Determining the stylistic origin of the Toledo Gate (La Puerta de Toledo) in Ciudad Real, La Mancha, Spain Using Terrestrial Laser Scanning

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Introduction

The Toledo Gate (*La Puerta De Toledo*), located in the northern part of Ciudad Real, in the Spanish region of La Mancha,[2] was built under the reign of the kings of Castile and León, Alfonso X and Alfonso XI, as a part of the city's fortifications.[3] **(Fig. 1)** It served as a refuge and a defensive bulwark on the royal road between Toledo and Seville, even into the 19th century, when, in 1809, after the Battle of Ciudad Real, Napoleon's army rushed towards the city.[4] It would later be declared a National Monument in 1915. Ciudad Real was founded in the 13th century and became a place, in

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[1] Special thanks to Sarah Blick and Bradley Hostetler, Professors of Art History at Kenyon College, for comments that greatly improved the manuscript, the anonymous reviewers, and James McLeod and Jeff Du Vernay, former co-workers at CVAST USF, for data acquisition.

[2] K. Lipscomb, *Castilla-La Mancha* (West Palm Beach, Florida, 2005), 1-20.

[3] L.R. Villegas Díaz, *Ciudad Real en la Edad Media. La ciudad y sus hombres (1255-1500)* (Ciudad Real, 1981), 56-61; L.R. Villegas, *El urbanismo de Ciudad Real en la Edad Media (Datos y reflexiones)* (Ciudad Real, 1984), 33-34.

[4] J. Rudnicki "Memories of Józef Rudnicki" in *Pismo Zbiorowe Wileńskie* (1862), 64; J. Golderos Vicario *La batalla de Ciudad Real (marzo 1809). Un episodio casi desconocido* (Ciudad Real, 2004).

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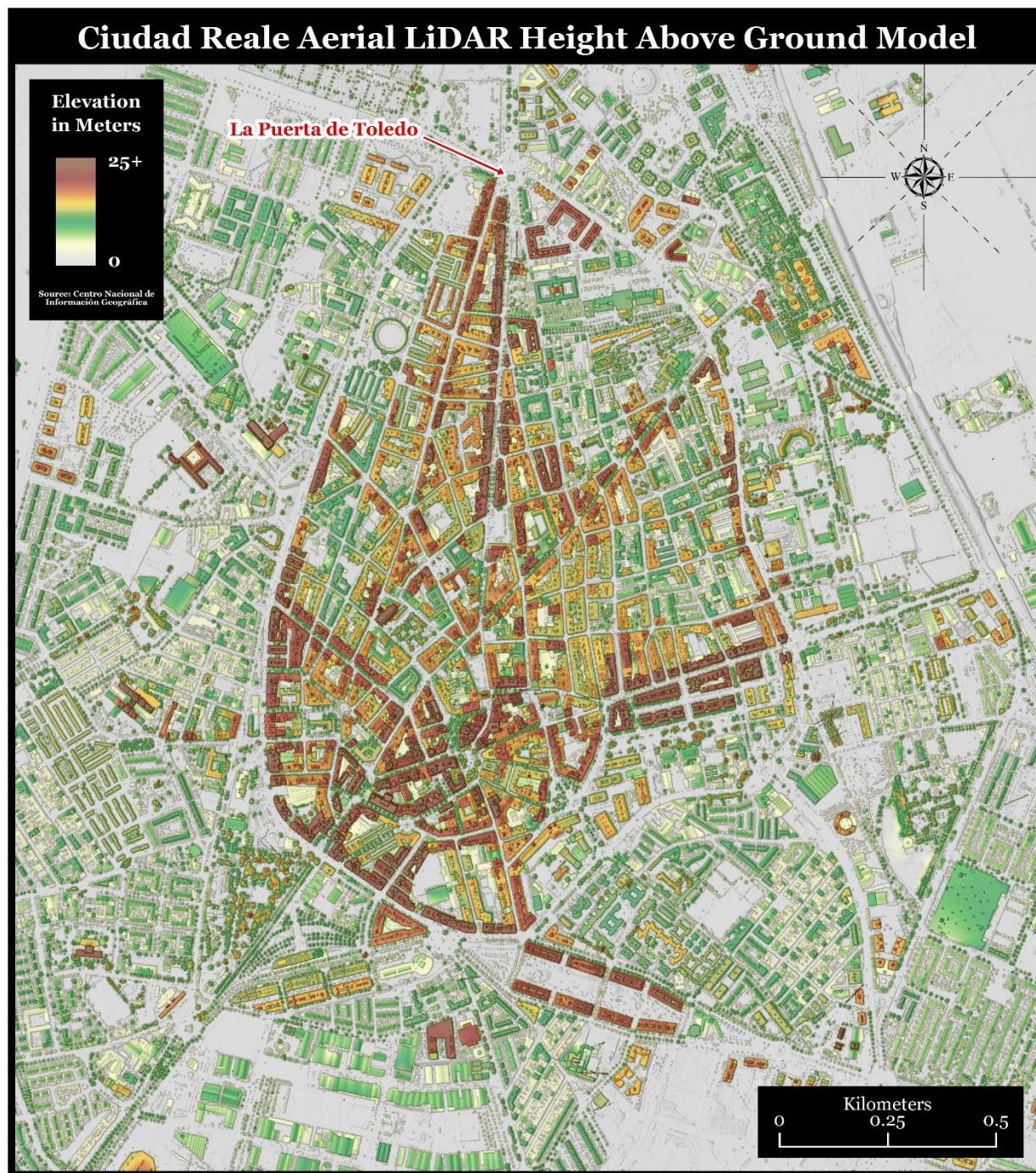the later Middle Ages, where three different cultures intertwined when a population of

Figure 1 The location of the Toledo Gate within the Aerial LiDAR elevation map of Ciudad Real, La Mancha, Spain, showing the height above the ground. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

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Muslims, Jews, and Christians formed the unified wealth of La Mancha.[5] Here, as in other parts of Spain, this unique cultural fusion resulted in an architectural style known as Mudéjar.[6] Because Mudéjar architecture was constructed in Iberia over a span of a centuries and was subject to regional variation, it was not a monolithic phenomenon. Virtually every architectural structure reflected the local interpretation of the style. Research on the Mudejar Toledo Gate undertaken by the University of South Florida's Center for Virtualization and Advanced Spatial Technology (USF CVAST) in 2016 included an analysis of architectural features, building phases, and ornamental decoration, in determining the construction period and stylistic provenience of the building. In particular, the Toledo Gate was documented using terrestrial laser scanning (TLS) which registered data as point clouds. The collected point clouds were processed and its derivatives, orthorectified images (a corrected image in uniform scale over its entire surface), analyzed **(Fig. 2 and 3)**. The orthoimages served as architectural documentation, sometimes replacing the traditional two-dimensional façade and elevation drawings, providing more detail, such as original colors and textures. This is

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[5] I. Ramírez González, "Informe de excavación arqueológica en el área afectada por la restauración y rehabilitación de la Puerta de Toledo de Ciudad Real," 2010 unpublished report, "Fundación Montemadrid" in A. Almagro Vida, I. Ramírez González, C. Clemente San Román (eds.), *When the virtual influences reality. The conservation project of the Toledo Gate in Ciudad Real (Spain), The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* (2015), 21-27.
[6] A. Pacios Lozano, *Bibliografía de arte mudéjar: Addenda (1992-2002)* (Teruel: Centro de Estudios Mudéjares del Instituto de Estudios, Turolenses, 2002), 7-10.

because the architectural features, down to the detail of each brick, could be analyzed

Figure 2 Orthographic image of a point cloud of the Toledo Gate in Ciudad Real, La Mancha, Spain, viewing the South and East elevations. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

via orthoimages. By analyzing these orthoimages, we were able to capture and describe

hidden and inaccessible ornaments, which allowed for a deeper analysis of the regional

stylistic variations of Mudejar, as well as the differences within *architectura militaris* and

its structures in La Mancha **(Fig. 4)**.

2. State of the Research

The results of the detailed excavations of Toledo's Gate area were published in

2010.[7] Prior to that, in 2009, the Toledo Gate Conservation Project was established

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[7] Ramírez González, *Informe de excavación arqueológica,* 1.

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Image Dimensions 22.8378m x 11.7059m   Image Scale 66.20615 pixels/metre   Camera Position 70.9731, 38.9771, 597.7565   Camera Direction 0.000, 1.000, 0.000
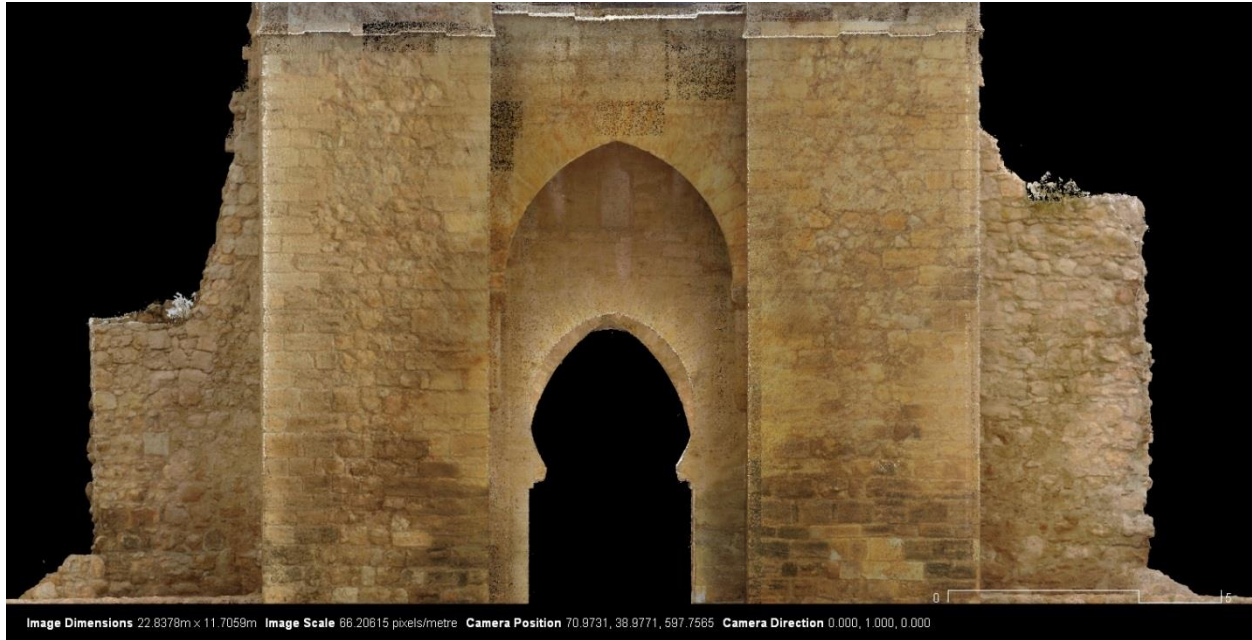
Figure 3 Orthographic image of a point cloud, viewing the South façade, of the Toledo Gate in Ciudad Real, La Mancha, Spain. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

Image Dimensions 27.5650m x 14.1289m   Image Scale 54.85209 pixels/metre   Camera Position 71.0155, 39.2107, 597.4509   Camera Direction 0.000, 1.000, 0.000

Figure 4 Orthographic image of a point cloud viewing the South elevation with the inside of the gate visible, including the stairwell and arches of the Toledo Gate in Ciudad Real, La Mancha, Spain. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

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and presented at the CIPA Symposium in Prague in 2011, then published in the article "The Toledo Gate in Ciudad Real, Spain. An Applied Case Study of the Seville Charter"[8] in 2015 in *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*.[9] The Montemadrid Foundation project created a photorealistic, virtual reconstruction of the Toledo Gate, informed by historical research. The reconstruction took into account the version of the Mudejar style from Toledo, which employed traditional Jewish decorative elements. Our conclusions, based on point cloud data, have led us to review the details of this study and to propose a small change to the reconstruction and stylistic provenience proposed by the Montemadrid Foundation.[10]

3. Methodology

The goal of the USF CVAST project was to create a detailed document of the architecture in a 1:1 representation of the object in its current surroundings. USF CVAST documented the exact state of the contemporary Toledo Gate with its preserved state of vaults, elevations, ornaments, and internal construction. The stylistic typology, descriptive analysis, and architectural studies were based on conscientious and

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[8] Almagro Vidal, *The Toledo Gate*, 1-8.

[9] A. Almagro Vidal *et al*, *When the virtual influences reality*, 21-27.

[10] A. Almagro Vidal *et al*, *When the virtual influences reality*, 25, fig. 13.
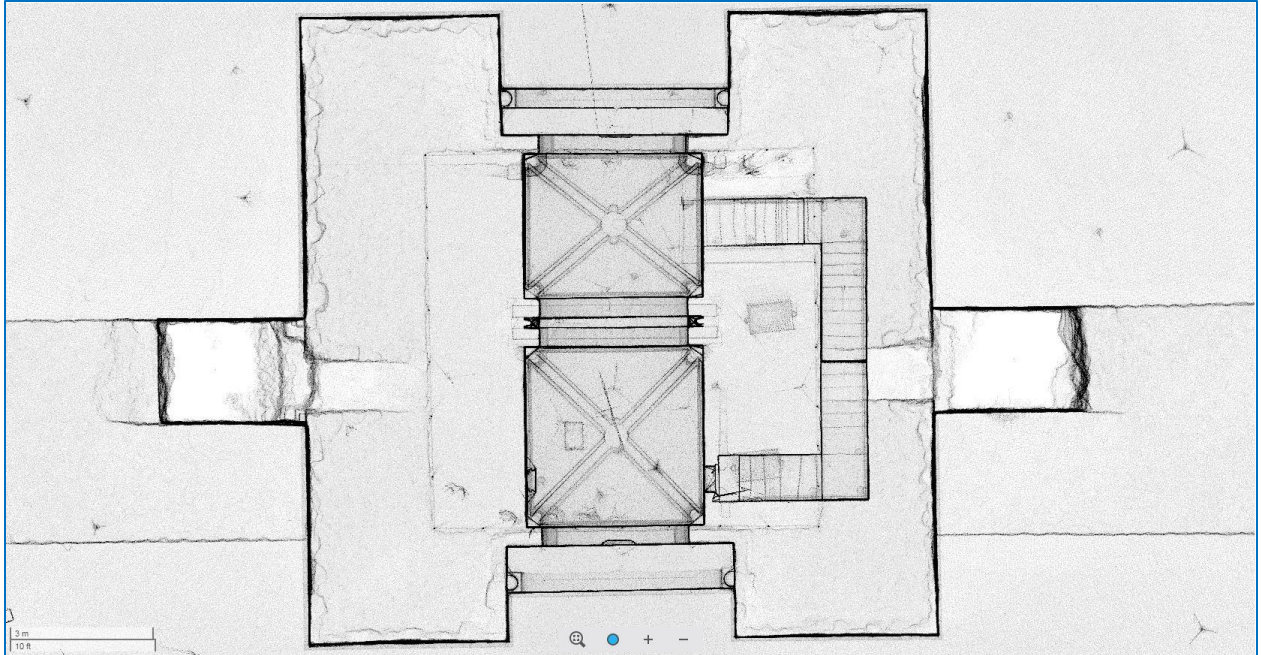
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Figure 5 Overview map as generated by FARO SCENE using the point cloud created by laser scans which shows the outline and features of the Toledo Gate, Ciudad Real, La Mancha, Spain. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

Figure 6 Color-corrected orthographic image showing the inside features, facing West, of the Toledo Gate, Ciudad Real, La Mancha, Spain. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.
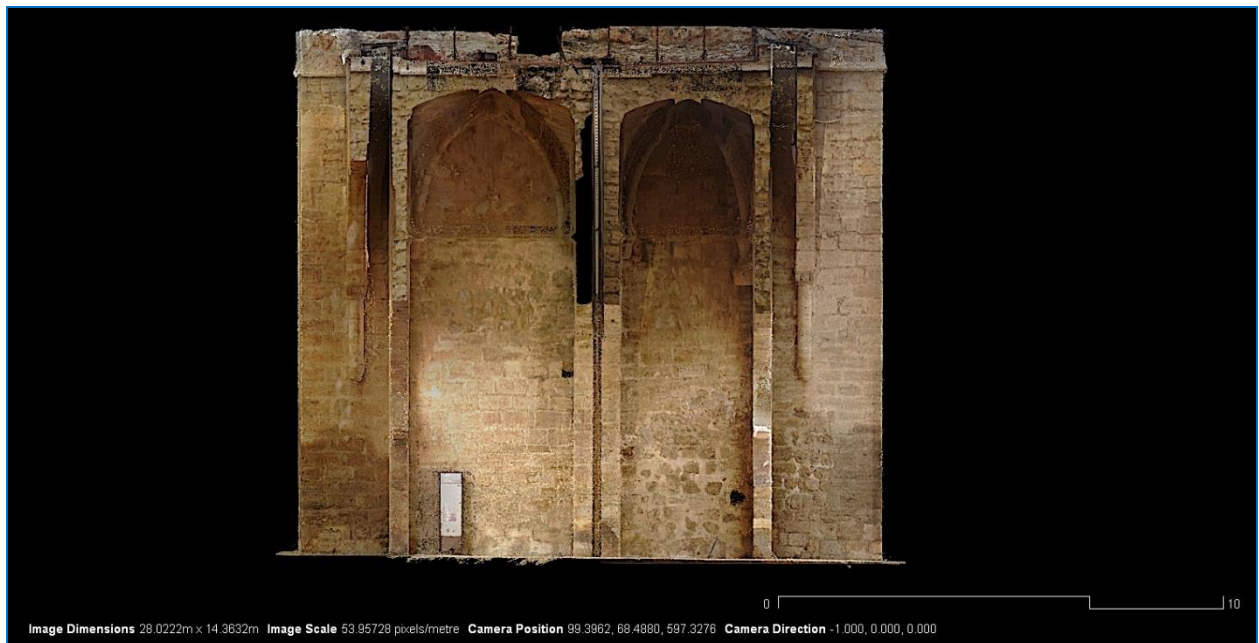
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fastidious drawings, which traditionally have been used as the documentation standard in architectural studies. Two-dimensional drawings of details provided technical specifics of the architecture, especially construction elements. The benefits of two-dimensional documentation are undeniable, however some situations require efficient action, immediate decisions, and proficient skills in order to salvage heritage, when there is no occasion for time-consuming, line-drawing documentation.

Advanced technology allows researchers to obtain fast, non-contact data acquisition. Based on this, documentation of a surveyed object can be used to create CAD (Computer Assisted Drawings) and quickly obtainable outputs. A point cloud represents points coordinated in a three-dimensional measuring system, which are defined by X, Y, Z. The aligned point cloud is a three-dimensional representation that can be used to generate traditional two-dimensional drawings or orthoimages. The higher the density and resolution of point clouds, the greater the accuracy and detail orthoimages can provide. Orthoimages created in TIF or in a JPG file can be attached to AutoCAD files and printed in standard documentation scale. Scanners and software can produce high - resolution images, so by using point clouds, researchers may reduce the amount of time spent rendering two-dimensional drawings. For example, computer software can measure the distance between points, generating more-precise dimensions than traditional methods.

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In extreme situations, orthoimages can be used as basic architectural documentation for stylistic classification, analysis of architectural features or for preservation, such as tracking erosion, structural disintegration, and measuring surface elevation, all of which are impossible to obtain when using traditional drawing methods **(Fig. 5)**. In addition, orthoimages provide an accurate representation of the area that may otherwise not be possible using traditional techniques. Orthoimages are also useful if architectural analysis and interpretation need to be performed without direct access to the surveying subject, or if some details require advanced study of aspects which are only noticeable by using various points of intensity and lightning **(Fig. 6)**. Focusing on the Toledo Gate as a case study here, will illustrated how decorative details of the gate's façade, which were easily to identify and measure by laser scanning, but which had hitherto been unknown years by researchers using traditional methods of documentation.

3.1. Methods

Two FARO Focus 330x terrestrial laser scanners were used to collect point cloud data. These laser scanners capture color as well as points during the scanning process, allowing for the production of a colored point cloud. Fifty-seven scans of the interior and exterior of the gate, including the stairwell and roof were done so that the current

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Figure 7 Color-corrected orthographic image of the West elevation of the Toledo Gate, Ciudad Real, La Mancha, Spain. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

standing gate (in its entirety) could be recorded for preservation and research purposes.

With the scanners' settings of a quarter-resolution point cloud with even-weighted

image capture and using the outside less than twenty-meter environmental setting, each

scan took around ten minutes to complete. Reference spheres were placed within the

scans with plans to be utilized later by the computer software. After collecting data in

the field, the scans were loaded into FARO SCENE 6.2 software for processing and

registration. This means that each scan was put in its proper place using the location of

reference spheres, as detected and assigned by the computer program, and color was

applied to the point cloud using the images collected by the scanner during the

scanning process. Once the software completed the process and registration steps, the

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reference spheres and other stray data points were manually removed from the point cloud. From FARO SCENE, the point cloud was exported as a PTS file for use in the Bentley Pointools software. Pointools allows for the creation of orthographic and perspective view images using the snapshot tool, providing easy exploration of the point cloud for research and analysis of the site. In order to perform detailed architectural analyses, Auto Desk ReCap 360 and Auto Desk Revit 2015 were also used.

This specific point cloud contained several instances of overexposure in certain places as a byproduct of using the scanner's inbuilt camera and collecting images outside during the day. To correct this overexposure, caused by the sun shining intensely on the east elevation, the orthographic images of the point cloud were brought into photo-viewing and editing software to darken and define the color and texture of the point cloud. In this case, these images were edited by changing the exposure, shadow, and contrast settings, utilizing the Macintosh Image Preview software. Through these changes to the orthographic images, the structural details were made more visible for analysis. For further exploration of the details of different elevations, the PTS files were uploaded to the free-to-use CloudCompare software. This software allows for the isolation of a desired portion of a point cloud through a clipping tool. Here the east elevation was isolated from the rest of the point cloud, rotated, and exported as a LAS file into ArcGIS software **(Fig. 7)**. Since the east elevation is a wall

and not a landscape, the wall had to be artificially rotated horizontally so that the

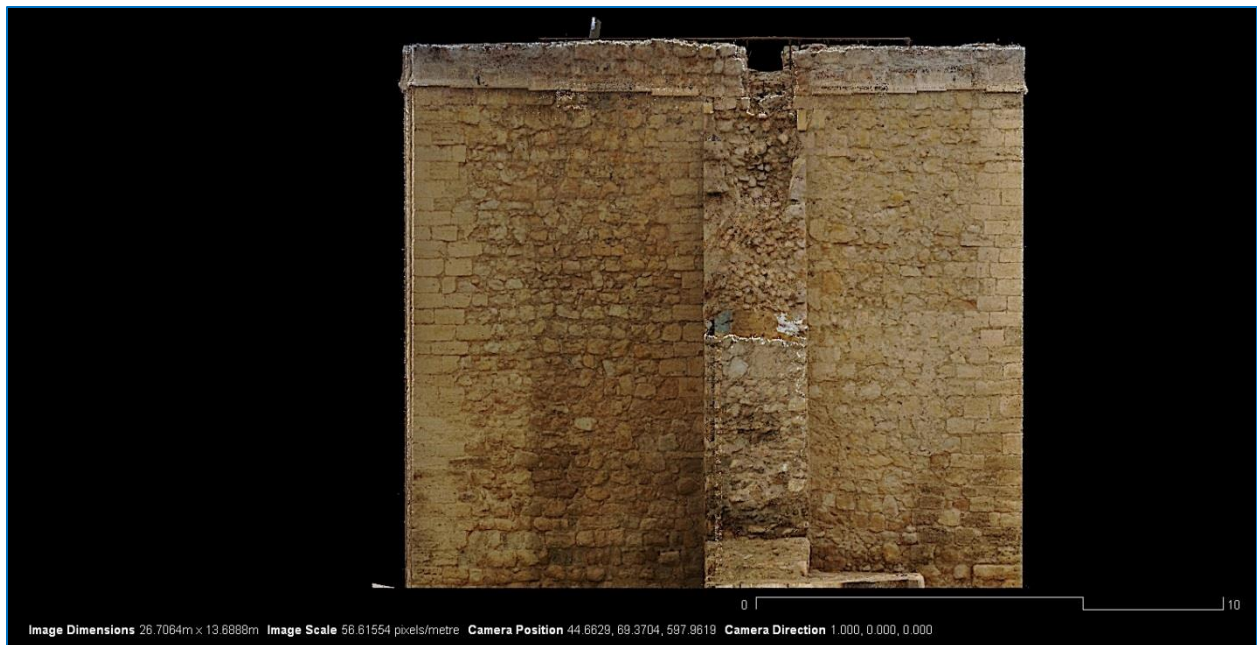software would read the wall's features with the values of an elevation. In ArcGIS,

Figure 8a and b Hillshade raster of the East elevation of the Toledo Gate as created in ArcGIS using the point cloud data collected by terrestrial laser scanners and converted from LAS to a raster. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

the LAS file (of around ten million points) was converted into a raster (graphics

utilizing a dot matrix data structure, generally a rectangular grid of pixels). This was

done using the nearest neighbor interpolation function where no points exist and the

point spacing measured 0.004 as seen in the LAS file **(Fig. 8a and b)**. The raster was then

used to produce hillshade **(Fig. 9a)** and multidirectional hillshade visualizations **(Fig.**

9b) that are used to make surface features distinguishable; in this case, each brick and

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its erosion were crisply defined. The hillshade used an azimuth (horizontal angle) of 315

and an angle of 35 degrees, which is the direction of an artificial light source used to

Puerta Del Toledo - East Elevation - Hillshade Raster

Figure 9a Hillshade raster of the East elevation of the Toledo Gate, Ciudad Real, La Mancha, Spain using point cloud data collected by terrestrial laser scans. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

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shade the raster. From this software, these rasters were exported as images for further

study.

Puerta Del Toledo - East Elevation - Multidirectional Hillshade Raster

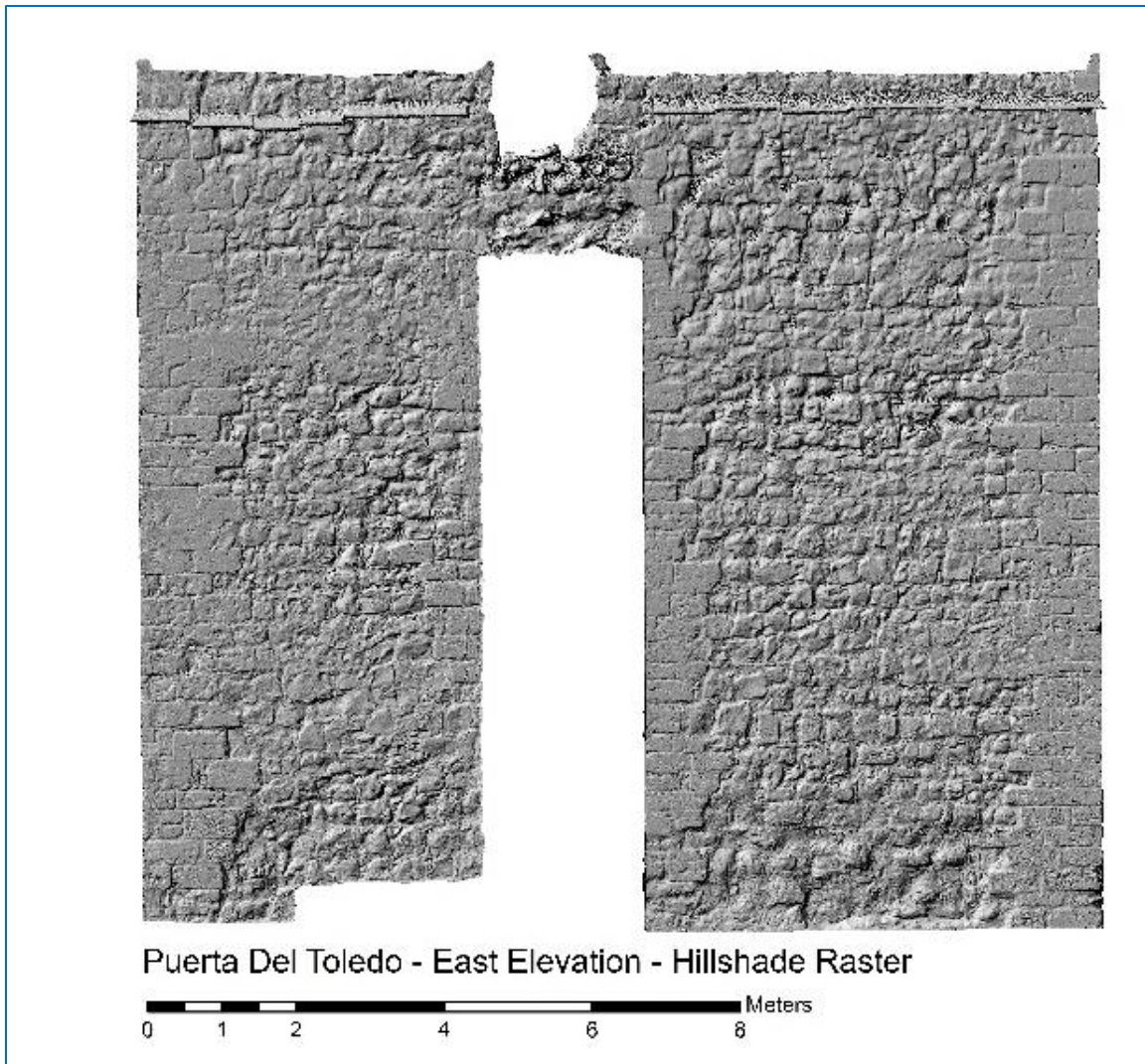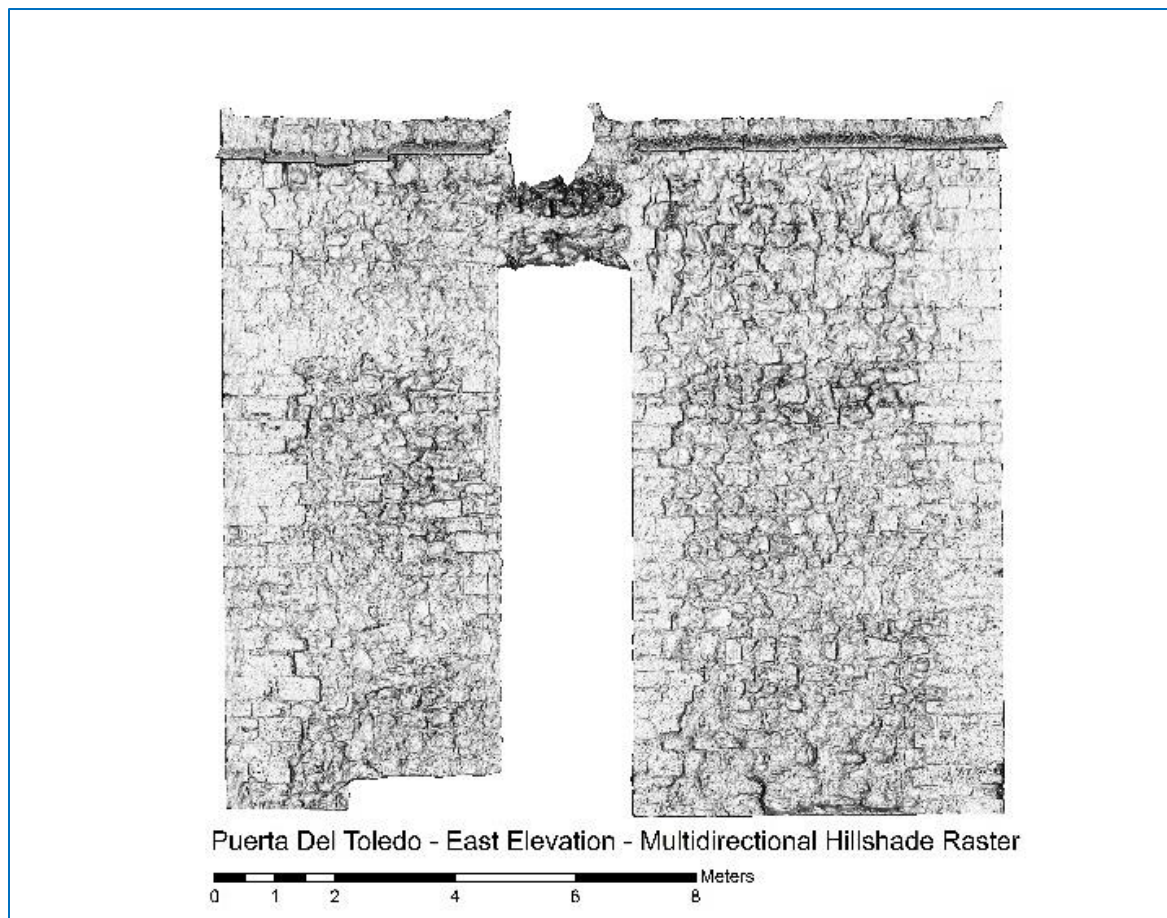**Figure 9b** Multi-directional hillshade raster of the East elevation of the Toledo Gate, Ciudad Real, La Mancha, Spain using point cloud data collected by terrestrial laser scans. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

4. Analysis

4.1. Architecture

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Crusader gate fortifications from the 11th and 12th centuries had distinctive architectural features. From the late 12th century they were constructed with two towers flanking a huge archway leading into a vaulted passage.[11] M. Histop writes that the twin towers projecting in front of the gateway made it possible to conduct a more-effective defense.[12] The lower third portion of the twin-towered gate was solid, whilst the upper two thirds housed a vaulted room pierced with arrow slits.[13] Consequently, the two towers were linked by a room that extended over the gate passage, and from which the portcullis and drawbridge mechanisms were operated.[14] This model was applied and developed by the builders of the Toledo Gate in Ciudad Real.

The Toledo Gate features a two-story internal elevation comprised of a blind upper story (created by a vaulted intersection) and a pointed transverse portcullis-arch wall, which, in turn, articulates the ground floor and divides the passage hallway into two bays. Both bays are covered by ribbed vaults resting on elaborately carved corbels/consoles attached to the walls on the level of the upper floor, along with the horizontal molding line articulating the internal wall sections on both tiers.

The Toledo Gate façade consists mainly of a horseshoe arch, flanked by avant-corps. The horseshoe arch rests on the mock capitals decorated with ornamented

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[11] According to M. Histop, *How to Read Castles* (London, 2016), 154, Because the gate was vulnerable to attack by fire, the gate passage was usually vaulted in stone.

[12] Histop, *How to Read Castles*, 156.

[13] A. Petersen, *Dictionary of Islamic Architecture* (New York, 1996), 89.

[14] Histop, *How to Read Castles*, 156.

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consoles. The façade's horizontal articulation repeats the internal horizontal structure, marking the internal vaults with machicolations, signified by a crowned pointed arch. This arch rests on the attached colonettes (half-columns applied to the structure), with capitals decorated by leafy vines. Columns were placed in the corners between the wall-façade and the avant-corps with the middle bay of the façade emphasizing the entrance, accentuated by the cascading effect of the superposed arches. Moreover, looking at the façade, the circularity of the horse-shoe arch framing the gate culvert is visually broken by diagonal arms of the internal pointed arch in its background. The visual break of the arches creates a decorative effect of a parabolic arch, evoking a sense of movement within the massive monolithic fortification. Placed between the façade arches, is the coat of arms of King Alfonso X of Castille and Leon.[15] The features made the façade an inviting and surprisingly decorative passageway through which to ride.

The walls of the edifice were erected using a type of wall construction employed throughout a vast area of Islamic architecture (i.e. Beq'a Valley, Lebanon).[16] Traditional photographic documentation of the Toledo Gate led to the following conclusions: that the walls (represented by stones) were used in a dressed form on the edges/corners and as uncut rubble joined with a large amount of mortar connecting the spaces in between.

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[15] Cf. T. Ruiz, "Towards a Symbolic History of Alfonso XI of Castile: Power, Ceremony and Triumph" in J. Todesca, (ed.), *The Emergance of Leon-Castile c. 1065-1500* (Franham, 2015).
[16] F. Ragette, *Architecture in Lebanon. The Lebanese House during the 18th and 19th centuries* (New York, 1980), 156.

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Yet, by using hillshade raster imaging, we observed that it is ashlar masonry that flanks

the central part of the structural wall. Its rubble masonry filling, constructed as rows of
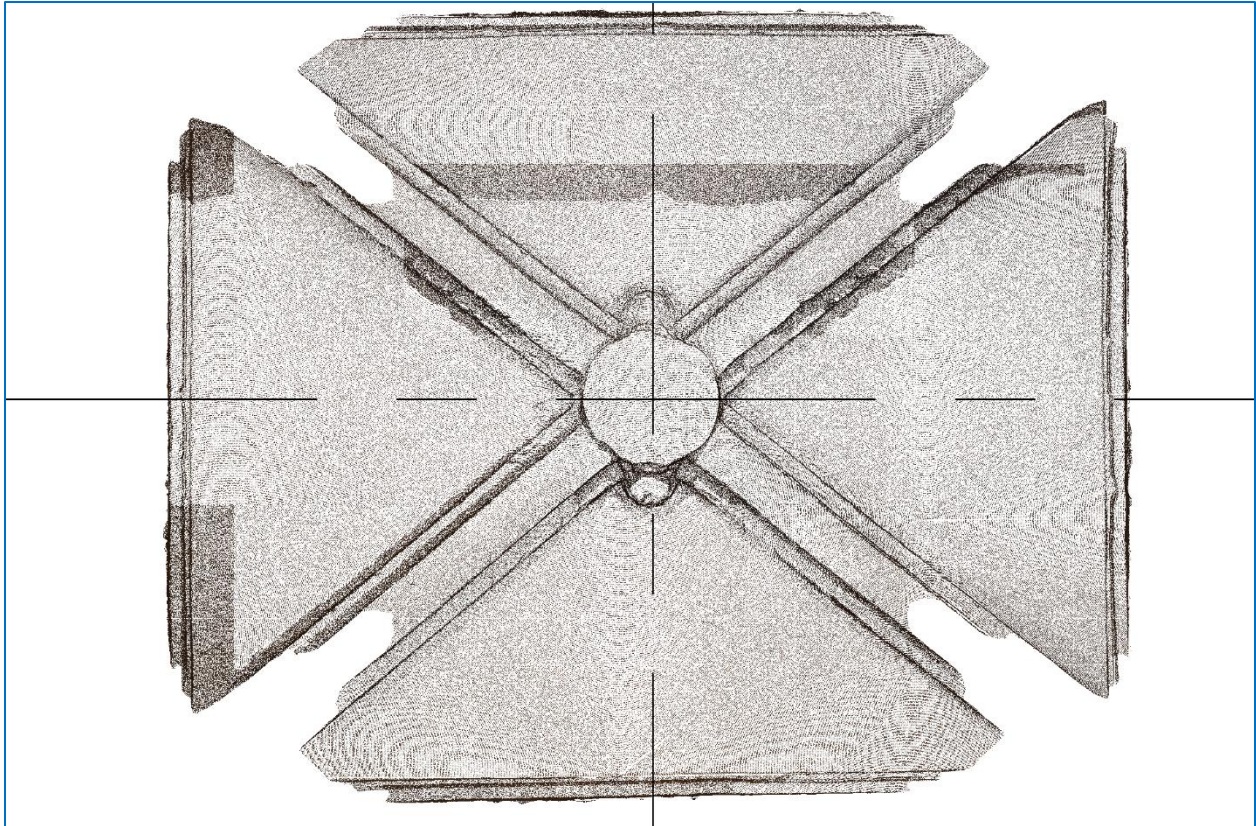

Figure 10 The Toledo Gate, Ciudad Real, La Mancha, Spain. The celling plan of the northern vault with the heads. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

roughly dressed stones, is neither obvious nor usual, while the central filling still

features a regular masonry course. Indeed, the in-between portion is articulated by the

profuse use of mortar, indicating that the structural walls might have been covered by

stone veneers which have since flaked off. Traces left by the veneers are noticeable in

each elevation.

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Using monochromatic orthoimages allows for detailed readings of the masonry surfaces. By utilizing the color overtop multi-directional hillshade raster of the
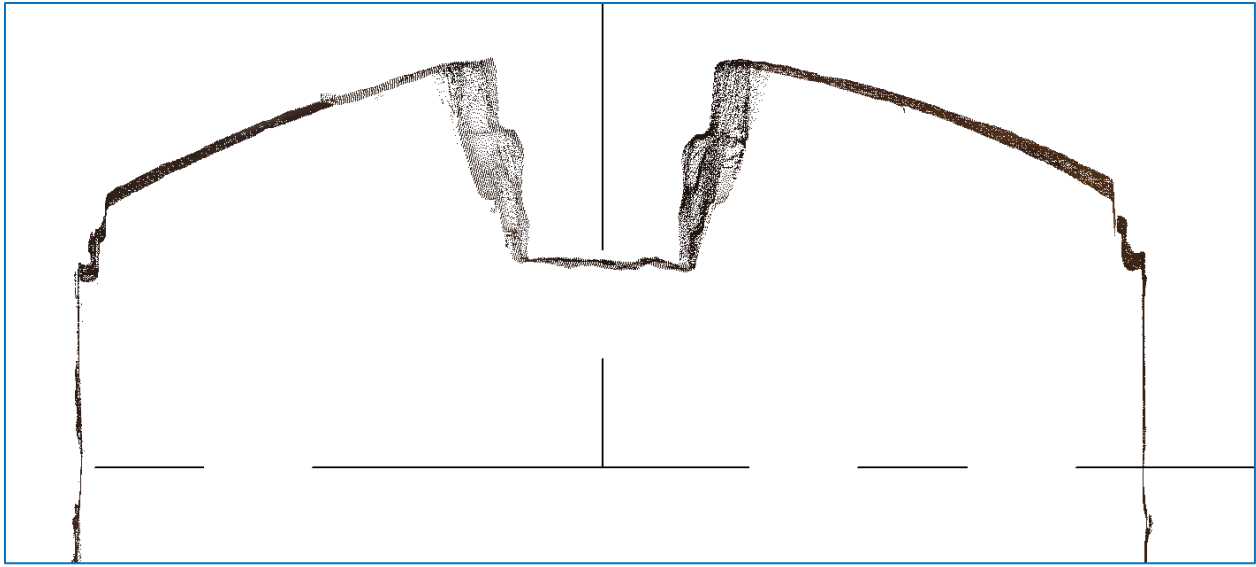

Figure 11 The Toledo Gate, Ciudad Real, La Mancha, Spain. Northern vault with profiles of the heads. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

elevations, we were able to control the minimal high-level differences between

particular layouts of the elevations. The imaging of elevation's vertical stratification

helped to define the chronology and pattern of surface constructing. As a result, when

the drawings or photographic documentation did not illustrate to what depth a

particular element was placed on the surface, the imaging could be used as a control

tool. Fusion of color overtop imaging with the hillshade raster allowed for a detailed

analysis of the wall structure. It showed which layers were laid down earlier/deeper to

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create a structural wall, as well as which part of the blocks or chunks of mortar were placed later to construct the final veneer masonry surfaces.

Such imaging variants assisted in the surface analysis consisting of descriptive and stylistic studies. Not only did they allow for the analysis of applied architectural structures, they demonstrated newer traces of erosions and other types of damage as well as helping scholars to analyze decoration. For example, the damaged and eroded lower third of the façade is decorated with rustication. This masonry technique emphasized the gate's edges/corners, creating an aesthetic effect contrasting rough uncut surfaces with the smoothly dressed ashlar blocks. While the rustication of the entire lower-part of the gate is typical, the higher the elevation, the weaker the rustication. This practice was found adorning the surfaces of ground gates and arcaded tier buildings (e.g. Porta Maggiore, Rome; Sanctuary of Jupiter Anxor podium, Terracina; and the Puerta de Bisagra, Toledo). The strong visual effect imitating or emphasizing the massive structure in the lowest part of the gate was desirable. Adding to the rustication, other decorative elements evoked the visual rhetoric of Mudejar defensive gates. These included exposed portions of the structure of arches, such as voussoirs, intrados, and extrados.

4.2. Detailed decoration

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The detailed scrutinizing of the point cloud allowed for exploring the highest

and most-hidden areas of the structure. Documenting the spatial relations between

specific elements, such as the distance between a rib vault's keystone and the upper

Figure 12 The Toledo Gate, Ciudad Real, La Mancha, Spain. The northern vault with the front head. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

elevation, or the upper internal portion of the machicolation, and the portcullis arch were never particularly accessible to scholars. The new techniques changed this and with the analysis of these ornaments, helped determine the chronology of buildings.

For example, during the 2013 reconstruction of the Toledo Gate, four decorative sculpted heads (placed in the rib vaults' key stones) were discovered by workers on scaffolds.[17] Prior to this, there was no indication that such sculptures ever existed, but working with terrestrial laser scanning (TLS) derivatives permitted researchers to examine these hidden details **(Fig. 12)**. Using point cloud interpretation and exploiting intensity data and light conditions, these sculptures were fully recorded **(Fig. 10)**. Three are situated on the northern side, while the fourth is placed on the keystone on the south. Once a close analysis of the sculpting technique is complete, it may allow researchers to assign a more secure date to the Toledo Gate **(Fig. 11)**.

Another decoration which was already known, but which has eluded close visual recording that was captured while scanning, is King Alfonso X of Castile and Leon's coat of arms, a popular form of decoration of gate façades, as seen on the gate of Alcantara Bridge in Toledo.

4. 3. Provenience

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[17] Published report: ciudad-real.es. Fundación Montemadrid: http://www.ciudadreal.es/turismo/qué-ver-en-ciudad-real/puerta-de-toledo.html.

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Scope for performing the analysis by means of orthoimages resulted in

ascertaining the quintessential stylistic features of the Toledo Gate, which, in turn,

determined a more-precise construction provenience of the Toledo Gate, even though

earlier studies classified them as one style. By comparing the Toledo Gate with other

medieval gates from the La Mancha region, it is easy to see that the differences in the

Figure 13 (Left and center) The head from the Toledo Gate (point cloud). Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies; (Right) Villard de Honnecourt's sketch of a head MS. 19093 French Collection, Bibliothèque Nationale, Paris, (No. 1104 Library of Saint-Germain-des Prés until *c*. 1800). Photo: Public Domain.

Mudejar gates are due to stylistic and chronological reasons. A. Almagro Vidal, I.

Ramírez González, and C. Clemente San Román had previously linked the Toledo Gate

with the main gate of the nearby Calatrava la Vieja. [18] Unfortunately, both gates'

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[18] A. Almagro Vidal *et al*, *When the virtual influences reality*, 24.

provenience emerge from two different architectural backgrounds. The main gate of

Calatrava la Vieja, designed as a crusader fortification,[19] is typical of Templar military

architecture such as that seen at Krak des Chevaliers, Syria, Toron, Lebanon, and

Belovoir, Israel).[20] In contrast, the Toledo Gate was a fortification designed within the

context of Islamic-Christian architecture.[21] This explicit difference is noticeable in its

aesthetic redaction.

Seeking the source of inspiration for the Toledo Gate among the Mudejar-styled

architecture within nearby regions, one gate located near Toledo and three gates of the

city walls in Toledo were analyzed. The gate, that of Castillo de San Servando,[22] is

located on the hill in front of city walls of Toledo. Here the kind of machicolation

applied along with jambs emphasizes the horseshoe arch which rests on a profiled

impost that forms part of the wall itself -- resembling those used in the Toledo Gate. The

first gate in the city walls of Toledo is the Puerta de Bisagna Antigua (also called Puerta

de Alfonso VI, after the King who captured Toledo in 1085).[23] The gate is related to the

[19] K.A.C. Creswell, "Fortification in Islam before AD 1250," *Proceedings of the British Academy 38* (1953), 45-67; R.D. Pringle, "Crusader castles; the first generation," *Fortress* 1 (1989),102-145.
[20] Cf. M. Piana M and Ch. Carlsson, *Archaeology and Architecture of the Military Orders* (Oxford, 2014).
[21] Cf. C. Rahn-Phillips, *Ciudad Real 1500-1750, Growth, Crisis, and Readjustment in the Spanish Economy* (Cambridge, MA, 1979); S. Menache, "Medieval states and military orders: the Order of Calatrava in the late Middle Ages" in I. Shagrir IR. Ellenblum, J. Riley-Smith (eds.), *In laudem Hierosolymitani: Studies in Crusades and Medieval Culture in Honour of Benjamin Z. Kedar* (Franham, 2014), 457-468.
[22] F. Fidel, "'Cuaderno IV. El monasterio toledano de San Servando en la segunda mitad del siglo X," *Boletín de la Real Academia de la historia* 59 (1906), 280–331.
[23] B. Pavon Maldonad, "La Puerta de Bisagra Vieja en Toledo, nuevas orientaciones sobre la arquitectura medieval toledana," *Toletum: boletin de la Real Academia de Bellas Artes y Ciencias Historicas de Toledo* 32(1995), 85-119; M. Sanchez, "Construccion y trazado de la Puerta de Bisagra Vieja, » *Anales toledanos* 36 (1998), 9-26.

Toledo Gate in terms of articulation of the jamb of the large archway and the use of external and smaller-internal horseshoe arches. Yet the Puerta de Bisagna Antigua was executed in the early- medieval Toledo Mudejar style,[24] characterized by the fusion of

Figures 14a and b (Left) Vaulting of the aisle of the León Cathedral. Photo: K. Oleś; (Right) Vaulting of the passage of the Toledo Gate in Ciudad Real (point cloud). Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies.

stone and brickwork creating ornamental façades, whereas the remains of the Toledo Gate façade are executed in stone only.

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[24] A. Bautista and E. Bordonau, "The Mudejar Bookbindings with interlaces of the cathedral of Toledo," *Anales de Documentacion* 15 (2012), 1-30.

The second gate is the Alcantara Gate (Puerta de Alcantara) in Toledo. Its horseshoe arch is flanked by corner avant-corps (risalits), a characteristic feature of the Toledo Gate in Ciudad Real. The Alcantara Gate, with the exception of the articulation of the façade by alternating stones with narrow horizontal layers of bricks, is aesthetically parallel to the Toledo Gate. Its ground floor is veneered with rustication, using massive stone blocks. The rustication of corners/edges are completed by brickwork, while the spaces between the rusticated corners are filled by regular masonry courses of roughly dressed stones. The same structure seems to have been employed in the Toledo Gate. Nonetheless, its façade was executed using only stones that varied in size, creating a similar decorative effect as that found on the Alcantara Gate. In addition, the horizontal decorative molding, which could be a cornice, or a variation of *taenia* (rail), crowns the second tier in a similar manner as the Toledo Gate.

In front of the Alacantra Gate, constructed on the eastern side of the walls, is where a gate of the Alacantra Bridge is located. This is the third gate in Toledo that might share the common source of inspiration with the Toledo Gate. The internal Gothic portcullis pointed arch of the bridge gate exactly matches the portcullis Gothic arch of the Toledo Gate in Ciudad Real. Hence, the Toledo Gate seems to be inspired by the same trends as the Alcantara bridge-gate complex; these were common throughout medieval Spain, as an advanced example of fortifications. In fact, although the Alcantara bridge dates back to Roman period, this damaged bridge was rebuilt and
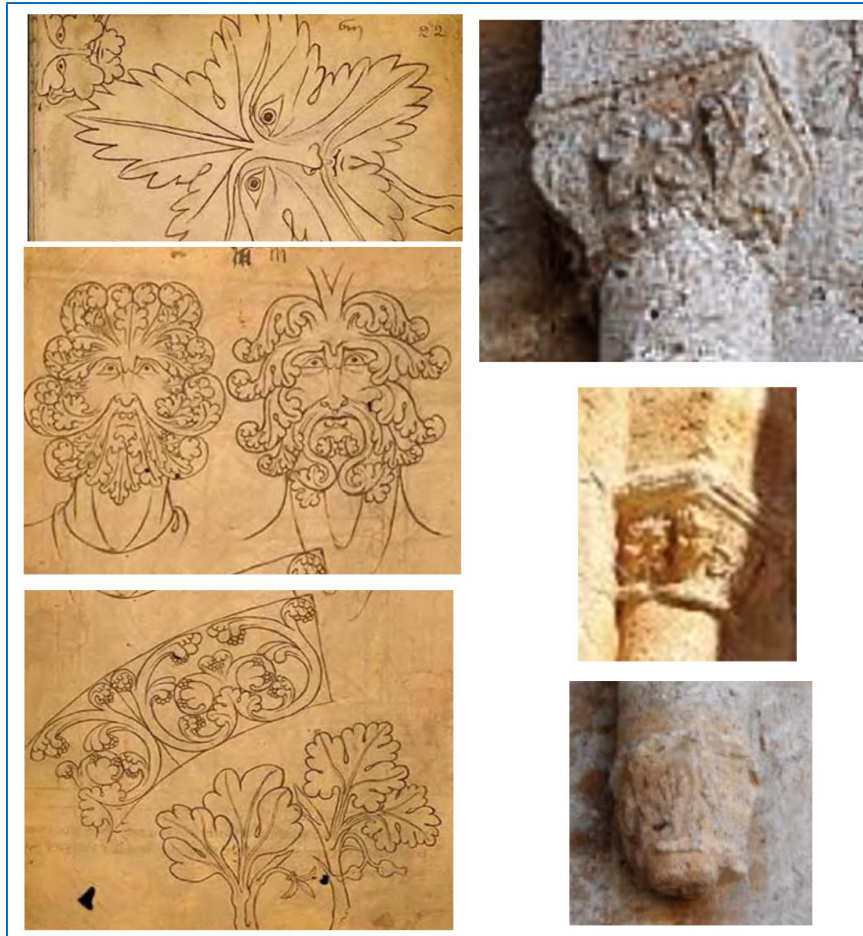
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Figure 15 The floral ornaments from the Toledo Gate (point cloud) and Villard de Honnecourt's sketches of the floral details (French Collection, Bibliothèque Nationale, Paris (No. 1104 Library of Saint-Germain-des Prés until *c*. 1800). Photo: Sketches, Public Domain and photographs, University of South Florida's Center for Virtualization and Applied Spatial Technologies.

expanded when Alfonso X of Castile and León added the Alcantara Gate in 1257[25] and

commissioned the construction of the Toledo Gate in Ciudad Real. The common source

of these buildings leads one to conclude that Alfonso X formulated a visual rhetoric of

his reign that can still be read from the specific aesthetic and architectural program

preserved in remnants from his period.

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[25] Cf. J. P. Cortès Pérez, J. J. de Sanjosé Blasco, A. D. Atkinson, L. M. del Río Pèrez, "Assessment of the Structural Integrity of the Roman Bridge of Alcantara (Spain) Using TLS and GPR", *Remote Sensing* 10 (2018), 387 (18 pages).

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When seeking the provenience of the Toledo Gate, it is worth considering the attached colonettes, a small slender column, placed between the wall-façade, and the avant-corps. The columns are detached from the ground, so their function does not seem to be supportive, but decorative. Nonetheless, such ornamental slender columns are a rare phenomenon in military architecture. Presumably, the reason why the columns, which are detached from the ground, appear in this context is that they are a modification of traditional consoles or corbels, on which a machicolation arch usually rests. However, the ribs, the vaults, decorative keystones are especially characteristic of French Îl-de-France Gothic that flourished in Spain by means of Burgos and León Cathedrals circa 1255.[26] Construction of the latter was supported by Alfonso X, the same King who commissioned the Alcantara bridge-gate complex in Toledo and the Toledo Gate in Ciudad Real **(Fig. 14 a and b)**. In contrast, Islamic architecture uses reduced columns/consoles in conjunction with horseshoe arches resting on mock capitals decorated with ornamental consoles, which are then crowned by a pointed arch above, as used in the Great Mosque of Timnal, Algeria **(Fig. 16)**.[27]

French influences in Toledo Gate are also indicated by the sculpted busts found in the vaults' keystones and in the manner of executing the floral ornaments. Descriptive features of busts, such as face articulation and the vine leaf forms **(Fig. 15)**,

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[26] Cf. J. J. Rivera Blanco, Las Catedrales de Castilla y León (León, 1992).
[27] D. Hill and L. Golvin, *The Islamic Architecture of North Africa* (London, 1976), 14.

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seem to follow the rules contained in the sketchbook of Villard de Honnecourt (*c*. 1200?-*c*. 1250?), utilized by traveling French workshops, which were scattered throughout medieval Europe. [28] The type with slim long facial features that characterized of the busts seems to follow Villard's explanatory drawings with the precise instructions for executing heads;[29] this was done by constructing an isosceles triangle on a given finite straight line. Such details as shapes of eyes, hairstyle, lips are also found in Villard's aesthetic program **(Fig. 13)**.

5. Limitations

A few problems arise in viewing and creating orthographic images. One of the most visible issues is the sections of the point cloud that were exposed to significant sunlight, causing large parts of it to be overexposed. This requires color correction to combat spots of intense light.

Vertical sections and higher areas of the model, such as at and under the arches, contain blurred images and lower point cloud density. In viewing the original point cloud data in FARO SCENE, it seems that these blurred sections emerge from the scans

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[28] MS. 19093 French Collection, Bibliothèque Nationale, Paris (No. 1104 Library of Saint-Germain-des Prés until c.1800); MS. 19093 French Collection, Bibliothèque Nationale, Paris, (No. 1104 Library of Saint-Germain-des Prés until *c*.1800).

[29] Cf. M. T. Zenner, "Villard de Honnecourt and Euclidean Geometry", *Nexus Network Journal* 4 (2002), 65-78; R. Bechmann, *Villard de Honnecourt. La pensée technique au XIIIe siècle et sa communication* (Paris, 1991), 72-73; J. Jarzewicz, "Rysunek architektów średniowiecza (Villard de Honnecourt i inni,"*Disegno – rysunek u źródeł sztuki nowożytnej* (Toruń, 2001), 73.
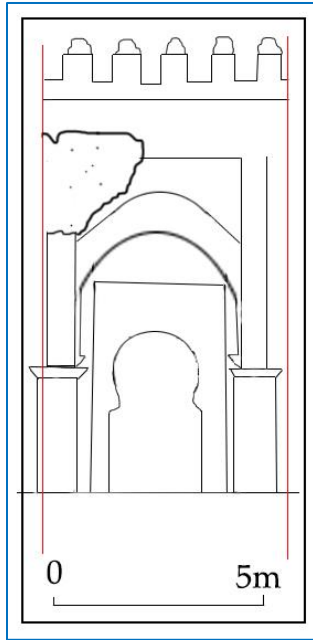
Figure 16 Section of the Great Mosque of Timnal, Algeria. Photo: University of South Florida's Center for Virtualization and Applied Spatial Technologies

themselves. Blurry images could not be found within the applied pictures. This image quality issue could be an artifact of the scanning process, as this site was not closed to the public— meaning various individuals walked through the scans during the scanning and photo capture process. These blurry images could also be a product of making a large number of scans of the area and so, too many pictures could be applied to the point cloud.

However, with scans like those from inside the arches, this seems unlikely. Image quality depends upon lighting situations. The inside arches receive less natural light than those outside areas of the gate; this may also be the cause of the blurriness in the pictures applied to those sections of the point cloud. An opposite problem occurs on the outside sections of the arches. This section contains a shiny metal plaque, creating different light effects depending on the position of the scanner and the sun. Shiny metal objects also create stray points that need to be removed from the point cloud so that the pictures from that area can still be applied to the correct data points. This could also account for the inability to find blurry images within the scanner photos.

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It is also important to note that weather conditions on the day of scanning varied between sun and rain. The scanning team, because of these weather problems, performed fewer scans, leading to a lower point density in some fields of the point cloud, especially when compared to other, more-complete point cloud, such as the east elevation. Blurry images and a few images with noticeable spots of rain can be removed, but they seem to make little difference to the image resolution. Weather conditions, combined with a limited amount of time, led the scanning team using a lower point cloud resolution setting on the scanner. With a higher point cloud resolution, it is possible to make fewer scans, but it also takes more time per scan.

Conclusions

This paper presents the advantages of using orthoimages as architectural documentation. Point cloud and orthoimages provide more spatial detail and more original colors and textures, which can significantly advance architectural research. By using the three-dimensional model of the Toledo Gate, along with descriptive analyses, it becomes possible to map spatial relations between particular architectural elements. As a result, we were able to describe, in detail, the "gate model" which was applied and developed by medieval builders while building the Toledo Gate. Analyzing point cloud and orthoimages (Hillshade raster imaging, monochromatic orthoimages, and the color over the top multi-shade raster of elevations) allowed for a detailed analysis of wall

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structures, determining the pattern of surface construction by showing the stratigraphy of the wall layers.

Moreover, various point cloud analysis let us record hidden detailed decoration, including four carved stone busts, as well as affording a closer study of the ornamental repertoire. Consequently, we were able to provide an advanced study considering the masonry techniques and the resulting visible effects, which, when combined with stylistic studies, resulted in a determination of the Toledo Gate's provenience. The Toledo Gate is a visible confluence of Islamic architectural elements (such as masonry wall construction and horseshoe arches, consoles) and elaborate French forms (pointed arches, attached colonettes, rib vaults, and an ornamental repertoire).

Thanks to the point cloud and orthoimage analysis, we were able to determine many features of the Toledo Gate, which could serve as a foundation for further research. By syncretizing a local variation of Mudejar architecture and new trends of the Îl-de-France Gothic style, the Toledo Gate is an example of a specific aesthetic that represents the architectural rhetoric of buildings commissioned by Alfonso X. The architectural similarities between the Alacantra Bridge Gate and the Alacantra Gate in Toledo, and the Toledo Gate located in Ciudad Real created a visual connection and articulation of the Royal Road between towns of Toledo and Seville.

While the stylistic reconstruction of the Toledo Gate proposed by Montemadrid Foundation is an interesting contribution in a historical sense, while taking into account

the version of the Mudejar style from Toledo, which employed Jewish elements, does

not include or consider the indicators which are readable in the existing gate. Whereas

Toledo Gate in Ciudad Real, according to our analysis, is an example of the Alacantra

Bridge Gate complex executed in Mudejar style with the addition of new French Gothic

style. ❧