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# ANALYSIS OF VISUAL IMPACT BY NEW BUILDING HEIGHT THROUGH UAVS AND PHOTOGRAMMETRY

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**Abstract.** Visual impact is defined as the modification of a visual resource of the landscape, generating an effect on the perception of potential observers. This effect is evaluated using the value of the landscape that has not been altered or destroyed (visual quality of the landscape), as is the case with building projects that generate visible changes in residential areas. Numerous authors have developed methodologies to evaluate visual intrusion; however, deficiencies exist, such as the predominance of subjectivity in procedures and the lack of evaluations for buildings. Therefore, this paper proposes a methodology to evaluate and quantify the visual impact of a new building in a high population density environment. This research is divided into a description of the basic methodology, the proposal of the methodology to capture and process photographs and information, and the application of a case study of a high-rise building in a sector of Valparaíso, Chile. The main contribution of this work is the delivery of a methodological proposal that allows the evaluation and quantification of the visual quality before and after the new structure to complement structural and urban design.

**Keywords:** visual impact, UAVs, high-rise building, landscape visual quality, new building, photogrammetry.

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## 1. Introduction

Urban growth began more than two centuries ago in the era of industrialization. However, over the past five decades, urban growth has been accelerating, and by 2030, one-third of the world population is expected to live in cities (Lladó, 2016). Urban growth has undergone several social transformations, such as population segregation, and territorial transformations, such as landscape changes (Lladó, 2016). Consequently, the growth of real estate investments has had and continues to have a significant effect on urban transformations, substantially modifying the organization, functioning, morphology, and appearance of the world's major urban agglomerations (De Mattos, 2018).

During the last decades, diverse experiences of excessive and uncontrolled infrastructure development have been recorded, which has generated different economic, environmental, social, visual, road, and energy impacts. The externalities of new buildings in urbanization cause more conflicts than contributions to the intervened territory. Externalities affect different dimensions for local urban development in a particular area and location trends (Lladó, 2016). Within these variables, one of the aspects least considered when designing a building is its visual impact, although construction projects generate visible changes in residential areas, which affect a significant number of observers and inhabitants (Mavrommatis & Menegaki, 2017). In addition, new buildings generate adverse effects on the original landscape due to changes in environmental components, such as the vegetation, morphology, and hydrology of the landscape (Fernandez Enríquez et al., 2019). Several authors have developed methodologies and techniques to quantify visual intrusion or perceived modification (del Val Román, 2012). Some methodologies for analyzing and evaluating visual impact include the subjective selection by experts of visually uniform landscapes (Zubelzu & Hernández, 2015), a vertical approach in a web environment (Jeong et al., 2014), and the analysis of visual impact visibility criteria (Manchado del Val, 2015). However, evaluating the landscape quality and perceived modification involves many subjective factors, such as individual perception, aesthetic taste, and visual understanding. For several decades, methods have been reported for assessing the effects the implementation of a new infrastructure generate on the landscape and visual resources of the territory (Manchado del Val, 2015).

Over the years, transformations have taken place that have benefited different areas, including the construction sector (Vega, 2012). The inclusion of technologies for improving productivity and sustainability in the construction industry is known as Construction 4.0 (Muñoz-La Rivera et al., 2020), which proposes automating and digitizing design and construction processes, with an important component associated with real-time data capture and incorporation of sensors into on-site construction processes to optimize the time, cost, quality, and worker safety (Muñoz-La Rivera et al., 2020). Some examples of technologies framed in Construction 4.0 are three-dimensional (3D) virtual modeling, sensors (e.g., thermography), 3D lasers, the cloud, building information modeling (BIM), the internet of things, and autonomous robots, among others (Craveiro et al., 2019).

Some technologies have already been tested and deployed in the construction industry with promising but still partial results, such as unmanned aerial vehicles (UAVs). The use of UAVs has progressed rapidly, and they are increasingly used in the construction industry because they allow large amounts of information to be captured from the work site via multiple sensors, such as cameras and lidar, among others (Craveiro et al., 2019). They offer the potential for aerial photography, as they capture images with better resolution and greater range (Suroso & Irmawan, 2019). In addition, investigations using UAVs under construction have provided information flow for processing feature extraction, recognizing reference points, and identifying elements (Radulescu & Vladareanu, 2017), which can support the preliminary design studies of new building projects, preliminary land studies, and topographic features of a site (Dupont et al., 2017).

Given the above discussion, how urbanization growth has generated many constructions is identified, and a series of new buildings has economic, social, road, environmental, energy, and visual impacts, among others. Each impact has a measurement methodology of the different identified effects; however, deficiencies in visual impact assessment methodologies have been identified. Many of these existing methodologies evaluate other types of infrastructure, such as agroforestry and wind farms. In addition, no method exists to quantify the visual impact of new buildings in high population density environments. Second, these methods use evaluation tools, such as preference surveys, population consultation criteria, or user sensitivity, so the visual impact is not quantified objectively but instead subjectively. In addition, these tools are considered expensive, easy to use, and require human resources, with no less time for their realization. Third, this impact is despised, as it is among the most perceived by inhabitants who observe the new building in their residential area. Consequently, residents can be against constructing a new building and can request a municipal lawsuit, which could cause the work to be stopped. Finally, because visual impact assessment is based on capturing photographs of a landscape, UAVs are a good alternative to replace the repetitive and manual process of manually capturing photographs. In addition, through digital modelling, the visual impact can be evaluated in stages before construction, during the project evaluation. In this context, this research proposes and develops a methodology to evaluate and quantify the visual impact when a new building is located at a height by capturing photographs using UAVs and photogrammetry. The integration of this technology can provide a better analysis of the environment of a new building. The proposed methodology was carried out in a case study in the city of Valparaíso (Chile).

## 2. Material and methods

The research methodology was divided into three stages to achieve the objective of this work: (1) description of the basic methodology for evaluating visual quality (VQ), (2) proposal of the methodology for capturing and processing photographs and information, and (3) a case study. Figure 1 presents the diagram of activities of the research methodology, divided into four columns: stages, tools, activities, and deliverables.

Figure 1 indicates that the first stage begins with the first deliverable, in which the process of diagramming of the measurement methodology is performed. Microsoft Visio was used for this, which corresponds to Microsoft support, which has access to tools to create diagrams of different styles to visually organize complex processes or ideas, as is the case for the selected methodology. In the second deliverable of the first stage, the matrix of the measurement method was created and encoded. A calculation form was created in Microsoft Excel for the preparation of the methodology assessment matrix. Subsequently, it was coded to automate and simplify the sequence of calculations and formulas it contains.

In the second phase, a proposed methodology for capturing photographs and information was developed and subdivided into three deliverables associated with three major activities. The first activity was to define the methodological configuration for capturing photographs and information. In this paper, how and with what the landscape photographs are captured for evaluation was established (e.g., UAVs), including how many photographs should be captured, the criteria for the number of selected image elements, and the area of influence of the visual impact. These criteria were defined by a committee/expert judgment by reviewing documents on the use of UAVs, such as books and papers, obtained primarily from search engines, such as *Scopus* and the *Web of Science*.

The second activity was to define the procedure for processing images. For collecting information, a sheet was created in Microsoft Excel to collect information for the previously elaborated matrices. Using Agisoft Metashape Professional and Autodesk Recap, a procedure was estab-

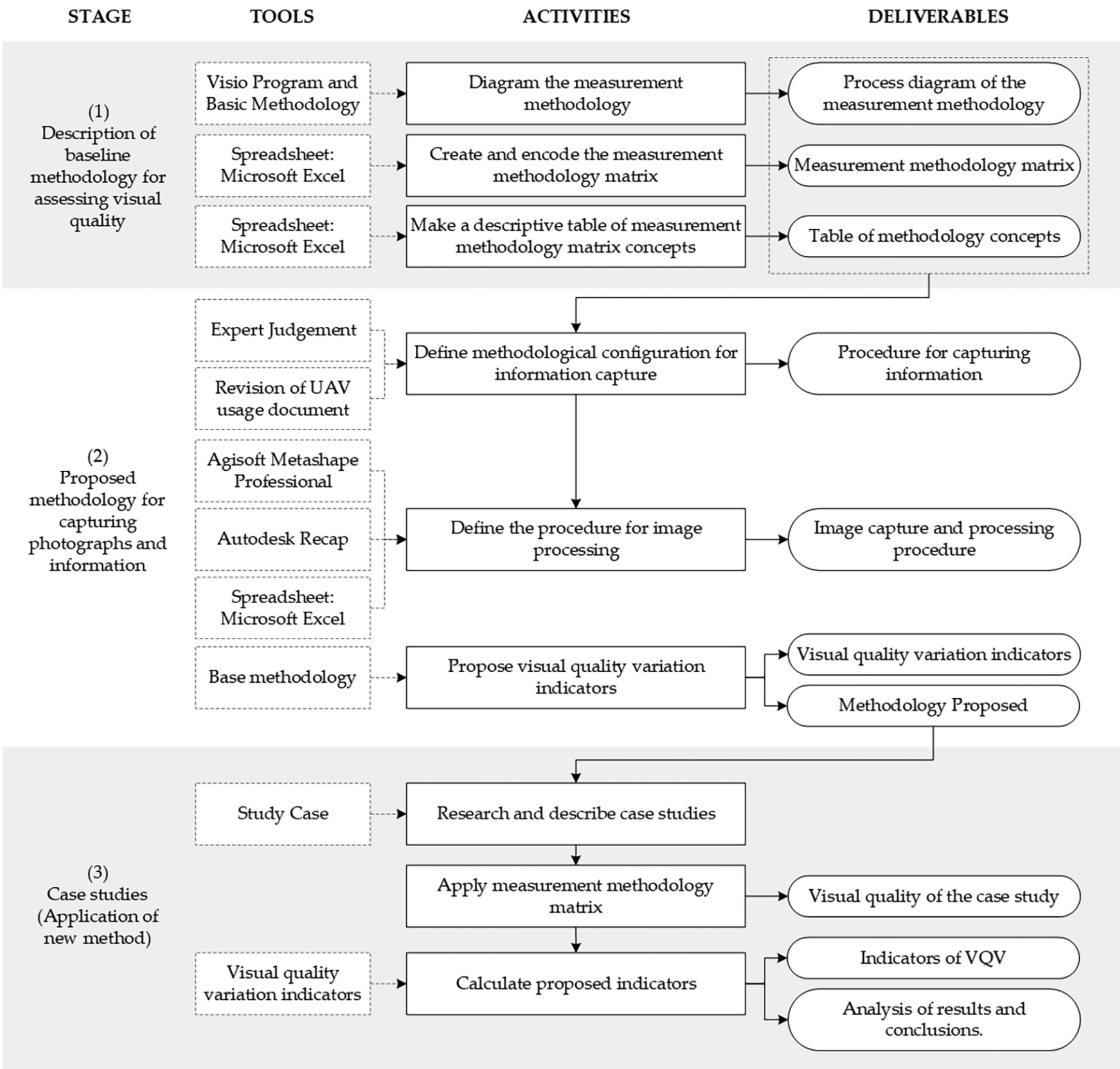


**Figure 1.** Diagram of activities in the research methodology

lished to process previously captured images. The last activity was to propose VQ reduction indicators. This indicator corresponds to a relationship between the VQ data obtained from one image and another; thus, the VQ values are compared for a better analysis regarding visual impact. Throughout this stage, a bibliographic collection was made for each deliverable, using search engines, such as *Google Scholar*, *Scopus*, and *Search Carrot*, using keywords, such as "visual impact", "buildings", "visual quality", "landscape", and "photogrammetry". The search for information was primarily in journal papers, theses, and books.

Finally, in the third stage, the study case was investigated and described, applying the methods or procedures described in the second stage. In this way, according to the study, the VQ of the captured images was obtained using the base methodology. Then, with the proposed indicators, these VQ variation (VQV) indicators were calculated based on the VQ of the photographs. An analysis of the results was performed to reach the conclusions. As for selecting the case study, a zone of Valparaíso was chosen because, in this zone, people constantly appreciate the view and landscape of the area. Because of its morphology, the landscape is one of the elements that add more tourist value to the city, making it a world heritage site according to the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Sepúlveda Manterola & Torres Rojas, 2004).

## 3. State of art

### 3.1. Baseline methodology for Visual Quality Assessment

Several methodologies can measure visual impact. Some evaluate infrastructure, others evaluate rural areas, agroforestry, and wind farms, among others. Subjective selection by experts of visually uniform landscapes, a vertical approach in a web environment, and the analysis of visual impact visibility criteria were explained above (Fernandez Enríquez et al., 2019). However, these methods are considered subjective because they use evaluation tools, such as preference surveys, population consultation criteria, or user sensitivity. In addition to being estimates based on public opinion, these tools are considered expensive, easy to use, and time-consuming (as is the case with surveys) (Fernandez Enríquez et al., 2019). Therefore, the selected methodology is called visual impact assessment, which is from the authors Fernández, Arcila, and García of the Department of History, Geography and Philosophy of the University of Cadiz (2019).

The landscape is an ambiguous term used by many professionals of different fields in the arts and sciences, such as geographers, engineers, architects, landscapers, poets, and planners (Escribano et al., 1989). Visual impact is the modification of a specific visual resource, which generates an effect on the perception of potential observers. Visual impact is adverse when the modification or alteration represents a discordant intrusion into the original landscape; that is, it reduces its VQ and generates an adverse reaction within the population (Dentoni et al., 2020).

Visual landscape considers aesthetics and observer perception. Different methods and procedures exist to evaluate a landscape. For this methodology, the landscape can be interpreted as a set of visual elements that integrate the territorial units as shapes, lines, colors, textures, scale, and motion (Fernandez Enríquez et al., 2019). A key concept for this visual impact assessment is VQ, which is defined as the value of the landscape that has not to be altered or destroyed, in other words, its merit so that its essence and the current structure are preserved (Montoya Ayala et al., 2003).

Regarding the concepts, understand this methodology on the visual properties of the elements of the medium and their compositions is necessary, as these properties constitute the expression of the landscape. After understanding the objective visual qualities of the methodology, the procedure of the visual impact assessment methodology has been explained by Fernandez Enríquez et al. (2019). Thus, a process diagram was produced using Visio to illustrate the measurement methodology procedures in greater detail for processes and subprocesses (see Appendix, Figure A1).

Initially, the methodology was divided into seven key steps, where the last three steps were broken down into three subprocesses. The first step corresponds to capturing landscape photographs, which correspond to the methodology input, using a camera. The second step concerns selecting panoramas or photographs. A photographic survey selects terrain views, which were contrasted with the photointerpretation of land use and topography and traced in a digital model of elevations and existing visual basins to select representative views with high visual incidence.

In the third step, visual schematics and component identification were plotted. Visual schemes, which simplify the observed reality of the images, were drawn. All components of the view (or image) should be grouped into categories. Then, the evaluator assigns each category a VQ weighting coefficient. In the fourth step, the components of interest were identified, corresponding to the photographed landscape. After grouping the landscape components and drawing the respective schemes, a selection of the components must be made for evaluation according to the categories. The evaluator must define the components that have the greatest predominance in the photography.

The fifth step was preparing a matrix for evaluating elements to conduct a formal evaluation in two parts. The first part of the matrix assessed the landscape, which requires three sections: elements, perception, and accessibility, which were divided into different criteria. The elements were subdivided into five criteria chosen by the evaluator and expert judge. The weighting coefficient is given a sign (+/–). According to the criterion, the sign depends on the degree of discordance or visual integration of the image element. Then, the second part of the assessment matrix was made, subdivided into five objective visual qualities, and each of these was divided into their respective criteria:

- Form: This quality was subdivided into three criteria: geometry, the complexity of form, and orientation;
- Line: This quality comprises three criteria: intensity, line complexity, and contrast;
- Colour: This quality was divided into three criteria: colour intensity, variability, and colour contrast;
- Texture: This quality was divided into four criteria: grain, density, regularity, and internal contrast;
- Scale: This quality comprises a single criterion/ contrast.

In the sixth step, the evaluator assigned the assessment for both the first and second parts of the matrix. In the first matrix section, the elements were subdivided by five criteria of ordinal qualities, as each criterion corresponds to a valuation between integers 1 and 5. In other words, Criterion 1 was assigned Value 1, Criterion 2 was assigned Value 2, and so on. However, for the elements, only one criterion was predominant for each component, and its corresponding value was assigned, followed by the sign (+/–). The evaluation assignment of the criteria for objective visual qualities defined in the previous step depends on the evaluated component. After obtaining a maximum value for each item (weighting explained above), the values were normalized. The element was expressed as a percentage of a range between –100% and 100%, obtaining the absolute quality of the element. Subsequently, it should be reduced to a percentage scale presented from 0 to 100%. The complete range and percentage reduction have an associated formula presented in Figure A1 (see Appendix). Finally, the percentage VQ of each element was averaged to obtain the VQ.

## 3.2. Previous experience on visual impact assessment

In recent years, efforts have been made to assess the visual impact of tall buildings in cities. The main experiences reported in the scientific literature are discussed below.

The significance of each of these aspects in the visual impact of the tall buildings was identified by a first study that evaluated the effectiveness of these physical features in the overall visual impact of these tall structures. In that study, Samavatekbatan et al. (2016) examined a tall building in a big city. They changed the building's physical characteristics (its height, top, and color), offering nine photos for each variable feature After combining these images, 27 trio photographs were created and evaluated by a sample of 384 persons drawn at random from Tehran's resident population. According to the findings, of the three characteristics, height had the greatest influence on how citizens saw people, followed by height and color (Samavatekbatan et al., 2016).

In a second study, an analytical network process (ANP) method was used to examine the visibility, significance, and beauty of tall buildings in a metropolis. The criteria and sub-criteria of the research are weighed using the multi-criteria decision analysis (MCDA) method (according to 22 experts and by using Super Decisions 2.8 software). Three towering structures in Frankfurt, Main Tower, OpernTurm, and the European Central Bank, were chosen to compare their effects on the city's skyline based on the three variables and their respective weights. Utilizing the concept of square degree score, ArcGIS Desktop 10.5 software looked at the ratio of these buildings' visible surfaces to observers' visual fields in urban open spaces and in an area with a centralized building structure over a radius of 2500 meters in order to determine the visual impact of these three buildings. A graphic questionnaire was created and given to 420 participants in order to ascertain the impact of the significance and aesthetics of these three structures on the metropolitan skyline. To evaluate how tall structures would affect the city skyline, the participant's preferences were taken into account. The weight of the criteria that were determined using the ANP approach were then taken into account for the outcomes of the visual, symbolic, and aesthetic criteria of the three tall structures in Frankfurt (Karimimoshaver & Winkemann, 2018).

The visual impact of tall buildings on urban interior space is the subject of a third study (i.e., streets, squares, undeveloped land, parks, lawns, palace gardens). These are places where residents can regularly encounter tall skyscrapers. The study looks for connections between tall buildings and the surrounding development that raise the latter's worth and, as a result, raise the standard of the neighborhood's public spaces. The first objective of that research was to develop fundamental guidelines for the development of tall buildings in a way that blends harmoniously with internal cityscapes in European cities while preserving spatial coherence with already-existing housing developments, including historically significant ones. The second was to conduct an impartial analysis of the relationships between a tall building and the city using digital tools and 3D city models (in line with rules defined). The four guidelines for choosing a desirable location for a tall structure are an idea and a contribution to a larger scientific debate on how to enhance urban planning. A computer simulation can be used to objectively apply some of the proposed regulations. Utilizing digital techniques and virtual 3D city models makes it possible to examine cityscapes that span large areas and have very complex urban structures while obtaining conclusive conclusions (Czynska, 2019).

In keeping with this, a fourth study uses ANP based on the opinions of experts and Super Decisions V2.8 software to rank and weight various criteria and sub-criteria, including the environment, access, social-economic, land-use, and physical context, to determine where tall buildings should be located in cities. In ArcGIS 10.3, layers matching to sub-criteria were constructed concurrently. A locating plan was then created using a weighted overlay (map algebra). The best part of the location plan's best-case scenario included seven hypothetical 20-story tall structures. In the following stage, it was determined how much of these buildings would be visible (fuzzy visibility) from the city's streets and open spaces. MATLAB software was used to model these processes, and ArcGIS was used to produce the final fuzzy visibility plan. Results for fuzzy visibility can aid city managers and planners in determining which area is ideal for a tall building and how much visibility may be necessary. In the future expansion of the city, the proposed model may position tall structures based on technical and aesthetic criteria, and it can be broadly applied in any city as long as the weights and criteria are localized (Karimimoshaver et al., 2020).

## 4. Results

### 4.1. Proposed methodology for capturing and processing information and images

The methodological proposal was divided into three stages outlined in the research methodology. First, the procedure for capturing information was defined. Second, the procedure for capturing and processing images was defined. Finally, indicators of VQ reduction were proposed (Figure 2).

#### *Stage 1: Information capture procedure*

The first activity involves obtaining preliminary information about the future building located in an urban area. This information includes basic project characteristics, the most relevant being the maximum projected building height and the new structure's location. The project owners are responsible for delivering the requested information.

The second activity was to delimit the area of influence, which corresponds to the geographical space from which the information to predict and evaluate the effect of the new building was obtained (Servicio de Evaluación Ambiental, 2017). For the assessment of visual impact, the area of influence was defined as the area where inhabitants are affected by the visual effects (changes in the availability of landscape vision) and adverse effects through the potential construction of a new building (Arroyo Chalco, 2012). It is appropriate for this methodology to cover an area where the structure is partially or totally visible, provided that it modifies the parameter of the visual landscape quality.

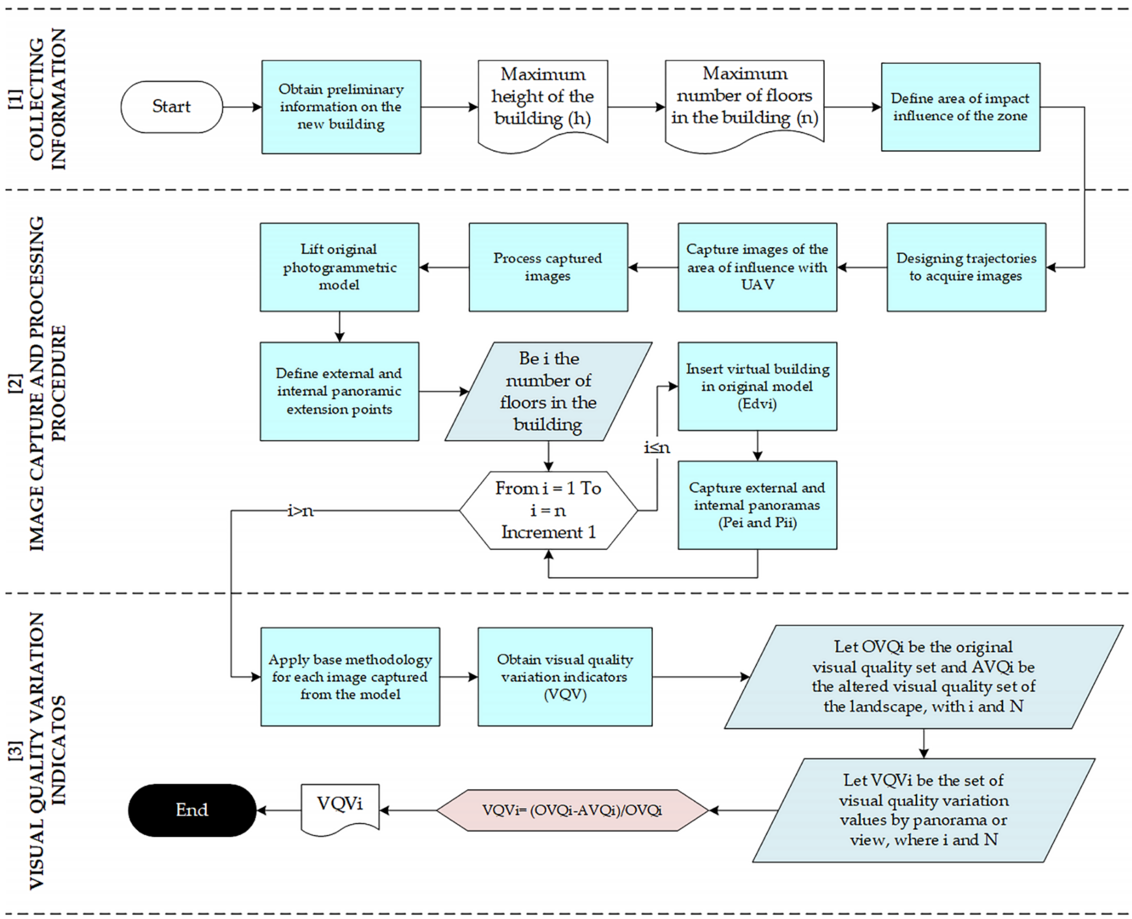


**Figure 2.** Process diagram of the proposed methodology

***Stage 2: Information capture procedure***

The second stage was defining the procedure for capturing and processing images. The first activity was designing the flight paths of the UAV to acquire images of the area of influence. For this, flight planning for the drone was carried out. The height and speed of flight, shooting times, and number of capture points or distances to ensure the required photographic coverage of the area of influence were determined, considering the characteristics of the photographic equipment (Paredes & Noguera, 2015). In the second activity, images were captured using the UAV, based on the defined area of influence, considering the flight and capture of images. The acquired photographs must be processed to generate 3D point clouds in the third activity. For this, treatment of the photographs must be performed using software providing a cloud of 3D points, orthophoto, a digital elevation model, and surfaces with level curves (Wefelscheid et al., 2012). The file can be exported (point cloud).

In the fourth activity, the photogrammetric survey was conducted. The file was imported to software that processes this cloud of points and obtains a digital model of the surface. The fifth activity corresponds to the definition of the extension points of external panoramas and internal views. These points are based on the place, orientation, and direction through which the image extraction was performed from the model. For external panoramas, points were selected from the contour of the area of influence, simulating the perspective of external observers for the area of influence. While the internal panoramas or views simulate the perspective of internal observers, such as inhabitants who walk through the area streets, these points are selected inside the area of influence.

The sixth activity was modifying the original photogrammetric model, inserting a virtual model of a new building to generate an altered landscape. An altered landscape was obtained with a virtual building of different heights. The virtual building simulation begins with a building of one floor up to the maximum number of floors (or maximum height) defined by the project. Finally, considering the extension points defined above, external panoramic images and internal views of the original and altered landscapes were captured.

***Stage 3: Proposal of Visual Quality Variation indicators***

The third stage includes the calculation of the VQV indicators. For each overview and view drawn from the model in the previous stage, the baseline methodology presented in Figure 2 is applied. The VQ of the original and altered landscapes was evaluated using the element assessment matrix. Then, VQV indicators were proposed, corresponding to the ratio between the altered VQ (AVQ) and original VQ (OVQ). The equation is presented in Figure 2, where the OVQ is the percentage value of the VQ of the original landscape without considering the new building in the photogrammetric model. In contrast, AVQ is the percentage value of the VQ of the altered landscape with the new building in the model. The VQV indicates how much the VQ of the landscape associated with each external panorama or internal view obtained from the model increases or reduces after inserting the virtual building concerning the original landscape.

## 4.2. Proposed methodology application: a case study

The methodological proposal presented in Figure 2 was applied to a case study in Valparaíso, Chile. In this case, the technological tools presented in the Figure A2 (see Appendix).

### *Stage 1: Capture and information procedure – case study*

The first activity collected basic information about the project. The selected case study was in Cerro Barón, in the city of Valparaíso, Chile. This area was selected due to real estate growth. Due to the age of the residences in this area, the renovation of the sector can be observed by the number of buildings by height built on the hill. Another important factor in the growth of this area is the public transport access and proximity to the city center. People appreciate the view and landscape of the area because of the morphology of the place. The landscape is one of the elements that add more tourist value to the city, making it a world heritage site according to UNESCO (Sepúlveda Manterola & Torres Rojas, 2004). It is also necessary to determine relevant characteristics, such as the maximum projected height (in this case study, a building at most 20 floors (60 m) is contemplated). We proceed to the delimitation of the area of influence, where the visual impact of a potential new building was evaluated. The area of interest has approximately 120,000 $m^2$, which is presented in Figure A3 (see Appendix).

### *Stage 2: Image capture and processing procedure – case study*

In the first activity, the flight paths of the UAV were defined, covering the area of influence (delimited in the previous stage) to obtain sequential images. Designed trajectories are recommended to be flat and horizontal. For this case study, the flight design considers the UAV trips with two horizontal and flat trajectories complemented by a trajectory capturing oblique photographs to cover surface spaces. Figure A4 depicts the trajectories of the UAV in the area of influence. The flight height depends on the elements in the defined area, selecting a height that exceeds structures in the sectors, such as houses, buildings, churches, and other obstacles. There is no possible interference or collision with these. In this activity, the visualization of the UAV was also considered in the flight execution. Adequate positioning of the operator is necessary, and distance, height, and the angle of visibility were chosen depending on the trajectories. In the study, a constant flight height of 80 m was selected due to a building with an approximate height of 50 m so that there is ample and safe flight space.

In the second activity, photographs were captured with the UAV, totaling 365 images. In this activity, the trajectories defined in Figure A4 (see Appendix) were followed. In addition, the operator must use the information provided by the remote-control screen of the device to control the constant speed and coordinate the shutter firing interval to obtain the photographs. Once the set of images was obtained, the processing of 365 photographs continued as the third activity. For the correct creation of the 3D model, meeting certain computational requirements is necessary, such as a high-end processor, RAM capacity close to 32 GB, and a graphics card of at least 2 GB. For processing, Agisoft Metashape Professional software was used (v. 1.5.2), which performs photogrammetric algorithms and reconstruction of the area with the images.

After processing the photos, the software generates a point cloud (3D mesh) exported in .las format. Thus, we proceeded to the fourth activity, corresponding to the photogrammetric survey of the original model of the zone. The point cloud was imported to ReCap, creating a 3D virtual model simulating reality. ReCap can also remove areas excluded from the virtual landscape analysis. There is a contrast between these, identifying their colors rather than the sharp detail. Then, the file was exported in .rcs format and imported into the Revit software to recreate the evaluated virtual scenario because it allows placing objects on the cloud of points imported to the software. In addition, Revit has a simple working interface to visualize the photogrammetric model and facilitates inserting the virtual building into the photogrammetric model.

In the fifth activity, extension points were defined. In this case, eight points, which are the location points for obtaining external panoramas, were defined in the contour of the area of influence. The views (or internal panoramas) were defined as six points within the area of influence, which simulate the internal observers of the hill. This definition of points for views was chosen depending on the intersections of the streets in the area (Figure A5, Appendix).

In the sixth activity, a virtual building was inserted into the original photogrammetric model. In this case study, we chose to insert a virtual building similar to Torre Barón 1, as no construction project exists in this area. Through the Revit software, the new building's location in the original photogrammetric model was virtually simulated to generate an altered landscape, in which this building must vary its number of floors or height. For this case, the maximum is 20 floors, and the minimum is two floors. Finally, the panoramas and views of the original and altered photogrammetric model were captured. These were obtained from the Revit interface for capturing external panoramas and are based on the eight extension points defined above. Figure 3 depicts the original external panoramic view (a) and altered view (b) for a virtual building insertion with the maximum of 20 floors (60 m). The 3D View Camera tool of Revit was used to obtain the views. Analogous to the panoramas, the view of the original landscape must be captured. After inserting the virtual building, the altered landscape must be captured, as displayed in Figure 4. Figure 4 shows the building view of a 1.65-meter-tall person looking parallel to the length of the street. (this is the reason that the 60-meter high building is not fully visible, since the person is not tilting his head). This is to represent the modification of the view of a person living in the surroundings of the potential new building and not necessarily a tourist, who prefers to see the spaces from a panoramic view, as depicted in Figure 3.

### *Stage 3: Visual Quality Variation indicators – case study*

At this stage, the baseline methodology should first be applied in each overview and view, as set out in Section 4.1. Following this line, identifying the elements of each catch and criteria for the valuation matrix should be considered. Although panoramic views do not contain all of the same elements, there are predominant elements: houses, the Barón tower buildings, apartments, trees (vegetation), and streets. These elements vary in the evaluation according to the appearance of the captured image. Nonetheless, the criteria remain constant in all images: infrastructure, urban views, undegraded and degraded nature, milestones, and effects. After considering the assigned components and criteria, they are evaluated with the VQ assessment matrix in Microsoft Excel to obtain the VQ of the landscape of each panorama and view. After evaluating the images, the VQ parameter behavior was plotted for both panoramas and views, according to the extension point. In other words, the VQ value of the panorama or original view was entered with the VQ values of panoramas or altered views. Figure 5 presents the VQ graphics of the six captured views (original and altered) versus the number of floors of the new virtual building.

a)

b)

**Figure 3.** External observers of the hill, panoramic: a – panoramic 1, original landscape and b – panoramic 1, altered landscape with virtual construction of 20 floors

a) b)

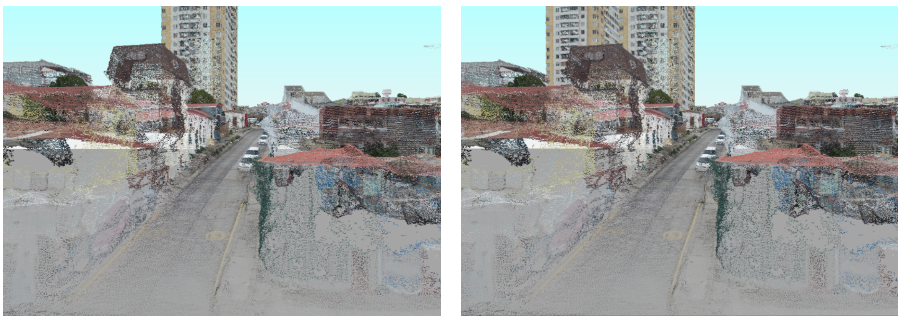

**Figure 4.** Internal observers of the hill, views: a – View 1, original landscape and b – View 1, altered landscape, insertion building with 20 floors

The curves presented in Figure A6 (see Appendix) indicate the general behaviour of the variation in VQ. Although the views begin with a value of 56.11% of the original landscape, this does not occur in View 5 because the building in this capture that alters the landscape is not appreciated at any time, and even the Torre Barón 1 building is not visualized. However, a similar pattern was found between Views 2, 3, 4, and 6. These indicate constant VQ values as the number of floors increases. However, the parameter corresponding to a six-floor building rises to 63%–64% because it does not alter or is not discordant with the landscape, although the structure is already appreciated. However, increasing two more floors by inserting an eight-story building generates a decrease in the parameter, reaching a value of approximately 44%. This procedure was performed for the panoramas, and the OVQ of the panoramas averaged 67%. A percentage increase occurred in the VQ when inserting a building of up to six floors, ranging from 67%–70%. However, a decrease of 56%–62% occurred when inserting a building starting from eight floors. As the last activity, the visual reduction indicators were calculated, as explained in the previous section, to determine the reduction or increase in the VQ of the landscape, as the original landscape is altered by inserting a virtual building at different heights. The OVQ and AVQ were obtained, and the VQV for each image was calculated with the corresponding parameters. Like the VQ, the behaviour of the VQV was plotted for the views. As presented in Figure 5, except for Views 1 and 5, an increase of 15% initially occurred in the VQ for the views for six floors, whereas for eight floors, the VQ reduced to 21%, remaining constant for up to 20 floors (60 meters).

When graphing the behavior of VQV, Figure 6 demonstrates that most panoramas increase the VQ by varying between 2% and 5% from floors 2 to 6; however, the VQ reduction was between the values of 9% and 14%, three times the increased value. Generally, the cutting axis in reducing the VQ in panoramas is produced to seven floors, as it is constant from the tenth floor. In summary, for internal observers (views) and external observers (panoramic) of the hill, an increase in the VQ of the landscape was observed. A significant decrease in VQ from the sixth to the eighth floors of the new virtual structure was observed.

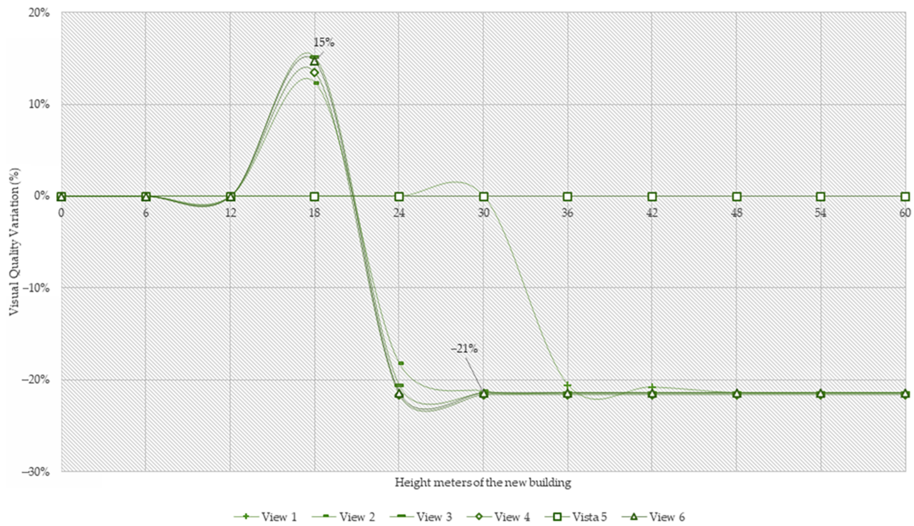


**Figure 5.** Graphic of variation of the visual quality (VQ) in views: variation of VQ vs. height in meters

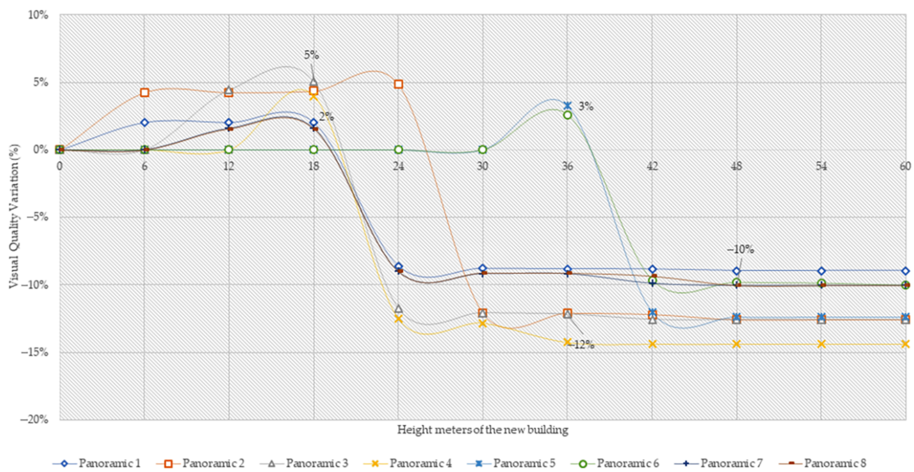


**Figure 6.** Graphic of variation of the visual quality (VQ) in external panoramas: variation of VQ vs, height in meters

More than one perspective in the capture of the observation points of the internal and external inhabitants of the hill is necessary because observation points exist in which the VQ remains constant or is slightly altered, as displayed in View 5 in Figure 5 and Panorama 6 in Figure 6. Moreover, observation points exist where the VQ is highly altered. As for the percentages, the changes are perceived more in the views than the panoramas. Despite these variations, global behavior is determined when observing the behavior graphs of panoramas and views. For this case study, the VQV change occurs on average on the seventh floor. However, this synthesis is not generalizable or extrapolatable to the whole city or analyzed hill. For each project, the results obtained in a particular way should be analyzed.

## 5. Discussions

Unlike previous studies on the evaluation of the visual impact of tall buildings in urban spaces, the proposed method has three fundamental characteristics: (1) the survey of the real existing conditions of the urban space to be intervened through unmanned aerial vehicles (UAVs); (2) the creation of a three-dimensional urban environment where the new building is projected (Figures A7 and A8, Appendix); and (3) the use of an integrative methodology of visual impact that includes the shape, line, color, texture, scale and height of the building.

Since the last decade, unmanned aerial vehicle photogrammetry (UAV's) has been used as a technological tool for topographic mapping. This is because drone photogrammetry allows for a generation of dense point clouds, generation of orthographic mosaics, models with 3D texture, linear maps, among others (Saadatseresht et al., 2015), that is, UAV photogrammetry introduces large- and small-scale applications. Among its characteristics are its low operating costs, greater operator safety, greater accessibility to irregular (or dangerous) areas, higher quality of space products and reliability of the mapping of relatively small, distributed areas (Saadatseresht et al., 2015). In addition, UAV photogrammetry also has advantages associated with handling time, cost, and quality problems, although it also has a number of limitations (Saadatseresht et al., 2015). Some of these are restricted by the range of flight, and similarly to line-of-sight flight. Another limitation is that they must operate with a backup pilot, who must have the ability to detect and follow the guidance of the UAV system (Moudrý et al., 2019). In civil engineering, drones are technological tools that can bring many benefits. They increase communication between the participants of the construction, improve the safety of the site, use topographic measurements of large areas, with the use of principles of aerial photogrammetry it is possible to create buildings of aerial topography, roads, saves project time and costs, among others (Tkáč & Mésároš, 2019). They also create real-time aerial images from building objects, general views reveal assets and challenges, as well as the extensive layout of the site, operators can share the site images with staff and subcontractors (Tkáč & Mésároš, 2019). The integration of new technologies can provide a solution and make a better analysis of the environment with a new building. For this reason, the visual impact study seeks the use of these new technologies such as drones, since there is no doubt that the UAVs have benefited different areas such as construction and civil engineering. Although previous studies have used GIS (Karimimoshaver & Winkemann, 2018; Karimimoshaver et al., 2020), UAVs include advantages associated with the actual characteristics of the urban space to be intervened, which is very helpful, especially when GIS do not have updated information. Notwithstanding the above, it is possible to integrate both methodologies to obtain the most benefits from different methodologies.

Previous studies usually superimpose the projected building on photographs, and with these photographs the impact studies are made (Czynska, 2019; Samavatekbatan et al., 2016). In contrast, the proposed method allows to create a three-dimensional urban space allowing to navigate the space from different perspectives, simulating in a real way how people will be affected by the new building, without the need to redo the photographs. The proposed method allows to make this tour from a computer; however, in future works, the model could be linked with immersive reality engines to make the immersive experience of the evaluator more realistic. The visual impact rating methodology is integrative since it includes several elements of perception of the visualization of the current and the intervened space. This method is complementary to previous methods (Karimimoshaver & Winkemann, 2018; Karimimoshaver et al., 2020), where multi-criteria evaluation methods are used; therefore, in the future it is proposed to make comparisons between the different mathematical algorithms to evaluate the visual quality index. However, different methodologies state the importance of height as a fundamental variable.

## 6. Conclusions

For several decades now, different assessment methods of the effects of implementing a new infrastructure on the landscape and visual resources of the territory in which it is based have been reported. These effects or modifications of the specific visual resources of the landscape are collectively called the visual impact, which generates an effect on the perception of potential observers. The value that a landscape has, when not altered or destroyed, corresponds to the VQ; thus, the evaluation of the landscape quality and the perceived modification involves many subjective factors, such as individual perception, aesthetic taste, and visual understanding, among others.

The proposed methodology using visual impact assessment defines the landscape as a set of objective visual elements that integrate territorial units, such as shapes, lines, colors, textures, scale, and movement. A set of elements to be evaluated is defined using panoramic capture to quantify the visual impact obtained using the visual reduction of quality. In addition, unlike the other methodologies, this technique was created to evaluate urban areas by analyzing before and after a planned construction.

The contribution of this study to knowledge corresponds to the proposal and development of a methodology for evaluating and quantifying visual impact by capturing and processing information and photographs using a photogrammetric survey obtained from a UAV. This assessment is for those areas where a new building is projected at a height with abnormal morphology. The proposed methodology can measure and analyze the visual impact of new buildings through a visual impact assessment (VQ assessment matrix) and capture a series of photographs from a photogrammetric model. The above serves as input for calculating the proposed mathematical indicators, which are a function of the VQ, allowing the analysis of the visual effect (decrease or increase) produced by the new building on the area inhabitants. Complementarily, this proposed methodology serves as the city's urban design because the landscape is one of the elements that add tourist value to the city and is the most perceived by inhabitants. The study methodology is primarily aimed at public or private entities (real estate, municipalities, etc.) and professionals (e.g., designers and architects). The integration of UAVs into this method contributes to a complete analysis of the project environment of the new building.

When applying the methodology in a case study, defining the building boundary height is possible, which does not generate a significant adverse visual impact in the area of influence. Although the results are consistent, this is not a generalized conclusion of the impact of the VQ of the landscape, nor can it be extrapolated because it depends on the project variables, such as the location, morphology, number of floors, or maximum building height. However, it is a practical procedure for visual and quantitative impact assessment through which more data can be collected, and important analyses can be made.

Regarding the research limitations and future lines of work, the new methodology does not completely resolve the degree of subjectivity of previous methodologies described in this article. However, with this methodology, the subjectivity considerably decreases because, in this proposal, the changes of the landscape affected by a new building are evaluated, considering such parameters as forms, lines, colors, textures, and scale. Another limitation of this study is that the proposed methodology was applied to a single case study. However, this allows replication to different landscapes. With this methodology, the project managers who want to place a new building have more information and can carry out further analyses of the visual impact of the building. This assessment is important because this aspect is the most perceived by inhabitants and can serve as a regulatory framework for different cities.

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## Author contributions

Conceptualization, R. H. and J. G.-P.; methodology, R. H.; software, J. G.-P.; validation, F. M., and E. A.; formal analysis, J. G.-P.; writing – original draft preparation, J. G.-P.; writing – review and editing, R. H., E. A. and F. M.; visualization, J. G-P. and F. M.; supervision, R. H. and E. A.

## Disclosure statement

The authors declare no conflict of interest.

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# APPENDIX

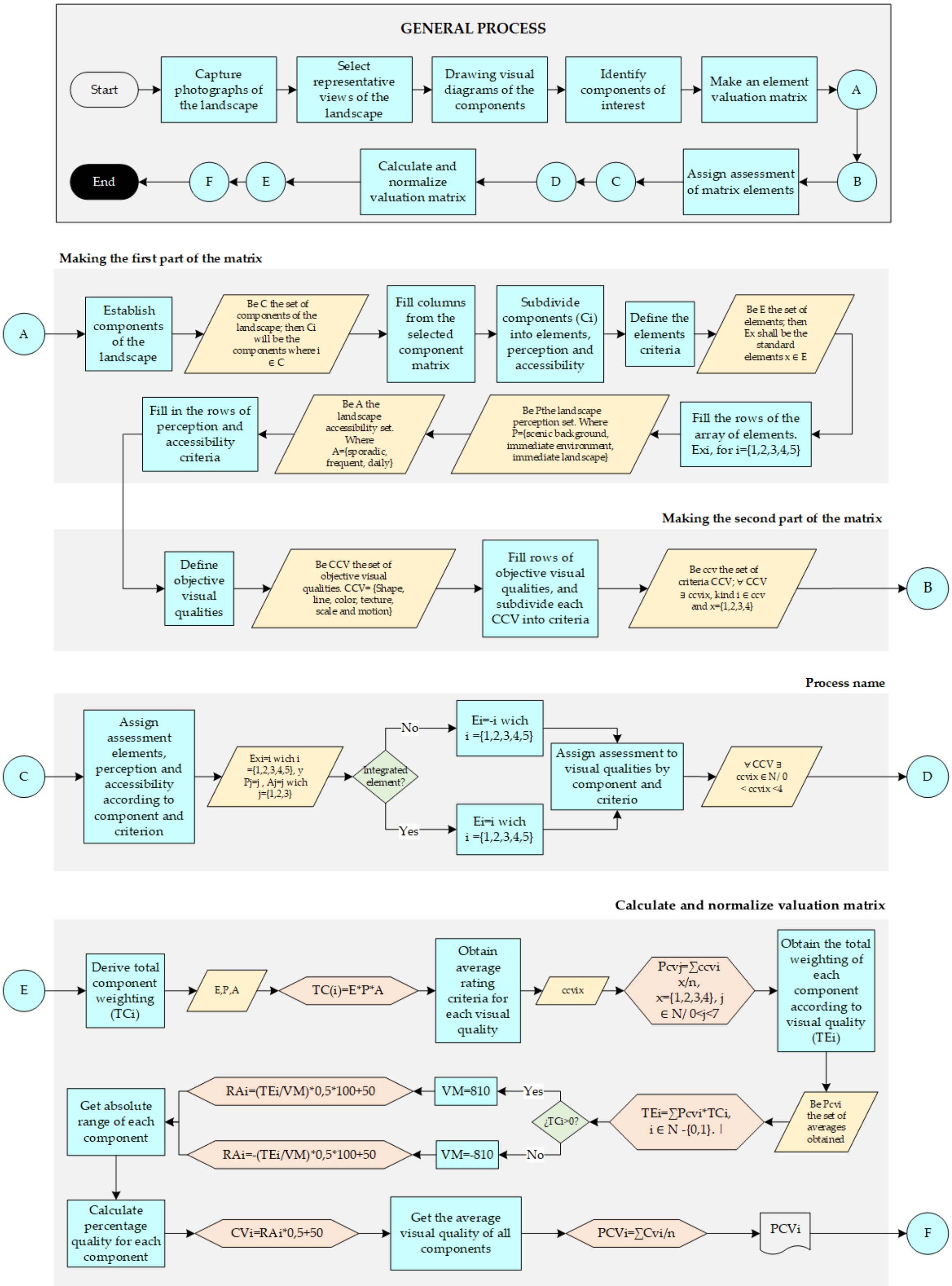


**Figure A1.** Process diagram of the measurement methodology

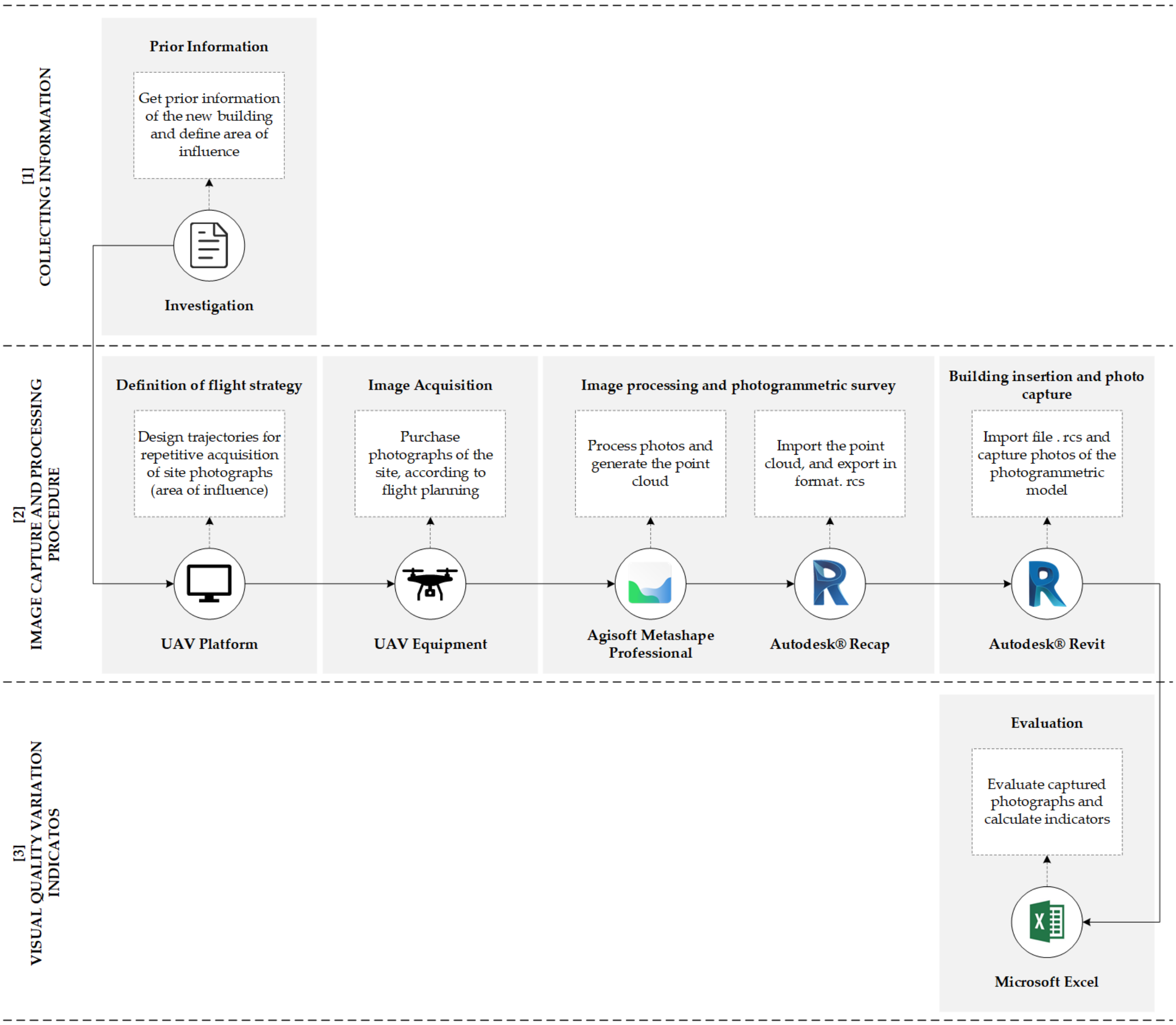


**Figure A2.** Tools used for the application of the methodology

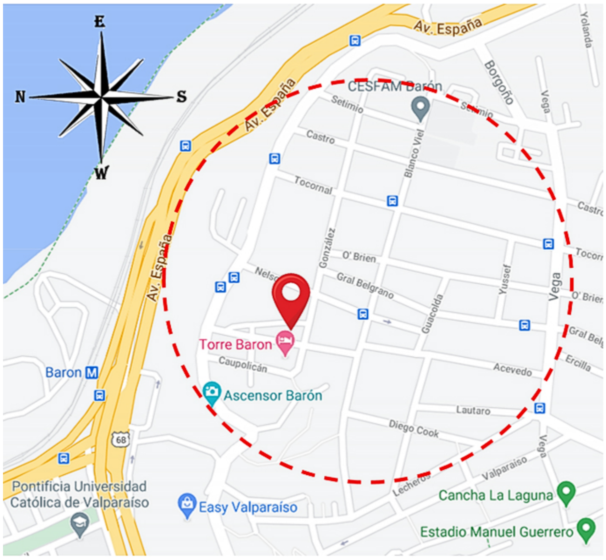


**Figure A3.** Defined area of influence, Cerro Barón

**Figure A4.** UAV flight path design: a – trajectory from above (horizontal form); b – trajectory from above (vertical form); c – trajectory from above (oblique form)

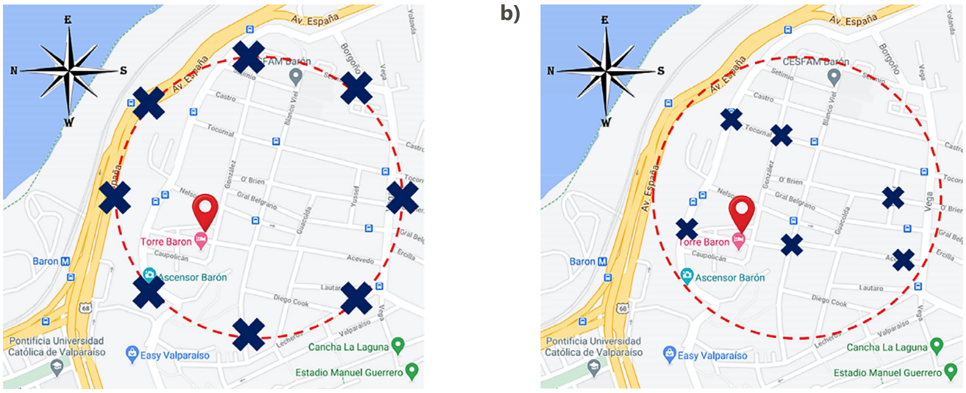

**Figure A5.** Defined extension points: a – in external panoramas in the contour of the area of influence and b – in internal panoramas within the area of influence

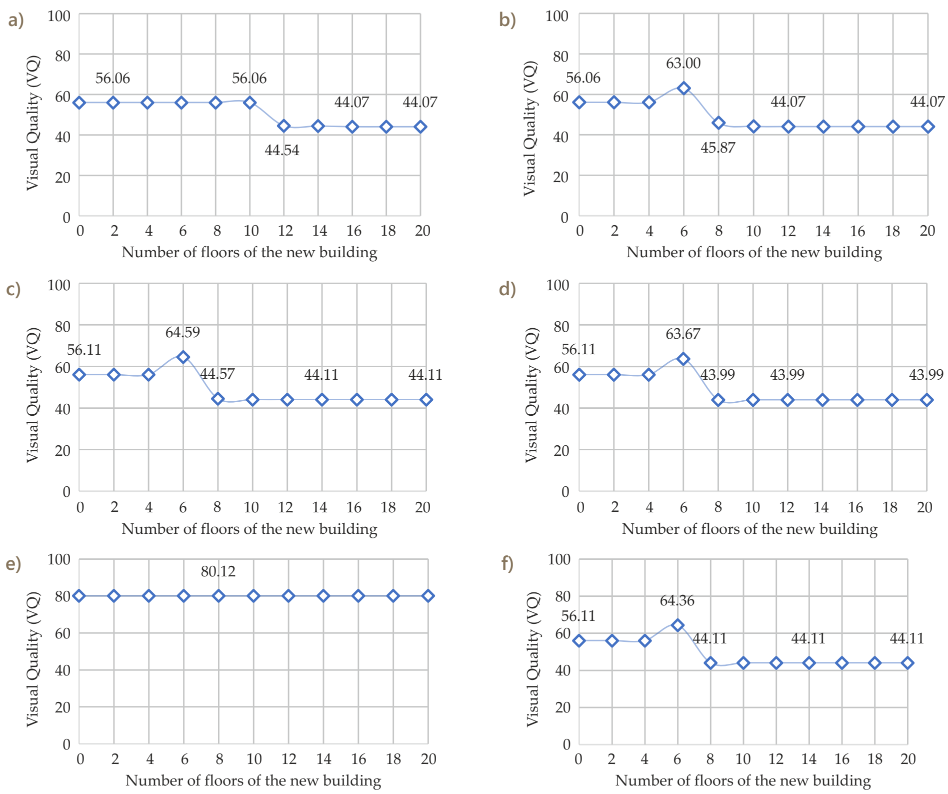


**Figure A6.** Visual quality variation graphs for each vs. view by the number of floors: a – View 1, b – View 2, c – View 3, d – View 4, e – View 5, f – View 6

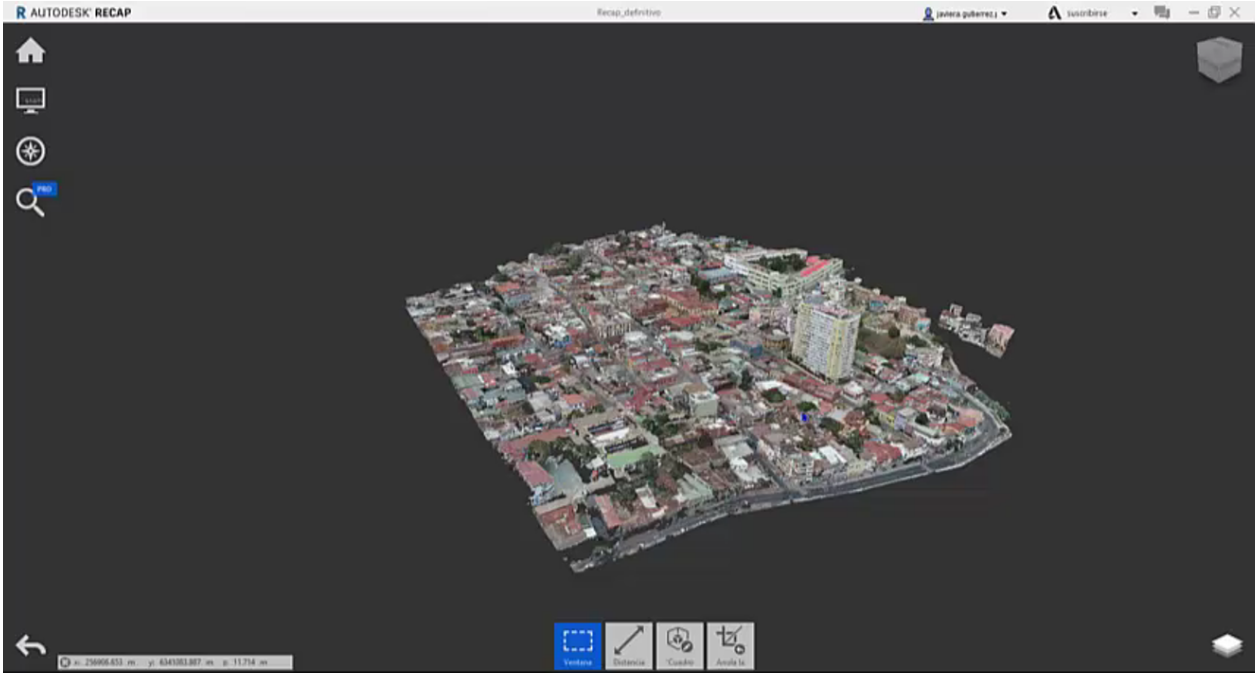


**Figure A7.** 3D virtual recreation of the actual urban space

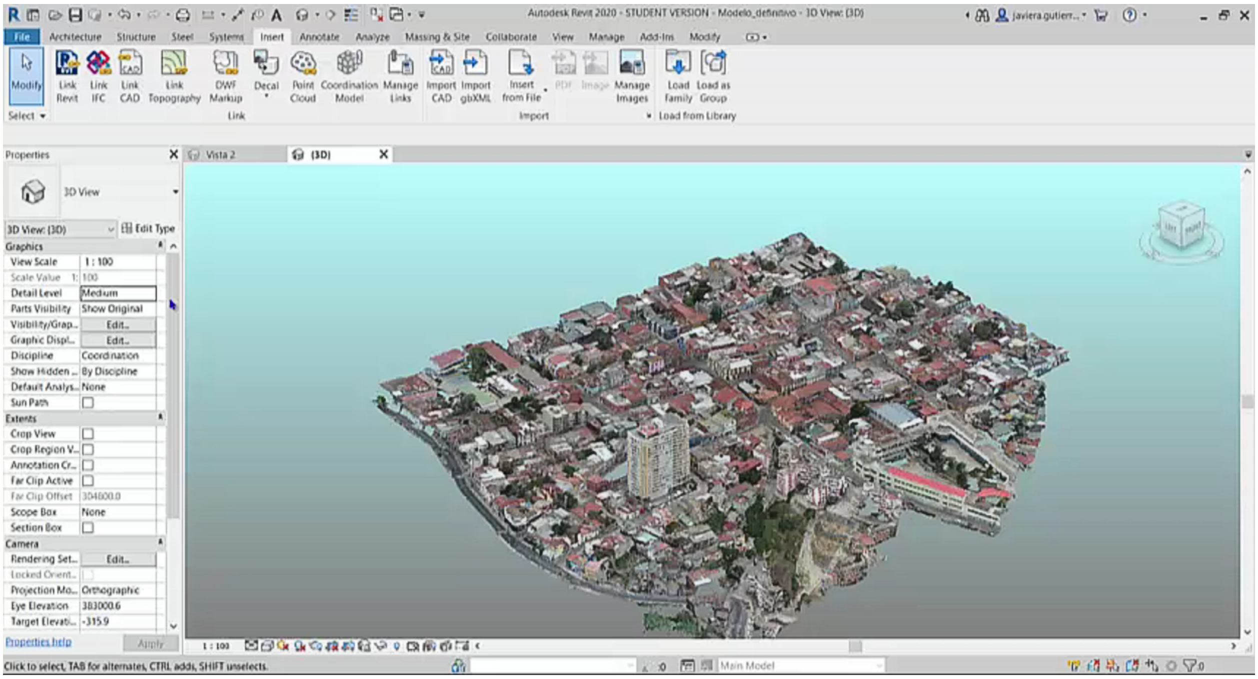


**Figure A8.** 3D virtual recreation of the potential urban space