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Geomatics Techniques for Cultural Heritage Dissemination in Augmented Reality: Bronzi di Riace Case Study

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Abstract: The Riace Bronzes are two full-size bronzes cast around the 5th century BC, located at the 'Museo Archeologico Nazionale della Magna Grecia' in Reggio Calabria; they truly represent significant sculptural masterpieces of Greek art in the world due to their outstanding manufacture. This paper describes the methodology for the achievement of a 3D model of the two sculptures lead by the Geomatics Laboratory of the Department of Civil, Energetic, Environmental and Material Engineering (DICEAM) of the Mediterranean University of Reggio Calabria. 3D modeling is based on the use of imaging techniques such as digital photogrammetry and computer vision. The achieved results demonstrate the effectiveness of the technique used in the cultural heritage field for the creation of a digital production and replication through 3D printing. Moreover, when considering renewed interest in the context of international museological studies, augmented reality (AR) innovation represents a new method for amplifying visitor numbers into museums despite concerns over returns on investment. Thus, in order to further valorize and disseminate archaeological heritage, we are developing an app for tourism purposes. The created app allows the user, in real time, to obtain additional information on the object of investigation, even allowing them to view the 3D model in AR.

Keywords: 3D model; 3D printing; virtual reality; augmented reality

1. Introduction

The "Bronzi di Riace" represent one of the greatest moments of sculptural production of all time and the most important archaeological discovery of the last century (Figure 1). For some time already, we are experiencing a revaluation of cultural heritage, which is no longer seen as the exclusive domain of specialized scholars but as a resource for the economic development of local communities and regions. The new approaches to the heritage values are, now more than ever, devoted to user applications and interactivity, generally for tourism purposes, and also to "very-close" users for dissemination/educational purposes.

(**a**) (**b**)

Figure 1. (**a**) Bronze A. (**b**) Bronze B.

In this process, the role of new technologies is fundamental: on the one hand they help scholars to simplify the management and analysis of scientific data, on the other they allow the general public a better understanding of the past thanks to interactive applications, personalized presentations, and environments in the virtual realm.

Scanning and 3D modeling technologies have become, in recent years, a powerful tool for presenting and analyzing artwork in virtual places, such as the web, or in real places, such as museums or cities.

By definition, 3D computer graphics is a branch of computer graphics that processes three-dimensional models for the creation of static or moving images, and it is exploited in the production or post-production of works for television, cinema, video games, architecture, engineering, art, and various scientific fields.

In this field, the use of 3D is aimed at acquiring a knowledge of cultural heritage otherwise precluded to the masses, or else difficult to access without taking an invasive approach to an extremely vast, ancient and, in some cases, delicate heritage [1].

Any single physical contact, such as a mold, with an artwork like the Riace Bronzes could damage the statues, leaving marks or abrasions that could jeopardize the work. Through 3D scanning, a highly detailed model of the statue can be obtained without any physical contact, which recreates an almost identical copy of the original by means of 3D printers [2].

The use of copies, in particular for statues located outdoors that are subject to the elements, to urban smog, and even to vandalism, proves vital in the preservation of priceless works, as they are unique among their kind.

This is one of the most obvious strengths of 3D and one of the main reasons experts and specialists in the field have shown such interest and adopted its use. Yet, going beyond creating copies, this procedure even makes hypothetical reconstructions of lost opuses [3].

Modern technology can further help to make information more attractive, presenting it in different and often lively ways; for example, an interactive activity can be used by museums to create guided tours of the works or to make the vast knowledge available without the user even entering the museum itself. Over the last few decades most museums have abandoned their simple container structure, becoming a livelier and richer reality, a communication tool that aims to exploit modern technologies to attract the public [4,5].

For this reason, in a wider project of diffusion and exploitation of the cultural assets present in the city, the Geomatics Laboratory of Reggio Calabria decided to include within its development process a multimedia app for tourist and academic purposes, which also details the reconstructions of artifacts present in the National Archeologic Museum of Reggio Calabria MArRC.

2. Materials and Methods: Survey and 3D Model Reconstruction

Three-dimensional reconstruction from photogrammetry techniques is widely used in architecture and archeology. It is based on a computer vision range imaging technique: the structure from motion (SfM) [6].

The principle on which the SfM technique is based follows what happens for stereoscopic photogrammetry, where generation of a 3D structure is defined and resolved through the superimposition of images. Unlike traditional photogrammetry, reconstruction of the scene through positioning and orienting the camera is automatically solved by the software used.

It is, therefore, necessary to carry out a photographic campaign of the scene required, consisting of multiple sockets with overlapping images (at least 80%).

This technique is particularly effective when the photographic shots are made up of a set of images with a high degree of overlap that allows a complete three-dimensional reconstruction of the acquired scene [7].

2.1. Data Acquisition

A Canon EOS 6D Body was used for the acquisition of digital images useful for the construction of a geometric 3D model.

The EOS 6D is a full 35 mm frame Digital Single Lens Reflex (DSLR) camera. It featured a 20.2 megapixel full-frame complementary metal-oxide semiconductor image sensors (CMOS) and a wide ISO range of 100–25,600, expandable to L: 50, H1: 51,200, and H2: 102,400, for greater image quality, even in low light. The effective pixel size was 26.2 megapixels.

In order to obtain a better reproduction of the three-dimensional model, we decided to carry out a filming position around the statues at every ten degrees, repeating the procedure at different heights, as shown in Figure 2.

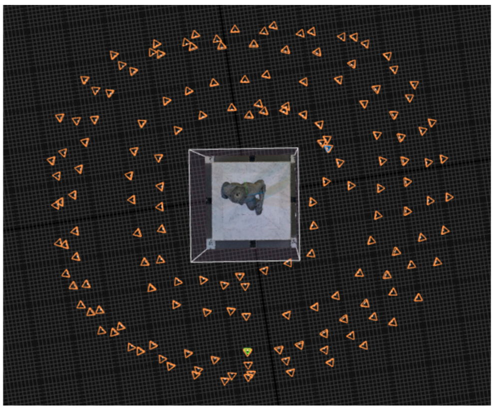


Figure 2. Camera positions.

2.2. Processing

To create the three-dimensional model, digital images were imported into Zephir 3D flow.

Zephyr is a low-cost commercial software produced by 3D Flow (free with some restrictions). This software implements a digital photogrammetric technique, applying computer vision algorithms and the latest multiview technologies, to generate 3D spatial data.

It allows the creation of 3D models from a photographic system through an automatic photogrammetric procedure using automatic correlation algorithms that are widely used in SfM photogrammetric software [8].

SfM identifies correlations with feature-matching processes between the block of images, called chunks, which must be stable with respect to variations in lighting and points of view. On each of them, a descriptor is generated which is based on a defined objective around the point. An algorithm similar to the scale-invariant feature transform (SIFT) was used to determine the correspondence between digital images, making the resolution of the internal and external orientation parameters possible [9,10].

Firstly, a crude algorithm found the camera shutter center coordinates, which were subsequently refined using bundle adjustment. Rebuilding the point-dense cloud used a multiple-view approach with merging depth maps.

Zephyr filters outliers and can be set on three levels (moderate, mild, aggressive), each fixed depending on the regularity of the surface, thus indicating the presence of a regularization factor.

It is essential to have a good set of digital photographs of the object required to reconstruct in 3D. In general, the photographs must be of quality—therefore, well-lit and well-contrasted—and capture the object from multiple points of view, ensuring that there is an overlap of at least 80% between adjacent photographs [11].

The workflow is completely automatic both in regard to the orientation of the images and for the generation and reconstruction of the model. This condition led to an optimization of processing times ensuring good performance of the machine/software complex [12].

The phases are elaborated as follows:

1. Align photos (photo alignment)—this is the most important phase of the entire photogrammetric process. In this phase, the software aligns the photographs with each other, calculating their position in space and reconstructing the so-called gripping geometry. Then, through a process of geometric triangulation, the software calculates the position of the elements present in the photographs in space. It follows that the quality of this alignment produces the quality of the final 3D model.

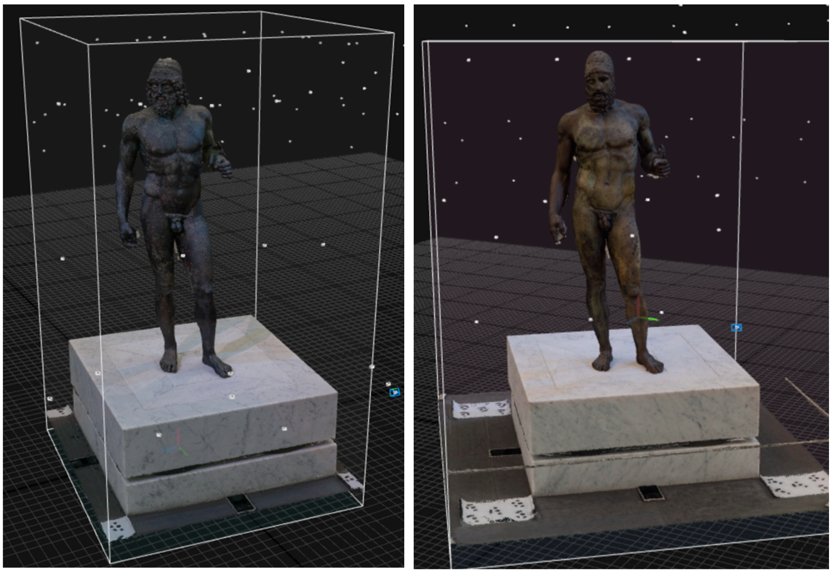
The result of this phase is a cloud of scattered points, or a sparse point cloud,

2. Build dense cloud—through this phase a dense cloud is constructed using dense image matching algorithms. These are subdivided into algorithms that use a stereo pair to find matches (stereo matching) and those that identify them in multiple images (stereo multi-view).

3. Extract mesh— a polygonal model based on the newly created dense cloud is generated. The mesh is a subdivision of a solid into smaller solids that have a polyhedral shape.

4. Build texture—this allows a better definition of the 3D representation of the work under investigation to be obtained (Figure 3).

The last step is metric control and scaling of the model, that is, the correct metric dimensions are assigned to the model in order to make precise measurements on it.



(**a**) (**b**)

Figure 3. 3D models: (**a**) Bronze A and (**b**) Bronze B.

3. 3D Printing

Once the digital 3D model has been obtained, "rapid prototyping" technology (better known as "3D printing") is applied, which is very useful in the field of cultural heritage. 3D printing is a technology capable of creating accurate reproductions of an object starting from its 3D digital model through a process that can use different materials (plastic, metal, stone, etc.) [13].

Different from the traditional approach, which requires the production of manually applied rubber molds on the original work (with the added risk of ruination) followed by the creation of plaster or resin copies that need to be 1:1 scale, 3D printing is much more flexible. 3D printing allows copies of the artefact (or any part of it) to be obtained in any scale both automatically and at an affordable cost.

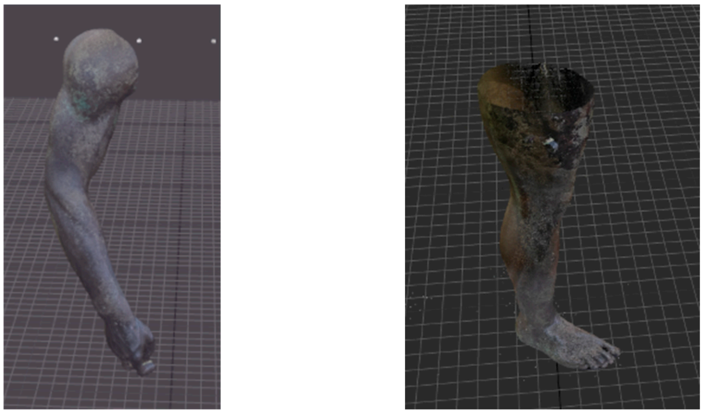
This technology can be "subtractive" or "additive": the first is based on the idea of producing a copy by carving a block of matter with a computer-controlled cutter; the second is based on the fusion of a thin plastic filament (or other material) that is deposited at different layers to create the desired shape. The latter has been very successful in recent years thanks to its simplicity of use and the compactness of the machines. In this way it is accessible not only to computer technicians but also to art scholars and museum curators [14].

The main application of "rapid prototyping" is the production of high-fidelity copies of original artefacts. In the world of cultural heritage these copies can be very useful in the following ways:

- permanent or temporary replacement of original works (if a museum were to remove a work temporarily, for restoration purposes, or permanently, to prevent further damage already suffered due to various factors);
- displaying of an artefact (if the original version is not available for loan or if the cost of transport is very high);
- support to blind people (their only way to discover sculptures, works of art, or paintings is their sense of touch, often forbidden in the case of original works);
- serial production for merchandising; and
- application of sensors (inside a museum it could be interesting to equip the exposed objects with sensors to offer the visitor a richer and more exciting interaction).

Another application, less usual but equally important, is the possibility of contributing to restoration. In fact, thanks to 3D printing technologies, it is possible to design and reproduce the missing parts of a work (in order to offer the public a more effective explanation of the artefact's original structure), rather than building support structures, often necessary to assemble fragments [15].

In our project, the role of 3D printing played a trivalent role. In fact, app users can either print an exact copy of the model or part of it (Figure 4), or they can reconstruct one by adding missing pieces.



(**a**) (**b**)

Figure 4. Particular 3D models of Bronze A: (**a**) arm and (**b**) Leg.

3.1. 3D Printer Used

Printing was carried out with "Bq Hephestos 2" 3D printer, a fused filament fabrication (FFF) 3D printer, based on an additive production technology that works by releasing the material on overlapping layers. This printer melts and extrudes a thermoplastic filament to draw all the lines that form the elements of a three-dimensional object. We chose to use polylactic acid (PLA) as our thermoplastic material. It is one of the most widespread materials for FFF 3D printers and one of the cheapest, presenting few difficulties in the printing phase.

3.2. 3D Model Analysis: Rhinoceros

Through Rhinoceros 3D ver.6 software (Robert McNeel & Associates, USA), we verified cohesion between the model and the tools in order to build polysurface objects. Once an open polysurface was detected, using the edge analysis tool, the naked edges were fixed with a joining operation. We joined the detached surface to the main body of the model, closing the object. In the case of missing surfaces, we proceeded by creating a new surface that was in perfect contact with the surrounding surface edges, or if the distance was less than Rhinoceros tolerance, we used a forced union. After this, through the select bad objects tool we located the bad objects. Once the bad surfaces were isolated, we proceeded to restore the edges of the surfaces to their original state before they were joined with the command "Rebuild Edges".

This, of course, resulted in differences between the scanned object and the model, but the differences found were very small.

3.3. Printing Phase

The first step was to generate the model in .stl format. The model was then subjected to a slicing phase (to break it down into horizontal sections or layers) (Figure 5).

Once these preliminary operations were completed, the object was generated by the 3D printer following the print settings defined in the slicing phase (Table 1).

The necessary printing time to reproduce a single model was about 5 h 30 min, using a quantity of 71 g of material, corresponding to 23.74 m of filament.

Table 1. Printing parameters.

Quality		**Shell**	
Layer height	0.2 mm	Wall thickness Upper/lower layer thickness:	1.2 mm 1 mm
Filling		**Material**	
Filling density Fill Configuration	20% Grid	Printing temperature Type material	205 °C PLA
Speed			
Filling speed Support speed displacement speed	80 mm/s 60 mm/s 100 mm/s	External/internal wall speed Initial layer speed	40 mm/s 30 mm/s
Support			
Support positioning	in all necessary points	Overhang angle of support	50°

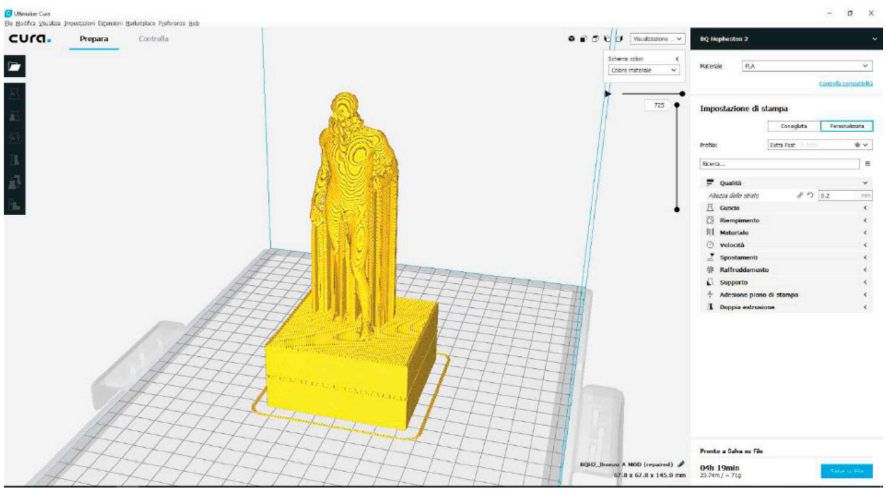


Figure 5. Preview of the 3D model ready to be printed.

Once printing was completed, the supports were removed using narrow-pointed pliers, and finishing was done with sandblasted paper (Figure 6).

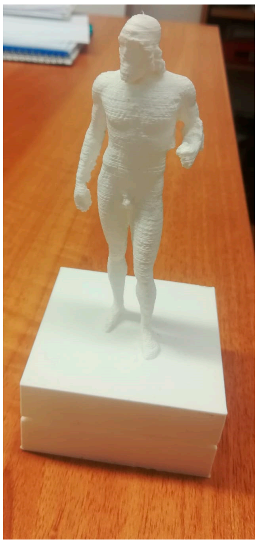


Figure 6. Preview of the 3D printed model.

4. Integration of 3D Models in Virtual Reality and Augmented Reality

A virtual reality (VR) system is generated combining the real scene (seen by the user) and the pre-registered digital virtual scene, which can be significantly influenced by the behavior of the active subject. The subject can "assist" a representation in a real space, or they can "explore" the real environment to which, in any case, virtual elements are superimposed.

Augmented reality (AR) is an effective tool to promote the process of disseminating information and enhancing cultural heritage. It is a technology whereby virtual content is added to a physical environment interactively and in real time.

Nowadays, museums have an important role in society. Their responsibility is to take the events of the past and show them in contemporary contexts with the aim of providing information and entertainment to the public [16]. Although many museums still tend to have a conservative style in their presentation of exhibits, a large number of the latter now understand that "modern times call for modern measures" and, therefore, make continuous efforts to explore different ways to interact with their visitors. In this context, the integration of 3D models in environments of augmented reality is appropriate. Augmented reality allows us to see a level of digital content in a real-life scenario. For this reason, many museums have started to give visitors a richer view of history. This technology, in addition to enriching virtual contents with what is real, makes it possible to activate the connections that man perceives in the world around them.

This new technology allows 3D virtual content to be added to a physical environment, in an interactive and real-time format. In particular, AR overlaps computer data for the real environment, so the user feels physically present in the landscape that they are viewing. The user sees on the screen the reality "augmented" by virtual objects that provide additional information on the real environment [17].

This enhancement of information extends the limits of knowledge because, thanks to the connection of every physical element to a telecommunications network, it creates a space in which everything is reachable through devices capable of accessing the Internet, characterized by ever-greater portability. Labels and tags allow visualizing and sharing knowledge through links that are no longer verbal (therefore, no longer confined to linguistic communities); they are visual and, therefore, understandable to all, opening the doors to a global sharing of knowledge that sees the virtual level converge towards the actual [18].

The Created App

The app created is a tourist app for mobile devices (still under development and improvement) that allows the user, in real time, to view the 3D model in AR, to have additional information on the object of investigation, and to book a printing of it; indeed it was conceived to give the museum visitor the possibility of being able to print miniatures of the 3D models of the reconstructed finds, to re-assemble them in virtual reality (shards), to entirely reconstruct missing parts, or to simply and imaginatively view compositions [19].

Therefore, a virtual tour is made with the app (with a viewer or simply through the screen of the device) in addition to being "accompanied" during the visit by a virtual guide that interacts with the surrounding environment [20].

In a wider tourism development project of the city of Reggio Calabria, the Geomatics Laboratory of the Mediterranean University is implementing (on Unity3D platform) an application for tourism and educational purposes, for mobile devices, which allows users to gain information on different points of interest in the city (squares, sculptures, churches, and museums using AR technology).

The app is still being defined and upgraded; it allows users to access different services based on the choices made (Figure 7). In particular, within the National Archaeological Museum of Reggio Calabria, the app is able to:

- display information of different types relating to the object captured by the device camera;
- view multimedia content associated with the object framed;
- highlight details directly on the object of study, making it easier to understand the work;
- view the 3D model, modify it, or assemble it (Figure 8);
- take a virtual tour (as a spectator or interact through the screen of the device), as well as being "accompanied" by a virtual guide who interrelates with the surrounding environment;
- visualize the visitor's position inside the museum's floor plans with the names of the exhibition rooms (Figure 9); and
- reconstruct and assemble (even imaginatively) multiple 3D models and then book a 3D print.

The project consists of a series of scenes—an initial, loading, and a scene for exploration—all managed by the SceneManagerScript script to perform initialization operations and the SceneLoader script that controls the transition from one scene to another.

The first part of the project is focused on the creation of a single scene, the basic elements of a virtual tour. It contains all the information of an immersive environment. In fact, a virtual tour can be thought of as a sequence of scenes.

Each object in the scene is a GameObject. It can ideally be thought of as an empty "container" within which the user can insert components that will characterize it. Scripts associated with the "GameObjects" (which may or may not have a graphic representation) are extensions of the "MonoBehaviour" base class, which defines their behavior thanks to the use of particular functions called "event handlers".

This Unity script, linked to a GameObject running on both the server and the client, is responsible for verifying in each frame the presence of new data inside the buffer; therefore, based on these, its representation both on the server side and client side is updated.

A collision calculation tool (Collider) is a component that can be associated with a GameObject (Unity elementary primitive or 3D model imported into Unity) that already has a Rigidbody component, which allows it to collide if two GameObjects collide between of them and they both have the Collider and Rigidbody component; thus, the physical engine will calculate the collision.

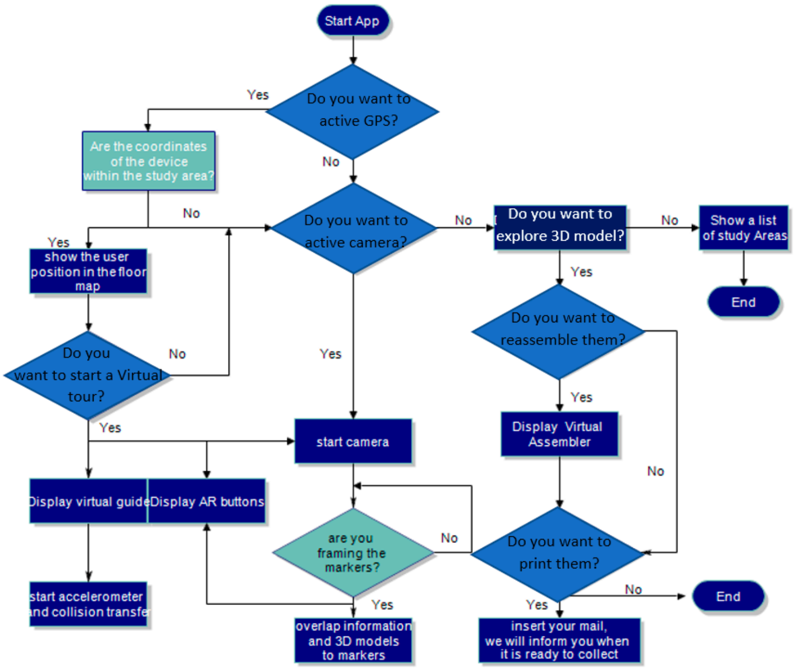


Figure 7. Preview 3D printed model.

Figure 8. Preview of the 3D printed model.

Figure 9. Visitor's position.

This effect is achieved thanks to the use of RPC functions.

Therefore, based on the content of the buffer, the action to be taken on the object under examination is chosen and executed both on the version of the object maintained on the server and on those maintained on the client devices [21,22].

5. Conclusions

Acquisition and use of 3D modeling systems is advancing its role in the management and enhancement of cultural heritage.

Today, new technologies used to disseminate information and to enhance cultural heritage are combined with traditional techniques, which complement each other, making sharing the immense knowledge kept in our cultural places easier and more enjoyable.

Use of apps in AR and VR means the viewer is no longer limited to observing but can use other senses to live a real and memorable experience. Thanks to digital 3D models and new technologies that allow you to explore environments in an interactive way, the "passive" viewer becomes "active" user, deciding what to see and the routes to follow, while sharing their opinions and feelings with others. In this way, the experience will remain in the memory of those who want to repeat the experience.

The proposed app, still under improvement and development, could be a good instrument both for scholars and those who are passionate to see the city from another point of view.

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