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2D and 3D Photogrammetric Registration Model of the Built Heritage of Cuenca

Modelo de registro fotogramétrico 2D y 3D del patrimonio edificado de Cuenca

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Abstract

Participatory cultural heritage management involves collaboration of different proposals and participants. In this article, the initiative that allows to register graphically the relevant built heritage of the historic center of the city of Cuenca by means of photogrammetry, and the management of it in a Geographic information System have been developed. The photographic study of the property or object is carried out (from multiple angles) by using individual or mounted on drone's cameras. Certain processes, supported by specialized software, are applied to this material to obtain a mosaic of images with which it is possible to obtain the correction of the perspective in the images (photogrammetry). Printable digital products are obtained in two-dimensions (paper) and three-dimensions (resins) forms with scale and precision. Compared to other procedures, this proposal has several advantages: ease, speed, low costs, good quality of the products. Although, we must also acknowledge some limitations. After the development of the project, it can be established that the technical and methodological availability allows to obtain a digitally documented information model integrated into a Geographic Information System; which has property information (cadastral record), delimitation of the areas of heritage value, representation of the two-dimensional and three-dimensional buildings, access to the respective website.

Keywords

Architectural photogrammetry, built heritage, 3D models, orthophotography, Geographic Information System, Geomatics.

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Resumen
La gestión participativa del patrimonio cultural supone la colaboración de diferentes propuestas y actores. En ese sentido, se ha desarrollado la iniciativa descrita en el presente artículo, la misma que permite por medio de fotogrametría, registrar gráficamente el patrimonio edificado relevante del centro histórico de la ciudad de Cuenca y gestionarlo en un Sistema de Información Geográfica. Usando cámaras fotográficas individuales o montadas en drones, se procede el levantamiento fotográfico del inmueble u objeto (desde múltiples ángulos), a este material se le aplican ciertos procesos, apoyados en software especializado, para obtener un mosaico de imágenes con el cual se puede conseguir la corrección de la perspectiva en las imágenes (proceso conocido como fotogrametría) con lo que se obtienen productos digitales imprimibles en formas bidimensionales (papel) y tridimensionales (resinas) con escala y precisión. Comparativamente con otros procedimientos, tiene varias ventajas: facilidad, rapidez, costos bajos, calidad, aunque evidencia ciertas limitaciones. Luego de la elaboración del proyecto, se puede establecer que las disponibilidades técnicas y metodológicas permiten conseguir un modelo de información documentada digitalmente e integrada en un Sistema de Información Geográfica; el cual dispone de información predial (ficha catastral), delimitación de las áreas de valor patrimonial, representación de las edificaciones bidimensional y tridimensionalmente, acceso al respectivo sitio web, y un potencial amplio para la catalogación, clasificación, mantenimiento, recuperación, estudio y promoción del patrimonio edificado.

Palabras clave
Fotogrametría arquitectural, patrimonio edificado, modelos 3D, ortofoto, Sistemas de Información Geográfica, Geomática.

Introduction

The landscape understood as: "The pattern of distribution of the significant elements in the organization of space" (Pisón, 1998), poses from the start the conditioning that the natural environment establishes on the structuring of the built environment, the same that is evidenced in the singular way in which a city is configured.

Additionally, and gradually, it is observed in the architecture of a city, the influence coming from cultural, economic, and social events throughout the historical evolution of the peoples (Roura & Ochoa, 2014).

In fact, the configuration of a city is the product of the concurrence of various elements that characterize it. In the case of the city of Cuenca, its historic center has received the influence of some architectural styles such as French Neoclassical, Spanish Arabic, Art Nouveau, Art Déco, among others. Which has constituted a series of urban sections of greater and lesser aesthetic relevance depending on the concordance that the set acquires.

The influence of these currents is produced in the architecture of the city at the beginning of the 20th century since the economic surplus obtained by a cuencan elite, from the commercialization of the husk, the toquilla straw hat, and the mining production; it allowed them to travel and acquire customs, fashions, and other references, mainly from Europe, which materialized in a landscape with urban characteristics that took it away from its silent, almost rural origin, inherited from the colonial era.

This is how Carlos Jaramillo (University of Cuenca/Autonomous Decentralized Government (ADG) of the Cuenca canton, 2017) refers to it:

> … It is not a Renaissance painting that must be seen from only one perspective. Rather, it is a spatial collage composed of architectural relics, juxtaposed stories, stacked times, broken texts, fragments, chronotopes, phenotypes... where their relationships are mobile and therefore form a highly significant symbolic set...

The uniqueness of the historic center of the city of Cuenca was submitted to UNESCO for consideration, with the purpose of requesting its inclusion in the list of cultural heritage of humanity, the same that was achieved on December 4, 1999.

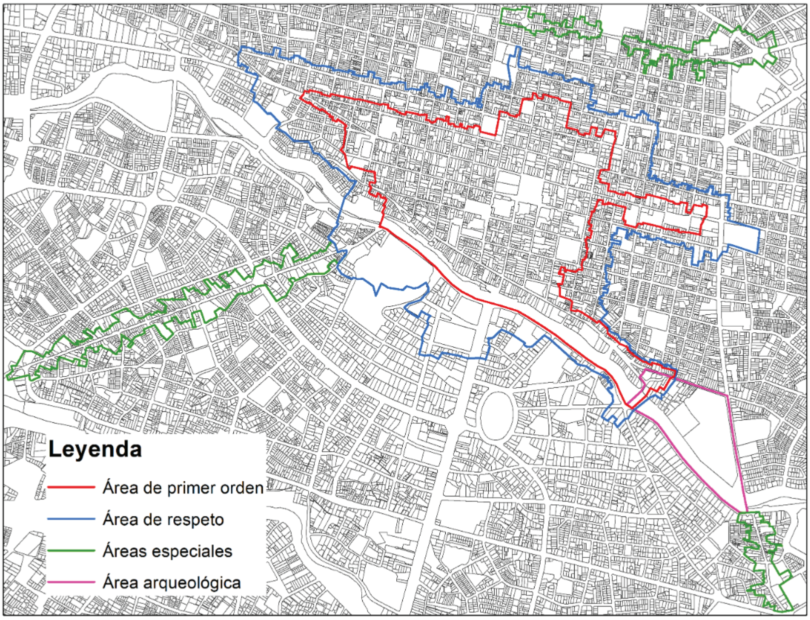
The declaration (file 863) recognizes, among other aspects, "… the beauty of its historic center, with a particular type of republican architecture…" and "… the harmony it maintains with its geographical environment…" (UNESCO, 2019).

The file establishes the delimitation of areas of heritage value in 4 areas: first order, respect, special and archaeological (Figure 1).

The aforementioned file indicates that there are the following buildings in the area defined in 1994:

- Buildings of Monumental Value 26
- Buildings of Architectural Value I 179
- Buildings of Architectural Value II 423
- Buildings of Environmental Value 830
- Total 1458

Figure 1
Categorization of the historic center of the city of Cuenca



Source: Own elaboration based on information from the Cuenca Municipal DAG for the year 1998

Consistent with the need to have graphic and thematic documentation that allows supporting adequate management of the city's built heritage, the University of Azuay since 2009, through the Geomatics and Territory research line, has developed a work that integrates: the registration of heritage buildings by means of a Geographic Information System, and two-dimensional and three-dimensional graphic modeling of buildings using photogrammetry.

The development achieved so far, considers what some authors such as Mario Santana (Santana, 2013) describe as the challenges of digitizing heritage sites, and it is indicated that care must be taken so that the repositories are shared, contain reliable information and that their records are carefully stored to avoid their loss (the author calls them: fragmentation, reliability, and longevity, respectively).

The approach to photogrammetric technology begins with the participation of the University in the "Ibero-American Network for the Application of Digital Architectural Photogrammetry and GIS for the Conservation of the Historical, Cultural and Archaeological Heritage of Cities for a Sustainable Tourism Management" (REFADC, 2019) promoted by CYTED.

Regarding the Geographic Information System, its development at the University of Azuay has occurred mainly since 1997 (Universidad del Azuay, 1997).

The progress made to date in the various aforementioned areas is described in this article.

Methodology

The components that make up the work carried out are:

- The Geographic Information System
- Two-dimensional (2D) photogrammetric modeling
- Three-dimensional (3D) photogrammetric modeling

The Geographic Information System

It constitutes the operational support in which the geoinformation of the cartographic, thematic, and digital aspects corresponding to the photogrammetric models generated is deposited. ArcGis software version 10.3 has been used.

Regarding the information with which the model has been generated, a part corresponds to that used in the Proposal for the Inscription of the Historic Center of Cuenca Ecuador in the world heritage list and that was approved by UNESCO (UNESCO, 2019), which corresponds to:

- Base cartography: contracted by the municipality to the Military Geographical Institute of Ecuador (IGM), with the purpose of using it in updating the cadaster of the city of Cuenca in 1997. Restored from aerial photography taken in the months of May and June of 1994 at a 1: 1000 scale and in analog and digital formats.

- Property Cadaster: with the information collected through the cadastral file that was used in the 1997 cadastral update project (Salgado-Arteaga & Ochoa-Arias, 2011) which contains the information of all the properties of the city and particularly the corresponding to the historic center.
- Database model and graphic structure: The entity-relationship model was generated to compile the information collected in the cadastral file within the project "Model of the Cuenca Geographical Information System" (Universidad del Azuay, 1997), the same that consists of 8 relational tables linked to each other.
- Delimitation of historic areas, according to ordinance 04-28-1983 of the Cuenca municipality.

Another part of the information corresponds to:

- Characterization of the buildings in the area of the Historic Center and the Ejido according to their heritage value (Municipality of Cuenca, 2016).
- Identification of the buildings that have been digitally modeled on their facades, both two-dimensionally and three-dimensionally, as well as their respective web links that describe them in detail (IERSE, Universidad del Azuay, 2019)
- Orthophotography of the Cuenca area, scale 1: 5000 from the SIGTierras Project (MAG-SIGTierras, 2019)

All the cartographic information originally used for the preparation of the UNESCO file was migrated from the psad56 datum to the wgs84, thus making it compatible with the other new thematic maps and the SIGTierras orthophotos.

The information on the characterization of buildings according to their heritage value was generated by digitizing the map available on the Cuenca Digital portal (Municipality of Cuenca, 2019).

Two-dimensional (2D) photogrammetric modeling

To achieve a digital photogrammetric model of a building, correcting the natural perspective with which the object is viewed from an observation point, the technique called photogrammetry is applied (Jáuregui, 2008), which consists of projecting the object onto a plane of reference perpendicular to it (orthogonal), using instruments (currently software) that process the photographic survey obtained from the building.

The procedure is called digital restitution; it can be done automatically or manually. If it is done manually, an operator is required, after entering the photographs of the object into the computer, to point out on the screen the coinciding points in the different photographs, in any case, in the end, an orientation procedure is applied in a mathematical form in which the images are correlated to obtain the digital product in raster or vector formats.

Photographic survey

Once the object to be surveyed (building) was chosen, a photograph was taken in the field using a Canon Rebel 3Ti 18mm digital camera. For this purpose, the camera is located at a convenient distance from the object, using two types of tripod, one with a short height (1.5 meters) and the other long (up to 6 meters in height).

In the beginning, an automatic focus of the lens was applied to achieve a correct adjustment, then it is switched to manual mode and the focal length is fixed (18 mm) according to the calibration applied by the software.

The recommendations that have already been applied were taken into account (Ochoa-Arias, 2013):

- Capture the images in such a way that the angle formed between the first and last is 90 degrees like a semicircle
- Try to take the photos on a day with not much sunlight, to avoid the inclusion of shadows that will hinder the restoration process carried out by the computer.
- Use at least 3 photographs at each point of capture, in a simple building 3 stations are required and in total at least 10 photographs.
- Accurately take at least 2 measurements between points or elements that are within reach, to incorporate them into the software, and to scale the model.

Construction of the model

The set of photographs obtained in the field were uploaded to the Photomodeler 2012 software, previously eliminating those that are redundant, have poor quality or the system does not recognize them as belonging to the used camera.

To carry out the procedure of orientation of the photographs, the same points are located in several of them, with which the software can establish the necessary x, y, and z values of each point and manage to properly overlap the photographic mosaic and establish the coordinate axes of the whole.

In order to guarantee that the procedure works properly, points were chosen that are distributed in a balanced way, that is, that cover several geometrically equidistant points in the building.

The task of building the two-dimensional model required an interactive work that seeks to achieve residual errors of less than 5 pixels, which means constantly consulting the quality table of the points.

The points can be observed in three-dimensional space and the system shows the position in which the camera was located for each photographic shooting station, allowing inconsistencies to be detected.

At this level of processing, it is feasible to determine the quality of the model that is being generated and if the procedures were carried out properly.

Next, we proceeded to indicate the surface areas that make up the parts that make up the set using the points already located three-dimensionally (Figure 2). This task allows us to correct the perspective view of the original photographs.

With the surfaces already established, we proceed to assign the textures, this is the photographic fill corresponding to each surface. This procedure can be carried out automatically by the software, for which it will choose, from the original mosaic, the photographic portion that best fits in it.

Finally, the obtained product constitutes the orthophoto of the building, that is, the orthorectified facade in 2D (Figure 5a)

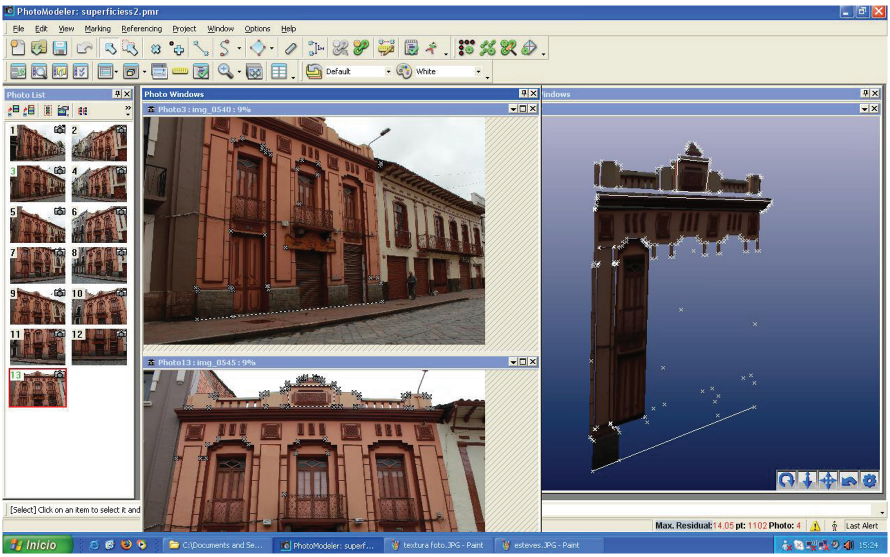
Three-dimensional (3D) photogrammetric modeling

Considering the same principle used for the orthogonalization of the photographs that allow obtaining two-dimensional products (2D), the three-dimensional modeling is generated, as it results from the export of the same product to a format enabled for 3D processing.

The generated model is exported to a vector format that allows obtaining the 3D model for subsequent printing in resin or filament. For this, we have used the following equipment:

- Canon Rebel 3Ti 18mm digital camera
- DJI Phantom 4 Pro Drone
- Tripod
- Digital distance meter
- Flexometer
- Agisoft Metashape Pro software
- Meshlab and Meshmixer software

Figure 2
Assigning textures to the obtained surfaces



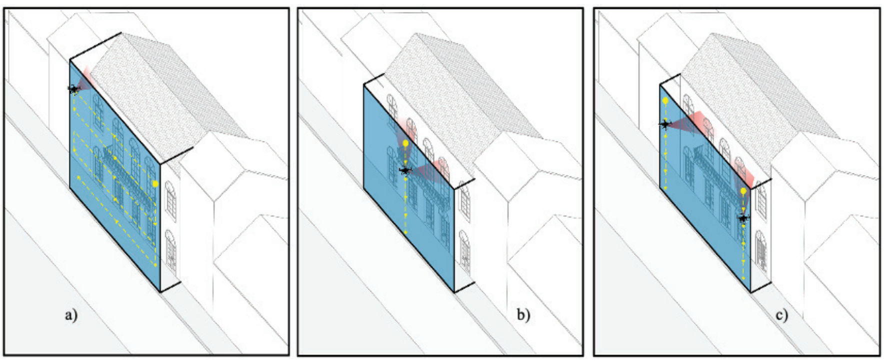
Source: Own elaboration

For the photographic survey, the camera is placed following the recommendations already indicated for the 2D photographic survey, the exception is due to the characteristics of the equipment, in this case, a drone, which requires specific guidelines for its use, in order to facilitate image processing since Agisoft Metashape Pro software recommends not changing the focal length as it could cause depth distortions in the objects to be modeled. For this case, a focal length of 18 mm was established on the reflex camera and 8 mm on the drone's own camera.

The previsions to be taken for the photographic survey are the same as those indicated in the previous section, but additionally, when it comes to the use of the drone, a flight plan was prepared that ensures a total sweep of the building using an orthogonal grid that, when being scrolled through the device, take pictures every 2 seconds.

In the first flight sequence, images are captured perpendicular to the facade, making a horizontal sweep at different heights (figure 3a). In the following sequence, one travels vertically from the center of the building looking to the sides (figure 3b). The last sequence runs vertically from the sides of the building looking at the center (figure 3c). These last two are intended to capture the depths and details.

Figure 3
Drone trajectory sequences for image capture:
a) horizontal sweep at different heights, b) sweep from the center with a view to the sides, c) sweep from the sides with a view to the center



Source: own elaboration

For the 3D object modeling, the assignment to the coordinate system is deactivated from the metadata of each image, in order to avoid the automatic scaling that the software does, which would limit the possibilities of manipulating the model, after which the photos are sent to Agisoft Metashape Pro software.

Once the images were registered, we proceeded to align them, within the configurations for the alignment of photos offered by the Metashape Pro software, we select the highest setting because it is interesting to capture the details of the object. Next, the point cloud was created with an intermediate level of detail.

Finally, the 3D mesh is generated, this step is crucial since no implicit 3D object has been created so far. To create it, we set the software settings to high again, this processing will generate a mesh based on the point cloud that we previously obtained, triangulating the information from it to obtain a mesh with information.

Once the surfaces have been established, the textures are assigned using the options offered by Agisoft Metashape, that is, a mosaic will be generated that covers the created surfaces and from it, it is possible to take it to a digital model format of TIN (Triangular Irregular Network) and those that allow 3D printing, as seen in figure 5, that is, in literal b) the three-dimensional model with texture, in c) the three-dimensional model of points (TIN), and in d) 3D printing of the model using plastic filament.

Results and discussion

The Geographic Information System

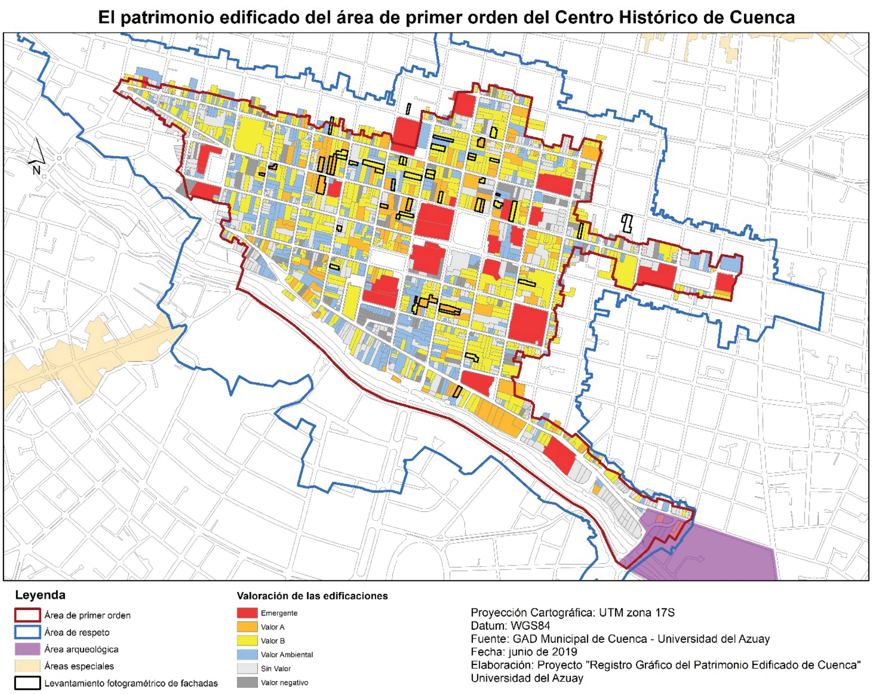
An information management model for buildings of heritage value has been obtained for the first-order area of the city of Cuenca, which is supported by a Geographic Information System (figure 4), which has property information (cadaster), delimitation of the areas of heritage value, categorization of buildings, identification of buildings that have two-dimensional and three-dimensional digital models, access to information from the cadastral file and the respective website that contains detailed information on the building's graphic registry (https://bit.ly/32inSVW).

Regarding the valuation of the generated system, it can be described from the aspects related to its relevance, effectiveness, efficiency, and sustainability.

- Relevance: The applications and simulations carried out in exercises worked with the mother system, on which the specific development proposed in this article is based, show its significance (Salgado-Arteaga & Ochoa-Arias, 2011), so much so that the system is currently used in the Municipal DAG of Cuenca (Municipality of Cuenca, 2019) working on the same model since they have a common origin as a result of the project "Model of the Cuenca Geographic Information System" (Universidad del Azuay, 1997).
- Effectiveness: The common origin that the proposed system has with the existing one in the Municipality of Cuenca, makes them share information that ensures its interoperability since it allows connection possibilities based on the cadastral code and ensures its effectiveness since it establishes a potential connection with the information that has the assigned access key, the same that corresponds to the cadastral key.
- Efficiency: Taking into account that the cadastral information is kept by the Municipal DAG of Cuenca, with the inherent responsibility of keeping it updated, it should only be managed the thematic layer of Heritage Buildings without requiring additional investments that would involve the management of the entire system.
- Sustainability: Allowing the integration of information with other databases, projects a possibility of continuity since it becomes one more gear of the information system for territorial management. At this level, it is convenient to facilitate the establishment of a management committee that indicates the general policies and a technical one that operates them (Universidad del Azuay, 1997), all this could be shared in a Spatial Data Infrastructure (SDI) that could take as a main node the one implemented by the municipality of Cuenca.

We must start from the premise that establishes that the participatory management of cultural heritage generates a dynamic that allows the sustainability of the initiatives, as expressed in the works of (Asmal-Guamán, 2019; Siguencia et al., 2018), since the conception of the object of work includes the population, so that it results in a comprehensive improvement based on the potentialities of each community as expressed by Alfredo Conti (Conti, 2016), and supported by several authors who highlight the necessary interaction between the physical and human component of the city (Carofilis & García, 2015).

Figure 4
The Geographic Information system for the management of information on the built heritage



Source: own elaboration from information of the Municipal DAG of Cuenca.

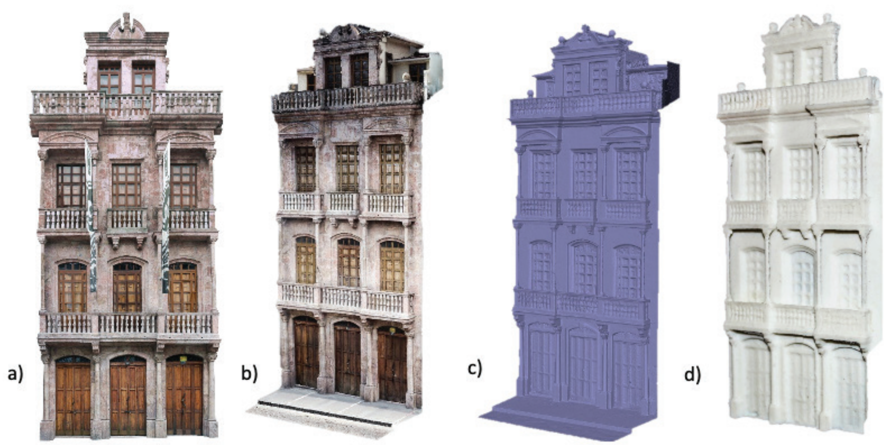
The impulse that the INPC (National Institute of Cultural Heritage) can give to the construction of the system is important, being able to incorporate other aspects of heritage such as archaeological, documentary, intangible and movable property, an example of this is the project "Applications of

Geographic Information Technologies (GIT) for the Management of cultural heritage in the province of Azuay" (López, 2009).

Two-dimensional and three-dimensional photogrammetric models

The digital models that were obtained have required an iterative purification process that allows the real object to be recorded with fidelity, the difficulty arises from the need to capture as many photographic images from all possible angles in order to ensure that the details are properly recorded. Particularly when it is intended to obtain a three-dimensional model, this implies placing the camera at different heights, positions and as close to the object as possible, which has only been possible with the use of the drone, some comparative studies between different possible techniques to be applied show of its advantages (Preti & Tituana, 2017) and point out its low cost (Pacheco-Prado, 2017).

Figure 5
Obtained products: a) orthorectified facade in 2D, b) three-dimensional model with texture, c) three-dimensional model of points (TIN), d) printing of the 3D model using plastic filament



Source: own elaboration

The resulting products are: 50 orthorectified facades in 2D, 5 orthorectified facades in 3D, generated in virtual reality, and printed on plastic filament, as well as several sections of the city surveyed for analysis of aesthetic concordance. These products can be downloaded or viewed at the website http://gis.uazuay.edu.ec/patrimonio.php. In Figure 5, you can see an example of the indicated products. For the facade of the building signed with the number 28 (internal code of the survey), corresponding to Bolívar street 13-89 in the city of Cuenca, the following figure can be seen: the orthorectified facade in 2D (a), orthorectified facade in 3D (b), the three-dimensional point model (TIN) (c) and 3D filament printing (d).

Conclusion

The technical and methodological availabilities have made it possible to generate a digitally documented information model and integrated into a Geographic Information System; in which real estate information (cadastral file), delimitation of areas of heritage value, two-dimensional and three-dimensional representation of buildings, access to the respective website, and a broad potential for the management of built heritage, is available.

The convenience of generating participatory heritage management makes it necessary to make a greater effort to ensure the integration of organizations and the information that is their responsibility. The existence of growing availability of procedures, techniques, instruments, and, above all, of knowledge, as has been pointed out in this article, would allow heritage management in a concurrent and shared mode.

However, it requires the detonation of an administrative decision aimed at specifying the emergence of these spaces. To do this, one of the actors could be encouraged to take the initiative, however, the system should be administered by local public bodies.

The information should not be physically concentrated, in addition, the use of the data and the knowledge necessary to use the technology that manages them must be shared, the latter means that the universities dynamize the corresponding research and training component.

It would be desirable to generate an SDI (Spatial Data Infrastructure), for which it is convenient to develop a model of it, in which a distribution of responsibilities could be proposed and allow the confluence of the visualization of the products generated by the different sources or nodes where it would reside.

The Heritage SDI model should emerge from the beginning ensuring its interoperability with existing SDI, which have a certain degree of consolidation, such as: "The information platform for territorial planning of Zone 6" of Ecuador.

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