following by clicking on one of the two maps. It allows georeferencing in parallel or with one image on top of another with transparencies. On the website there are videos and documentation explaining the process. As an extra, the commercial map has a



textual search engine to directly search the area to be georeferenced. The maximum score has been given because, from the perspective of the authors, is the most advanced of systems for georeferencing.

In QGIS it is necessary to first activate the GDAL georeferencer plugin and then open it. It allows georeferencing by coordinates or with a reference map, which is called 'from map canvas'. It offers two options: 1. Both images are in the same visual panel. Within this option it is possible to click on the raster to georeference and then zoom in on the support georeferenced raster and then click. 2. Both images should not be in the same visual panel. Reference mapping should be searched and added to the process. Although the whole process is explained on the QGIS website. It does not predict the fourth and following point. Therefore, it scores a 2.

In Arcgis the process is done through ArcMap. Once you open a new project and add the image to georeferencing, simply click on imagery and georeference. Arcgis has a base map as reference cartography. It allows georeferencing with a reference image or manually. It does not allow georeferencing images in parallel, seeing both in the viewer as gvSIG, Maptiler and Qgis do. It is therefore necessary to spend time adding the points, by activating and deactivating the layers. In turn, it facilitates georeferencing by bringing the layers closer together with a fit-to-display device and automatically allows users to play with the transfer to facilitate the process. The control points are added with 'add control points'. It does not predict the fourth point or following. It has positive points and negative points; it gets a 2.

GvSIG opens a new view and adds the image to georeferencing and the reference image. It shows the raster layer symbol, geographical transformations and within that georeferencing, which is not very intuitive. It allows georeferencing with or without reference cartography. With reference mapping the screen opens directly divided into 4, the two main ones and below on both sides the zoom of the central part of each layer, which facilitates the process.

Adding control points is not intuitive, they appear as 'registration' and it does not calculate the fourth and following points. However, it does allow you to zoom in and add points without having to change tools. On the web there are videos and instructions that explain the process (Maciá-Martínez, 2017). For these reasons the final score is 2.

In the last item analysed, 'Facility for Web Publishing. Intuitive', several concepts are evaluated:

- That it is not necessary to know code or programming in order to make the web publication.
- That there is no need for heavy configurations of the servers, more typical of large companies.
- The process is explained in the program documentation.
- Both raster and vector data can be easily published.

The maximum score would be achieved by software whose end result would be a folder structure ready to upload to the server with an ftp, or a simple, high-performance cloud application. In web publishing Maptiler and gvSIG get the best score.

In Maptiler, once cartography has been georeferenced, the program offers various publication alternatives. Folder is the main one, this option and the others only request the user to name a directory where the result is to be saved, the rest is taken care of by the program, which creates the index and folder structure ready to upload to ftp. There is no need to make configurations or write lines of code. The process is explained on the program's website with video tutorials. Maptiler Cloud also allows users to upload to the web raster easily by paying a fixed quota per month. Maptiler Desktop would be oriented for users who want to upload documentation to their own website and Maptiler Cloud for users who want to upload their data to this platform.

Gvsig only offers gvSIG Online. After the appropriate tests it is observed that its use is intuitive and does not require any configuration or programming knowledge. Quality information has been found on the web (Gvsig, 2020b) and clear tutorials on youtube (Gvsig, 2020c) on the functioning of the gvSIG Online platform. It includes updated information and is available in Spanish. Although some functionality is lacking compared to Maptiler, what is offered is intuitive.

In the case of QGIS and Arcgis, they both receive a score of two. Although both have different tools to be able to publish vector cartography easily, with raster cartography it is more complicated, both because of insufficient storage capacity and because of arrangements through writing codes that are not intuitive. Although QGIS offers many options, few allow Raster and those that do, do not have easy configurations. With Arcgis a similar situation occurs. Arcgis enterprise allows raster but it is complicated to use and Arcgis online is very limited for raster in exchange for being easy to handle.

Table 8. Valuation facility for georeferencing and web publishing. Source: own elaboration.

<b>Software</b>	<b>Web publishing types</b>	<b>Georeferencing facility. Intuitive</b>	<b>Web publishing facility. Intuitive</b>	<b>Total</b>
<b>QGIS</b>	2	2	2	<b>6</b>
<b>ArcGIS</b>	2	2	2	<b>6</b>
<b>GvSIG</b>	2	2	3	<b>7</b>
<b>MapTiler</b>	3	3	3	<b>9</b>

#### 4. Discussion and conclusions

The summary table of the set of previous results is offered below, with the partial scores of each program in each module, and the total sum of these, in order to carry out the discussion and comparative analysis of the final result of each program (Table 9).

In this summary table of the set of results achieved section by section, it is found that there is a GIS that stands out from the rest, meeting each and every one of the proposed analysis and evaluation items, obtaining a final score of 45 out of 50 possible points: QGIS. The rest of the GIS are in a second scoring level, slightly staggered one after the other, highlighting Arcgis as the one that gets the best score (40), relegating gvSIG (38) and Maptiler (36) in third and fourth place.

Table 9. Summary table. Source: own elaboration.

Software	QGIS	ArcGIS	GvSIG	MapTiler
<b>General characteristics</b>	9	4	9	4
<b>Descriptive Standards</b>	3	4	0	0
<b>Table of OGC standards</b>	9	9	9	6
<b>Input/output formats, etc.</b>	9	8	7	8
<b>ControlPoints</b>	2	2	2	2
<b>Types of raster transformation.</b>	3	3	1	3
<b>Available methods of resampling.</b>	4	4	3	4
<b>Types of publication, etc.</b>	6	6	7	9
<b>Total</b>	<b>45</b>	<b>40</b>	<b>38</b>	<b>36</b>
<b>Theoretical total</b>	<b>50</b>			

The four GIS covered by this review, analysis and evaluation illustrate the wide range of alternatives in this market. Each of the existing solutions are generally oriented towards a specific business or organizational sector. Its usual modular architecture and scalability configure a rich ecosystem of solutions to choose from. It depends on whether the organization or institution interested in adopting them needs to cover a wide variety of workflows or only the specific functionalities to be satisfied, as well as the cost willing to be covered, the election should lead to one or the other of the existing options. In summary, there is no GIS that is the best at everything or the best for all users. Rather the opposite as each product is suitable for a particular sector or user.

As the results of the present investigation demonstrate, the four GIS analysed are undoubtedly satisfactory and generally appropriate in relation to the set of characteristics and functionalities evaluated, even though the range of results achieved underlines and emphasizes both the identity of each one of them, and the focus and organizational segment to which each one is primarily directed.

As a general summary, the results allow us to conclude the overall satisfaction with QGIS, this software shows an excellent all round performance. On the other hand, Arcgis gives a remarkable performance although its main weaknesses are the price and the platforms where it could be installed. Finally, gvSIG and Maptiler are located at the bottom of the table with gvSIG having to improve its descriptive standards and the types of transformation of the raster that it offers, while in the case of Maptiler improvements are needed in the languages in which it is available, the descriptive standards it offers, as well as the OGC standards.

Below we will highlight the questions that we found most interesting or surprising when analyzing the results:

First of all, we are surprised that Arcgis, which is the leading GIS in the private sector, is only available in Windows, this is a point that should be improved. Equally unusual is that Maptiler is only available in English because the interface is so simple that it would not require great effort to implement other widely used languages.

Secondly, from our point of view as documentalists and information professionals, it is curious to observe how all the GIS, except for Arcgis, do not do well with metadata, it is another point that could be improved with minimal effort.

Furthermore, considering that the most time-consuming element of the georeferencing process is the introduction of the control points, a critical point of improvement of the GIS, except in Maptiler, would be to incorporate the automatic calculation of the next point on each one because of its limited technical complexity.

Moreover, we see it as a positive point that all GIS score well on transformation types, resampling methods, coordinate systems, as well as on supported inputs and outputs and WMS / WMTS services, despite the fact that this is something that is generally expected of a good GIS.

Finally, we believe that the two most widely used GIS software today, QGIS and Arcgis, have not managed to facilitate the publication of raster cartography on the web in an intuitive way like, for example, Maptiler, their use seems more oriented to complex geoprocessing tasks. Given the current rate of evolution of technologies, we estimate that it will be a step that will be taken in the near future.

In light of the results obtained by each of the programmes analysed, it can be concluded that both QGIS and Arcgis have well earned their reputation as referents in the world of desktop GIS. They are very similar in this study, in five of the sections they receive the same score and in two others they show minimal differences. The scoring difference is because QGIS is free and Arcgis has a fee, plus Arcgis only works natively on Windows, leaving a large number of users without service. As far as georeferencing is concerned, it is not advisable, after seeing the results of this research, to make a significant disbursement of money in Arcgis to do the type of work of the existing QGIS.

These programs are indicated for users who, in addition to georeferencing, do other types of work with the GIS, as they behave more than acceptably in this specific field, but offer many more services. The only section where Arcgis offers better marks, than both QGIS and the rest, is in the description standards (metadata), so this GIS would be suitable for those institutions that need this type of work.

The other free desktop GIS, gvSIG, is a good GIS program but loses out on many aspects to QGIS. For users, organizations or institutions that are not interested in descriptive standards, that use a cartography of their own support or that the software provides, that always choose the type of polynomial transformation, as well as resampling those provided by the GIS, they could find the most intuitive georeferencing viewer, and a web publishing of the results through gvSIG Online improved, compared to the top competitors of its segment QGIS and Arcgis. This research suspects that the lack of options in various items may be due to the fact that this software was born for the specific management of the Ministry of Infrastructure and Transport of the Generalitat Valenciana and therefore was developed according to the main criteria that institution needed. For public institutions doing similar work, their performance is likely to be higher than for other GIS.

Finally, Maptiler, as an example of software specialized in georeferencing, tessellation and preparing cartography for web publishing in various formats, concludes this evaluation. Despite getting the best score in the last four sections analysed, it is its negative performance in the first four that weighs down its score. Its main virtue, the specialization that makes it intuitive and easy to use, is what penalizes it in this study, as it leaves many users out. It is only available in English, does not work with descriptive metadata, certain OCG standards are not incorporated and it only offers the main commercial and free maps as supporting cartography.

Users who are willing to pay a content price and are not interested in the aforementioned restrictions will certainly have in Maptiler the most intuitive software to georeference and publish online. Not only is it easy to use, but it also saves a lot of time in performing all the processes compared to the other GIS analysed. Although Maptiler has the pro version for large companies that use the program for other needs that are not connected with historical mapping, due to the previously-mentioned reasons, the content price of the start or plus version and the very short learning curve of the software, is the right product for the small user, as well as for small institutions.

We would like to point out some future lines of research. In our opinion, the georeferencing process is still complex and tedious, although Maptiler has made it more intuitive. The future must require the semi-automation of these tasks, for example through the recognition of patterns and graphics in such a way that the GIS is able to recognize old planes which are not too deformed with respect to reality and place them above their precise geographical area. If there are several possible geographical places about which the GIS has doubts, the user may choose the exact one, since the system would offer the different alternatives.

A second interesting line of research has to do with publication on the web and how to visualize various previously georeferenced cartography from the same place. It would involve making videos where you can see the growth and expansion of different cities or countries through information provided by old plans and maps. As each plan has a different aesthetic and a different way of representing buildings, green areas, etc. the system should be able to combine all these styles into a single three-dimensional

type. There are some experiences in this regard (Time Machine Atlas, 2020) which are still in their infancy but that may be exportable to other territories.

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