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Aleppo Pixelated: An Urban Reading through Digitized Historical Maps and High-Resolution Orthomosaics Case Study of al-ʿAqaba and al-Jallūm Quarters

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Abstract: This article relies on a combination of digital and analog data to analyze the 2D urban development of al-ʿAqaba and Jallūm districts in the Old City of Aleppo. The dataset consists of vectorized historical maps of the city spanning various historical periods. The oldest map in the collection dates back to the 1900s. Additionally, there are high-resolution orthomosaics created from a 3D model obtained through Terrestrial Laser Scanning (TLS) and Aerial Photogrammetry techniques. Through the analysis and integration of these various data types, the article proposes an analog-digital workflow that tracks the alterations in the urban fabric of the designated study area. The analysis primarily examines the alterations in the city's two-dimensional layout and the distribution of mass and void. Tracking the changes in the street network of the studied area is the main goal of this research, along with recognizing the spatial changes in the built environment. The article identified changes in both the open spaces and the street layout.

Keywords: digital urban heritage; laser scanning; point cloud; aerial photogrammetry; historical map; cartographic visualization; changes in urban space

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1. Introduction

The digitization of historical analog maps serves as reference points to better understand and trace the development of historical centers. For example, the digitization of historical maps allows researchers to compare the layout of cities from different time periods. By overlaying these maps, it is possible to analyze how historical centers grew over time and identify those urban expansions. This process provides invaluable insights into the factors that have shaped the development of cities, such as the influence of trade routes, political and religious influences, and population growth. However, this process poses several challenges, with the biggest one being the limited survey techniques used to produce these maps.

Equally important is the use of digital technology and its innovative approaches for studying and analyzing the historical urban fabric, particularly in cases of significant damage. It not only allows for rapid field acquisition and off-site damage assessment, but also informs post-disaster decisions, restoration, and conservation projects. Additionally, it enables tracking the progress and quality of such projects and provides insights into the past and a broader context of the 3D spatial development of a city.

The Old City of Aleppo is an outstanding example of urban forms in the Mediterranean region. The city is characterized by a complex network of narrow and winding streets that reflect an older palimpsest from the Hellenistic period [1]. Still, some researchers posit that the conscious planning of the city goes back to the Bronze Age [2].

This study takes advantage of technological leaps in the field of 3D documentation, visualization, and analysis. It utilizes a hybrid point cloud acquired through Terrestrial Laser Scanning and Aerial Photogrammetry to compare and identify the 2D changes of the urban fabric in two districts in the Old City of Aleppo. The study area encompasses al-Jallūm and al-ʿAqaba quarters, from the Umayyad Mosque in the east and north to Bāb Qinnasrin in the south and Bāb Antakia in the west.

2. State-of-the-Art

With the rapid development of photogrammetric and laser mapping, both aerial and terrestrial, acquiring high-resolution spatial information is becoming easier, faster, and more effective [3,4]. The spatial data are finding their applications in various domains. One of the most prominent is in urban heritage.

Using digital models in urban heritage studies has been an ever-growing trend. Initially, reality-capture models provided the opportunity to create aesthetic and accurate historical models of cities [5]. However, their use has developed to be a tool in smart-city mapping and land administration [6].

Essentially, it can be considered the ideal platform for implementing various analyses, such as urban thermal environments for investigating thermal comfort [7], solar potential estimation [8], urban accessibility [9], geometric analyses for conservation and valorization purposes [10], and designing interactive experiences [11]. One of the most interesting applications of 3D urban data sets is applying feature-based and deep learning methods to extract information about roads and traffic that can be used for the creation of High-Definition (HD) maps necessary for the development of autonomous driving and traffic visibility evaluation [12].

Cartographic representations play a pivotal role in the design, planning, and implementation of any restoration or renovation work. Historical maps provide invaluable information about the development and the state of conservation of an urban area. The transition into the digital platform has brought forward extensive research concerning the methods of transforming, geo-referencing, and disseminating old maps in the digital age. Lia Maria Papa explored the innovative techniques for cartography in the 19th century and the use of technology to design innovative approaches to extract valuable information from old maps [13]. Milan Talich discusses requirements for the digitization of old maps, as well as the different workflows for the online geo-referencing of said maps [14].

An example of the use of old maps in tracking urban development is the work of Shujing Dong and Danjie Shen [15]. The authors suggest the creation of a digital historical urban landscape information database in Luoyang, China, in different historical periods, based on information available in historical maps. A group of researchers also investigated the reconstruction of the landscape through old maps of Katowice, Poland [16].

Closer to home, and in the case of war-afflicted historical centers, the diversity of the damage has rendered the traditional methods of survey, documentation, and analysis very longsome, unpractical, and possibly inaccurate. Therefore, 3D urban surveys can be used to conduct in-depth analysis of other aspects of the urban spaces, such as urban density and monitoring the change in mass and void. Inherently, "as-built" models offer an increased accuracy of the results of the analysis because of the reliability and precision of the models, as well as the wide range of available tools and plugins that can be used for analysis. Recent restoration projects in Aleppo are already utilizing digital technology such as Terrestrial Laser Scanning (TLS) and Photogrammetry as a base and/or supplement for the projects' workflows [17,18].

3. Materials and Methods

Aleppo's layout is characterized by a street grid that still preserves the palimpsest of the Hippodamian plan of Hellenistic Aleppo [1]. Various maps were prepared for Aleppo, the earliest of which was prepared by Carsten Niebuhr in 1778 and published in his book titled, *Travels through Arabia and other countries in the East* [19]. Despite the limited accuracy and the lack of scale, it is the first cartographic map prepared for Aleppo, outlining the street network, built blocks, and the most important urban elements of the city [19].

By the late 18th century, the use of the accurate topographical survey was a necessity, mainly to facilitate the planning of infrastructure projects, recording and organizing of ownership rights, and overseeing the urban growth of any urban center. Various government agencies have mapped Aleppo throughout different historical periods, ranging from the Ottoman era to the French Mandate period (1919–1946), as well as in the 20th and 21st centuries [19]. Researchers have also created maps of the city during their studies [20].

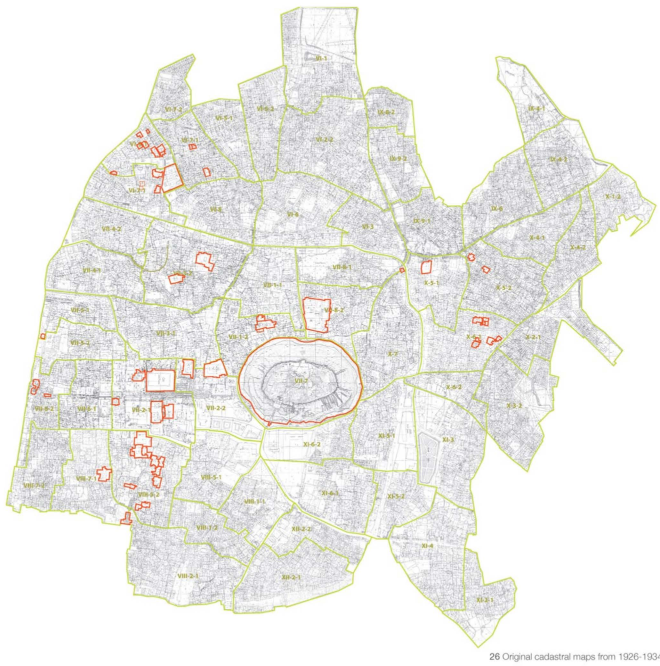
Aleppo has been the subject of many urban and architectural studies by renowned researchers [20] such as Heinz Gaube and Eugen Wirth [21], Jean-Claude David [22], Jean Sauvaget [23], and Giulia Annalinda Neglia [24,25]. These studies heavily relied on 2D plans and sections to visualize the urban development of Aleppo. This reliance is understandable given the technological limitations of the 19th and 20th centuries in terms of surveying, modeling, and visualization.

This study relies on the combination of three maps: the Ottoman map of Aleppo, the French cadastral maps of the 1930s, and the maps of the Aleppo Archive in Exile project 2017 (Table 1).

The Ottoman map of Aleppo is the oldest map of the city with scale reference. Gaube and Wirth mentioned it, but it was not accessible to them with full resolution [21]. This map is now digitally available through the website of the National Library of France under the title "Plan Gabriel de la ville d'Halep" [26]. In the library archives, the map is attributed to the 18th century without providing a definite date. However, Gaube and Wirth suggest it is from 1900, and this paper follows suit. They also mention that it was prepared by the Ottoman Road and Bridges engineers, with a scale of 1:5000 (Figure 1a) [21].

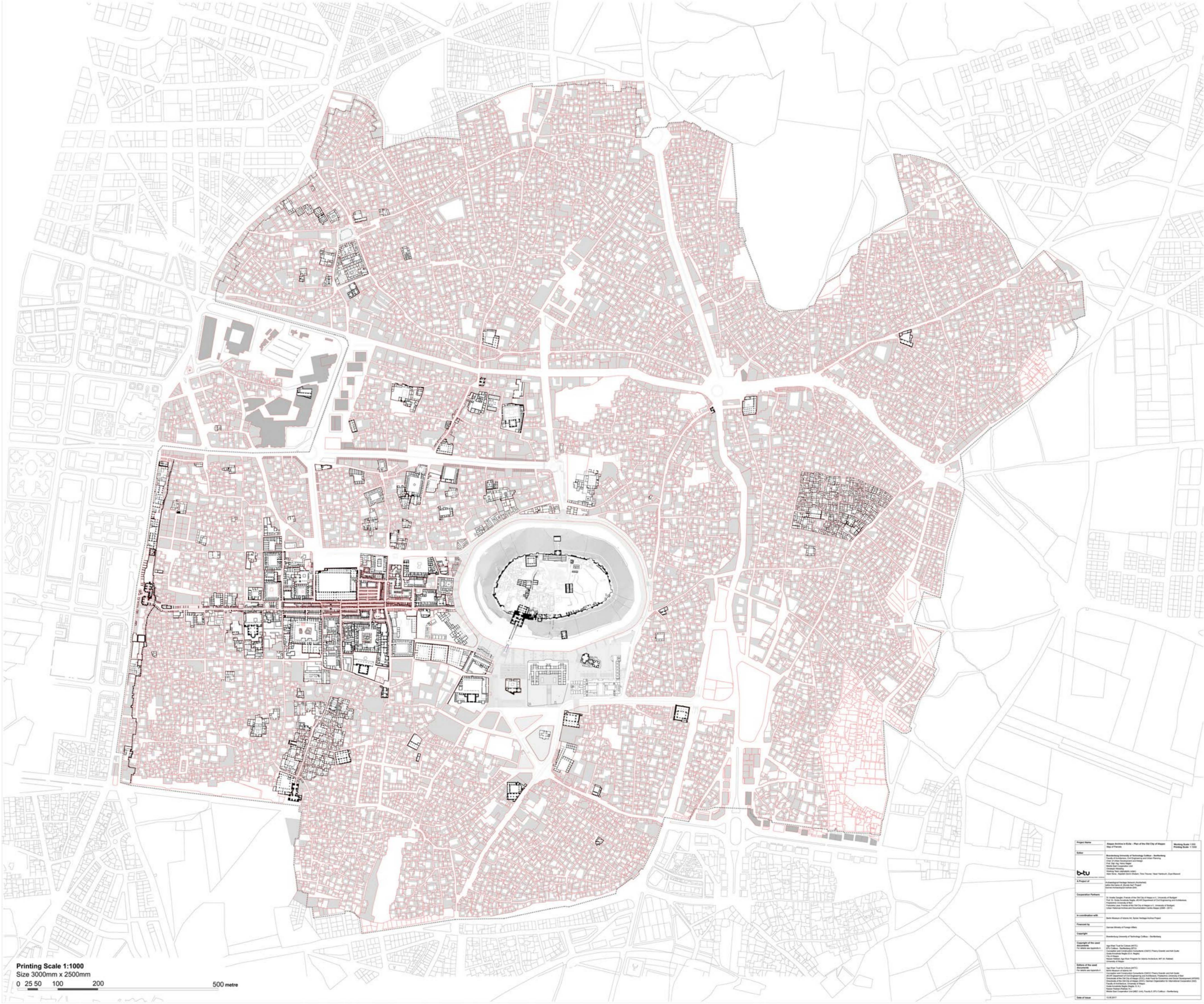
This map depicted buildings with the earliest drawing of the contour lines, which makes it one of the most valuable topographical resources of the city. The map was never studied in relation to urban fabric development. Therefore, it can provide enhanced insight into the transformation of quarters, cul-de-sac formation, and changes in void and mass ratio. The map has visible deformation in the center (Figure 1a), therefore, the two maps (the French cadastral maps of the 1930s and the maps of the Aleppo Archive in Exile project 2017) were chosen to facilitate the referencing process of the Ottoman map and the survey orthomosaic.

(**a**)



(**b**)

Figure 1. *Cont.*



(**c**)

Figure 1. (**a**) A section of the digital copy of the map from the website of The National Library of France [26]. (**b**) The French Cadastral Map [27]. (**c**) The BTU map [28].

The French Cadastral maps of the 1930s offer an accurate survey of the city [22] before the drastic 20th-century changed the fabric of the city as a result of the master plans of Gutton and Banshoya (Figure 1b) [27]. The maps combine dense visual information prepared for Aleppo, such as the parcels, courtyards, and the function of buildings.

The third map, prepared by the Brandenburg University of Technology (BTU) under the Aleppo Archive in Exile project [28], was chosen because of the bulk of information and metadata incorporated in the maps (Figure 1c). They include cartographic information about courtyards, parcels, and a number of the most important buildings and their detailed floor plans [28].

By using three maps of the city from different time periods with different information, the comparisons with survey orthomosaic are not only easier in terms of identifying similar features across the cartographic dataset but also enrich the axes of comparisons. It provides insight not only into the post-war damage but also into the prominent changes in the study area in the past 100 years.

Therefore, this research aims to apply a digital workflow of the study of the urban transformation of that section of Aleppo in terms of the quantitative changes to the street network and mass-and-void distribution. For the street networks, the research aims to identify the change of orientation, the addition of new streets, the closure of streets, and the creation of cul-de-sac streets. In terms of mass-and-void distribution, this research aims to pinpoint the change in the size and distribution of open spaces, the relation between mass and void, and changes in the layout of the city in response to the changes in the streets. The unit of choice for the analysis is meters.

Table 1. A comparison between the various maps used in the research.

Map Name	Date	Scale	Accuracy	Origin	Method of Acquisition
The Ottoman map	18th	1:5000	There is a noticeable deviation in the linearity of streets.	The Ottoman Road and Bridges Engineers	Possibly made through topographic surveys.
The French cadastral maps	1930s		No available information.	A team headed by C. Duraffourd [21]	Topographic Surveys.
Aleppo Archive in Exile—Plan of the Old City of Aleppo	2017	1:1000	No available information.	The Brandenburg University of Technology (BTU) [28]	Combination of the following survey maps of Aleppo: 1-Aleppo Cadastral Plan. In Syrian Heritage Archive Project. Adapted from DOC, GIZ (eds.) (1997–1998) Digitized Cadastral Plan of Aleppo based on French Cadastral Plans of Old Aleppo (1926–1930). 2-Directorate of the Old City of Aleppo (ed.) Aleppo Cadastral Plan with Courtyard. Urban Historical Archive and Documentation Center for Aleppo.
Digital Orthomosaics	2018	1:1	1:1 $\pm$ 20 cm	The Author	Laser scanning and Aerial Photogrammetry

3.1. Digital Workflow and Methodology

The digital workflow was developed on three fronts: first, the hybrid point cloud was acquired, and processed, and the orthomosaic was generated. Second, the historical cartographic dataset was vectorized. Third, the analysis workflow was designed to combine all the maps and orthomosaic. Since the analysis aims to pinpoint the two-dimensional changes in the city, the process involves vectorizing the raster maps and geo-referencing them based on the survey map in QGIS. By combining these datasets and utilizing appropriate analysis techniques, valuable insights can be gained regarding changes to the built environment.

3.2. Hybrid Point Cloud Acquisition and Processing

The field survey was conducted in 2018 as part of the Ph.D. dissertation titled "Digital Reconstruction of The Urban Morphology of The Old City of Aleppo: Between the Mamluk and the Post-War City, the case of "Jallūm and al-ʿAqaba Districts. A parametric Study". During the survey, 1823 scans were acquired using FARO focus 330X (The instrument was donated to the Directorate of Antiquities, Syria by CYARK during the collaboration for project ANQA. Available online: https://anqaproject.org/#1) with various resolution and quality settings, depending on the level of detail of the reordered areas [29].

The scans were then processed in Autodesk Recap, sub-sampled to a target resolution of 5 cm, and exported as a point cloud. The aerial photogrammetry data was acquired from a private drone pilot who used DJI Phantom 4 to record the area in early 2018. The data set included 3600 geo-referenced photos. The photos were preprocessed in Adobe Lightroom Classic (10) and then processed in Agisoft Metashape (1.7.4) to generate a dense point cloud. However, since the drone photos were not performed for the purpose of photogrammetry, they were not distributed homogeneously. Therefore, small blank spots appear in the orthomosaic (Figure 2). These blank areas were compensated for by the laser scans and by generating another point cloud from videos taken by the same drone at the time of data acquisition. The missing data set is compromised solely because of roofs that can be annexed to the available data set at any moment. More importantly, for the scope of the urban study, it does not majorly affect the accuracy of the alignment (Figure 2).

Figure 2. The orthomosaic of the aerial photogrammetry, exported from Agisoft Metashape, by the author.

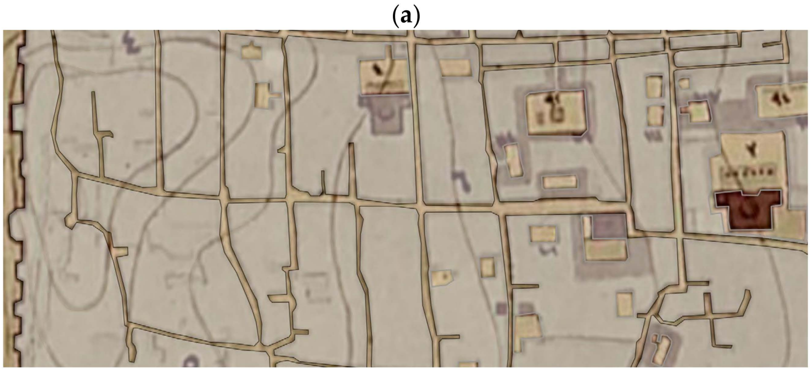
The laser and photogrammetric point clouds were combined in Agisoft Metashape, then meshed, and textured to generate the final orthomosaic. As the orthomosaic includes coordinate information, it was used for geo-referencing the vectorized cartographical dataset.

A detailed description of the data acquisition process and its challenges were presented and published in the 26th International Conference on Cultural Heritage and New Technologies (CHNT26) [29].

3.3. Aligning, Geo-Referencing and Superimposing Datasets

The Ottoman map is of great morphological importance. It is the oldest map of Aleppo, based on an on-site professional geometrical survey at the end of the Ottoman rule of Syria. The map incorporates details of the walls, important buildings, and elevation data. It offers valuable information about the expansion of the city. However, there is a clear deformation in the map, causing the central section of the city to appear curved (Figure 3a). This was probably caused by the early surveying techniques and is unlikely due to the digitization process.

(**a**)



(**b**)

Figure 3. (**a**) The vectorized intramural city based on the Ottoman map of Aleppo published by (Available online: https://gallica.bnf.fr/ark:/12148/btv1b52507324h/f3.item.zoom (accessed on 26 August 2023)) [26], redrawn by the author. (**b**) A section of vectorized map superimposed on the digital copy of the Ottoman map, showing the accuracy of the vectorizations, by the author.

It portrays the cul-de-sac streets and the final development of the city quarters within the walls before the destructive urban projects of the 19th century. However, the portrayal of the courtyard is not comprehensive, as only a few buildings include their interior courtyard in the map.

The initial stage of the digitizing workflow was tracing the intramural section of the Ottoman map (Figure 3b), the French cadastral map, and the map of BTU Cottbus in Autodesk AutoCAD. The vectorized versions were then imported to QGIS to be geo-referenced. They were aligned and geo-referenced manually, using the drone coordinates of orthomosaic (Figure 4).

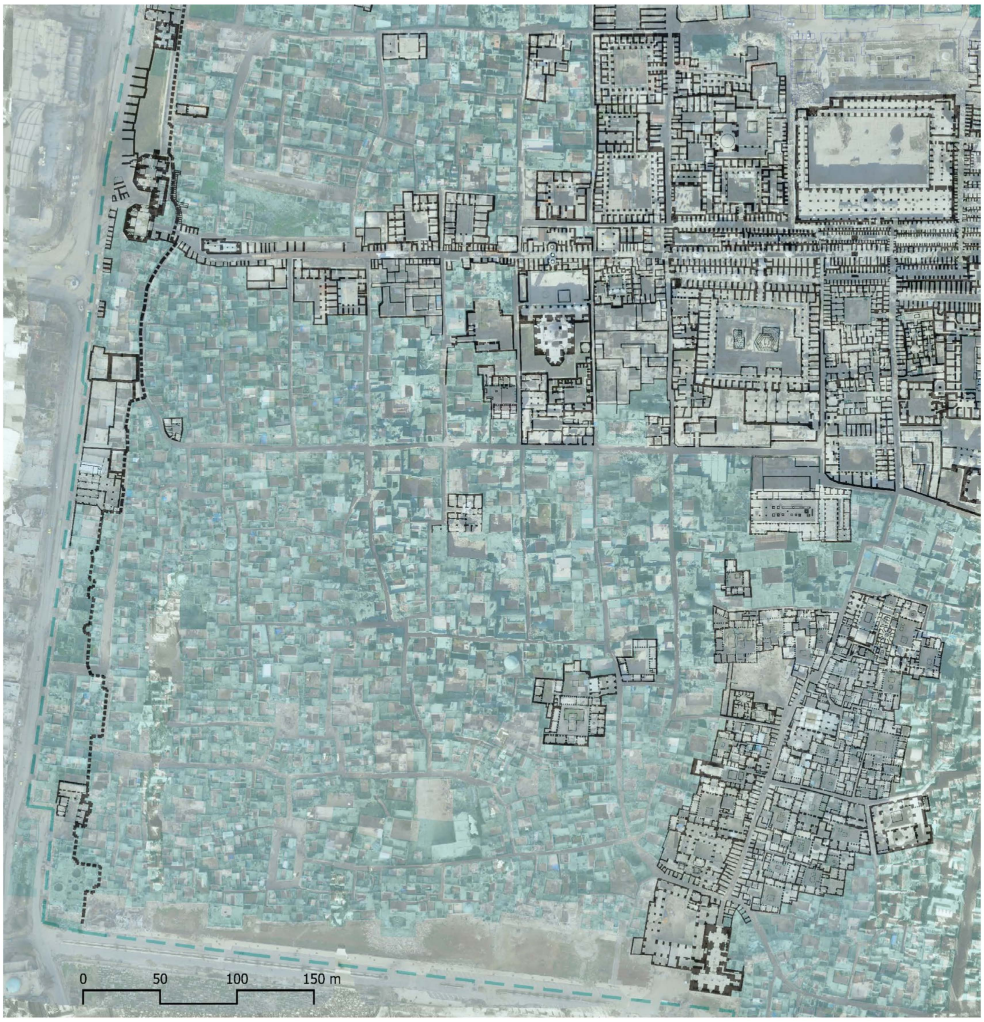


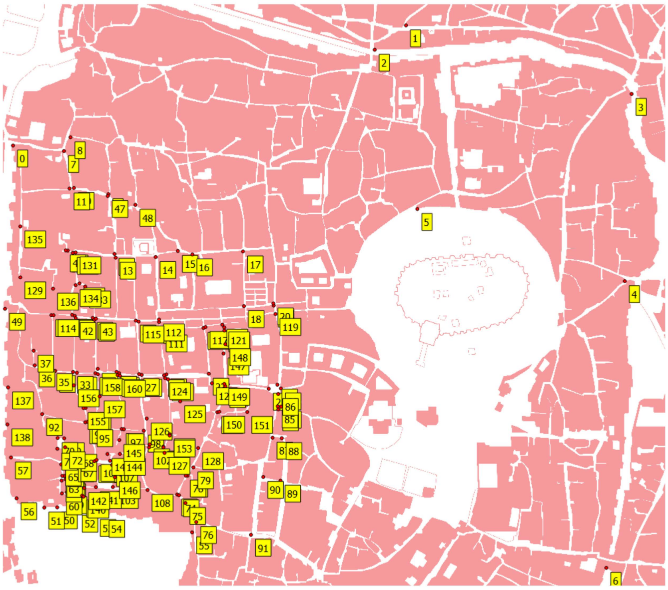
Figure 4. The orthomosaic from the survey superimposed with the Aleppo Archive in Exile map (in light blue tint), exported from QGIS, compiled by the author.

The easier alignment to begin with was the alignment of the French cadastral map and the BTU map, with orthomosaic from the field survey. Five reference points were selected from different areas on all maps; then a linear transformation was applied (Figure 4). Unlike previous processes, the geo-referencing of the Ottoman map was not as straightforward.

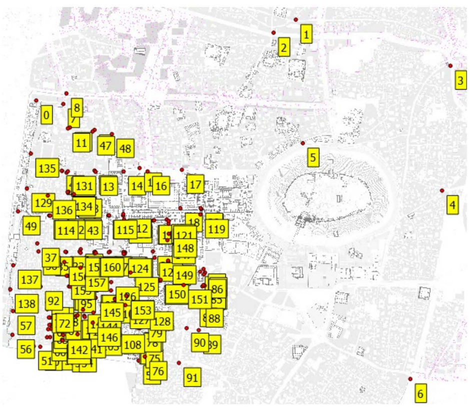
Aligning the Ottoman map to orthomosaic proved to be difficult because of the curved distortion in the center, the tilting distortion around the main souk, and the post-war destruction that compromised possible alignment points. To simplify this task, the Ottoman map was aligned with the BTU map, as it was easier to identify common elements between the two maps.

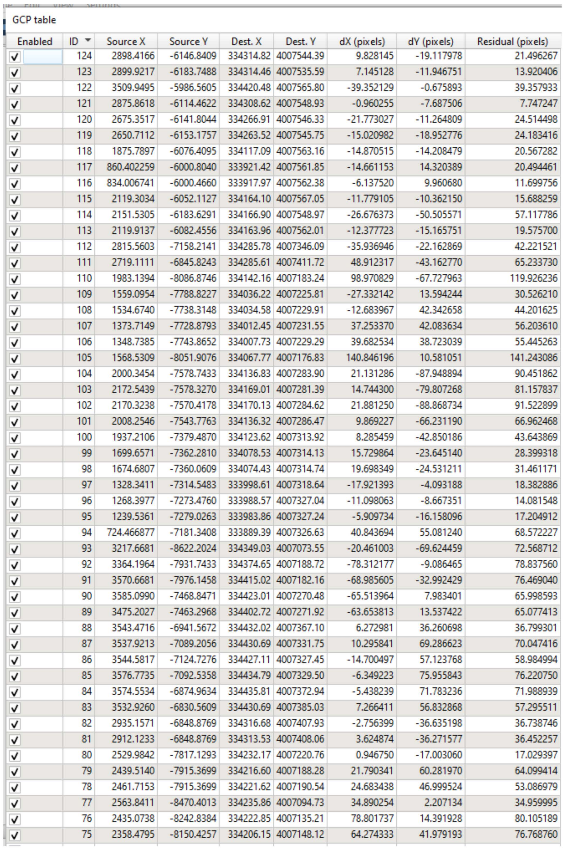
A testing protocol was developed to allow for an accurate placement of common points or Ground Control points (GCPs). The process revolves around testing different points on the Ottoman map that are more likely to have remained unchanged. Different combinations of points were tested to achieve the best superimposition with the least distortion and best correction of the deformation. Two transformations were tested using 160 (GCPs).

The first transformation was "Polynomial 3" while the other was the "Thin Plate Spline" (Figure 5a,b). The former resulted in moderate superimposition and correction of the deformation of the map but with significant distortion outside the studied area. Figure 5c displays values representing the errors of GCPs when applying the "Polynomial 3" transformation. With the latter option, the superimposition was improved, and the control over correcting the deformation was enhanced within the studied area. Considering the challenges that were discussed, the alignment result appeared to have an acceptable level of accuracy (Figure 6).



(**a**)





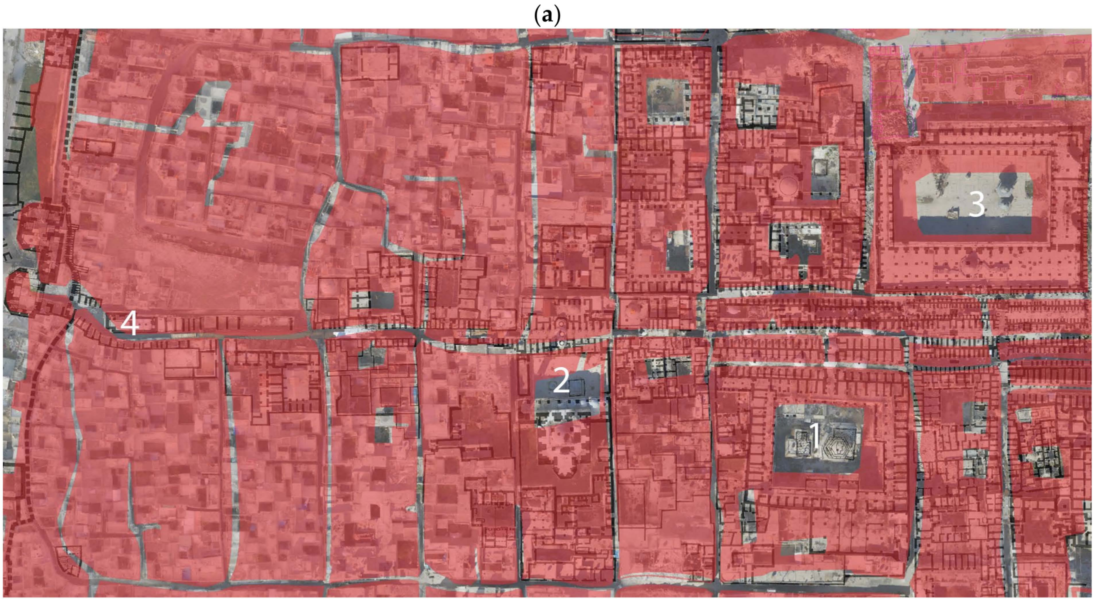
GCP table

Enabled	ID	Source X	Source Y	Dest. X	Dest. Y	dX (pixels)	dY (pixels)	Residual (pixels)
✓	124	2898.4166	-6146.8409	334314.82	4007544.39	9.828145	-19.117978	21.496267
✓	123	2899.9217	-6183.7488	334314.46	4007535.59	7.145128	-11.946751	13.920406
✓	122	3509.9495	-5986.5605	334420.48	4007565.80	-39.352129	-0.675893	39.357933
✓	121	2875.8618	-6114.4622	334308.62	4007548.93	-0.960255	-7.687506	7.747247
✓	120	2675.3517	-6141.8044	334266.91	4007546.33	-21.773027	-11.264809	24.514498
✓	119	2650.7112	-6153.1757	334263.52	4007545.75	-15.020982	-18.952776	24.183416
✓	118	1875.7897	-6076.4095	334117.09	4007563.16	-14.870515	-14.208479	20.567282
✓	117	860.402259	-6000.8040	333921.42	4007561.85	-14.661153	14.320389	20.494461
✓	116	834.006741	-6000.4660	333917.97	4007562.38	-6.137520	9.960680	11.699756
✓	115	2119.3034	-6052.1127	334164.10	4007567.05	-11.779105	-10.362150	15.688259
✓	114	2151.5305	-6183.6291	334166.90	4007548.97	-26.676373	-50.505571	57.117786
✓	113	2119.9137	-6082.4556	334163.96	4007562.01	-12.377723	-15.165751	19.575700
✓	112	2815.5603	-7158.2141	334285.78	4007346.09	-35.936946	-22.162869	42.221521
✓	111	2719.1111	-6845.8243	334285.61	4007411.72	48.912317	-43.162770	65.233730
✓	110	1983.1394	-8086.8746	334142.16	4007183.24	98.970829	-67.727963	119.926236
✓	109	1559.0954	-7788.8227	334036.22	4007225.81	-27.332142	13.594244	30.526210
✓	108	1534.6740	-7738.3148	334034.58	4007229.91	-12.683967	42.342658	44.201625
✓	107	1373.7149	-7728.8793	334012.45	4007231.55	37.253370	42.083634	56.203610
✓	106	1348.7385	-7743.8652	334007.73	4007229.29	39.682534	38.723039	55.445263
✓	105	1568.5309	-8051.9076	334067.77	4007176.83	140.846196	10.581051	141.243086
✓	104	2000.3454	-7578.7433	334136.83	4007283.90	21.131286	-87.948894	90.451862
✓	103	2172.5439	-7578.3270	334169.01	4007281.39	14.744300	-79.807268	81.157837
✓	102	2170.3238	-7570.4178	334170.13	4007284.62	21.881250	-88.868734	91.522899
✓	101	2008.2546	-7543.7763	334136.32	4007286.47	9.869227	-66.231190	66.962468
✓	100	1937.2106	-7379.4870	334123.62	4007313.92	8.285459	-42.850186	43.643869
✓	99	1699.6571	-7362.2810	334078.53	4007314.13	15.729864	-23.645140	28.399318
✓	98	1674.6807	-7360.0609	334074.43	4007314.74	19.698349	-24.531211	31.461171
✓	97	1328.3411	-7314.5483	333998.61	4007318.64	-17.921393	-4.093188	18.382886
✓	96	1268.3977	-7273.4760	333988.57	4007327.04	-11.098063	-8.667351	14.081548
✓	95	1239.5361	-7279.0263	333983.86	4007327.24	-5.909734	-16.158096	17.204912
✓	94	724.466877	-7181.3408	333889.39	4007326.63	40.843694	55.081240	68.572227
✓	93	3217.6681	-8622.2024	334349.03	4007073.55	-20.461003	-69.624459	72.568712
✓	92	3364.1964	-7931.7433	334374.65	4007188.72	-78.312177	-9.086465	78.837560
✓	91	3570.6681	-7976.1458	334415.02	4007182.16	-68.985605	-32.992429	76.469040
✓	90	3585.0990	-7468.8471	334423.01	4007270.48	-65.513964	7.983401	65.998593
✓	89	3475.2027	-7463.2968	334402.72	4007271.92	-63.653813	13.537422	65.077413
✓	88	3543.4716	-6941.5672	334432.02	4007367.10	6.272981	36.260698	36.799301
✓	87	3537.9213	-7089.2056	334430.69	4007331.75	10.295841	69.286623	70.047416
✓	86	3544.5817	-7124.7276	334427.11	4007327.45	-14.700497	57.123768	58.984994
✓	85	3576.7735	-7092.5358	334434.79	4007329.50	-6.349223	75.955843	76.220750
✓	84	3574.5534	-6874.9634	334435.81	4007372.94	-5.438239	71.783236	71.988939
✓	83	3532.9260	-6830.5609	334430.69	4007385.03	7.266411	56.832868	57.295511
✓	82	2935.1571	-6848.8769	334316.68	4007407.93	-2.756399	-36.635198	36.738746
✓	81	2912.1233	-6848.8769	334313.53	4007408.06	3.624874	-36.271577	36.452257
✓	80	2529.9842	-7817.1293	334232.17	4007220.76	0.946750	-17.003060	17.029397
✓	79	2439.5140	-7915.3699	334216.60	4007188.28	21.790341	60.281970	64.099414
✓	78	2461.7153	-7915.3699	334221.62	4007190.54	24.683438	46.999524	53.086979
✓	77	2563.8411	-8470.4013	334235.86	4007094.73	34.890254	2.207134	34.959995
✓	76	2435.0738	-8242.8384	334222.85	4007135.21	78.801737	14.391928	80.105189
✓	75	2358.4795	-8150.4257	334206.15	4007148.12	64.274333	41.979193	76.768760

(**b**) (**c**)

Figure 5. (**a**). Location and number of the ground control points (GCPs) on the Ottoman map. (**b**) Location and number of the (GCPs) on the BTU map. (**c**) The accuracy of the GCPs in Polynomial 3 transformation, exported from QGIS.

(**a**)



(**b**)

Figure 6. (**a**) The geo-referenced Ottoman map (in light red) and the BTU map (in black) overlaid on the orthomosaic (in RGB values) created in QGIS by the author. (**b**) An enlarged section of the geo-referenced Ottoman map focusing on the northern part of the studied area.

At this stage, a comprehensive layered map of Aleppo is created. It encompasses the prominent cartographic data of Aleppo, where each layer complements different missing elements of other maps. Besides the selected base maps, several aerial photographs were aligned in the same file, such as the aerial photograph taken by Michel Ecochard in 1936 [30] and images from the declassified archive of the Spy-Satellite "Corona" taken between 1968–1970 [31]. The alignment process allowed accurate tracking of the spread of the high-rise buildings, the division of courtyards, and new commercial and residential constructions.

4. Results

The Ottoman map not only documented the major streets in the studied quarters but also included some of the courtyards, particularly those belonging to important buildings such as Khan al-Jumruk (Figure 6b, number 1), al-Bahramiyya Mosque (Figure 6b, number 2) and The Umayyad Mosque. Additionally, the map suggested the presence of multiple defensive bastions positioned along the city walls, a detail that aligns with Arabic historical accounts [32,33]. While the general layout is preserved, there are several new streets and cul-de-sac streets (Figure 7). We can recognize that the biggest loss in mass is the removal of the area north of the Umayyad Mosque to create the road and the square in front of the mosque, as a result of the successive masterplans of André Gutton in 1954 and Gioji Banshoya in 1974 [34].

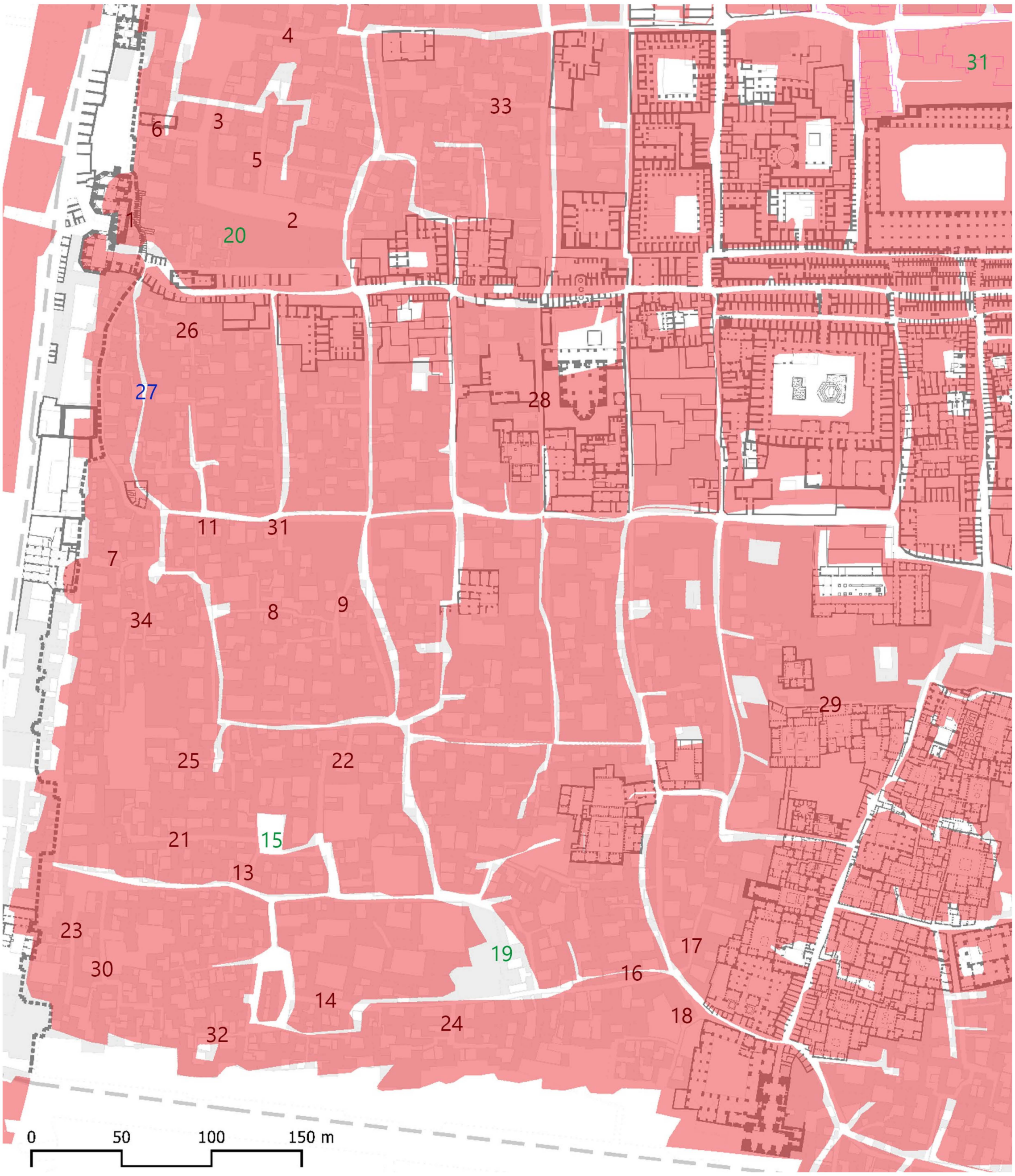


Figure 7. The geo-referenced maps of 1900 (in light red) and the BTU overlaid, exported from QGIS by the author.

From (Figure 7), we can classify the 2D morphological changes as the following:

1. The addition of cul-de-sac streets or new streets: The layout of the cul-de-sac streets is mostly preserved, particularly those located behind the city walls. However, there are two notable differences when comparing the modern map to the historical one. Firstly, the street directly behind the walls of the city (Figure 7, number 1) was a cul-de-sac that was extended until Bāb Antakiya. The perpendicular street (Figure 7, number 4) was also extended to meet the street parallel to the wall (Figure 7, number 1). Other cul-de-sac streets that were extended are visible in Figure 7, number 3, 28. However, street number 28 can either be a cul-de-sac that was converted to a street, or this representation could mean that the existing covered section of the street named "Ṣibāṭ Sūdān" was extending further.
2. New streets also emerged further separating the fabric (Figure 7, number 5, 6). Street 2 which is the wide street leading towards the higher elevation of al-ʿAqaba (Figure 7, number 2) is not visible in the Ottoman map. However, it seems unlikely that it did not exist due to the different elevations around its sides and the fact that it borders an open space number (20). At al-Shūʾaybiyya Mosque (Figure 6b, number 4), two streets diverge from each other (Figure 7, below area 20), which is only represented in the modern map.
3. The new streets and the extended cul-de-sac streets resulted in separating several insulae, especially the section of Tallet al-ʿAqaba behind the wall. It was separated into six distinct blocks that also accommodated high-rise buildings despite its initial advantageous elevation. Another division of blocks is visible around streets numbers 8, 10, 11, 12, 13, 14, 16,18, and 22. While added cul-de-sac streets can be observed in Figure 7, numbers 7, 9, 17, 21, 23, 24, 25, 26, 29, 30, 31, 32, 33, and 34. Street number 27 represents a unique example of a street that does not correspond to a modern street. It is possible that it is another surveying error, and this street was the one directly behind the western walls of the city.
4. The division or the removal of courtyards: In Figure 7, there are some noticeable differences regarding the size, and number of courtyards. Specifically, the number and size of courtyards have decreased possibly due to division of the family house into smaller units to accommodate the families of the children or the change of the residential function. Adding another layer from the cadaster map of the 1930s (Figure 8) reveals additional information compared to the survey results regarding the changes in the size and distribution of open spaces and courtyards. In Figures 8 and 9, courtyards marked with red have been subject to alteration, division, and or covering. On the other hand, courtyards that were not observed in the BTU map and the French cadaster are marked in light green.
5. The addition of buildings within a previously open space: Two open spaces were built partially, space number 20 and space 19, where a public school and some residential parcels were added (Figures 7 and 8). Space number 15 remained the same. Unfortunately, the Ottoman map does not contain additional information about the courtyards, which hinders a complete analysis of the changes in the open spaces.
6. The removal of buildings to create an open space: This change is only observed in two locations. The first one is the square in front of the Umayyad Mosque and the other is the removal of a small section of residential buildings to accommodate the yard of the public school (Figure 7, space 19). Both changes are marked in purple in (Figures 8 and 9).

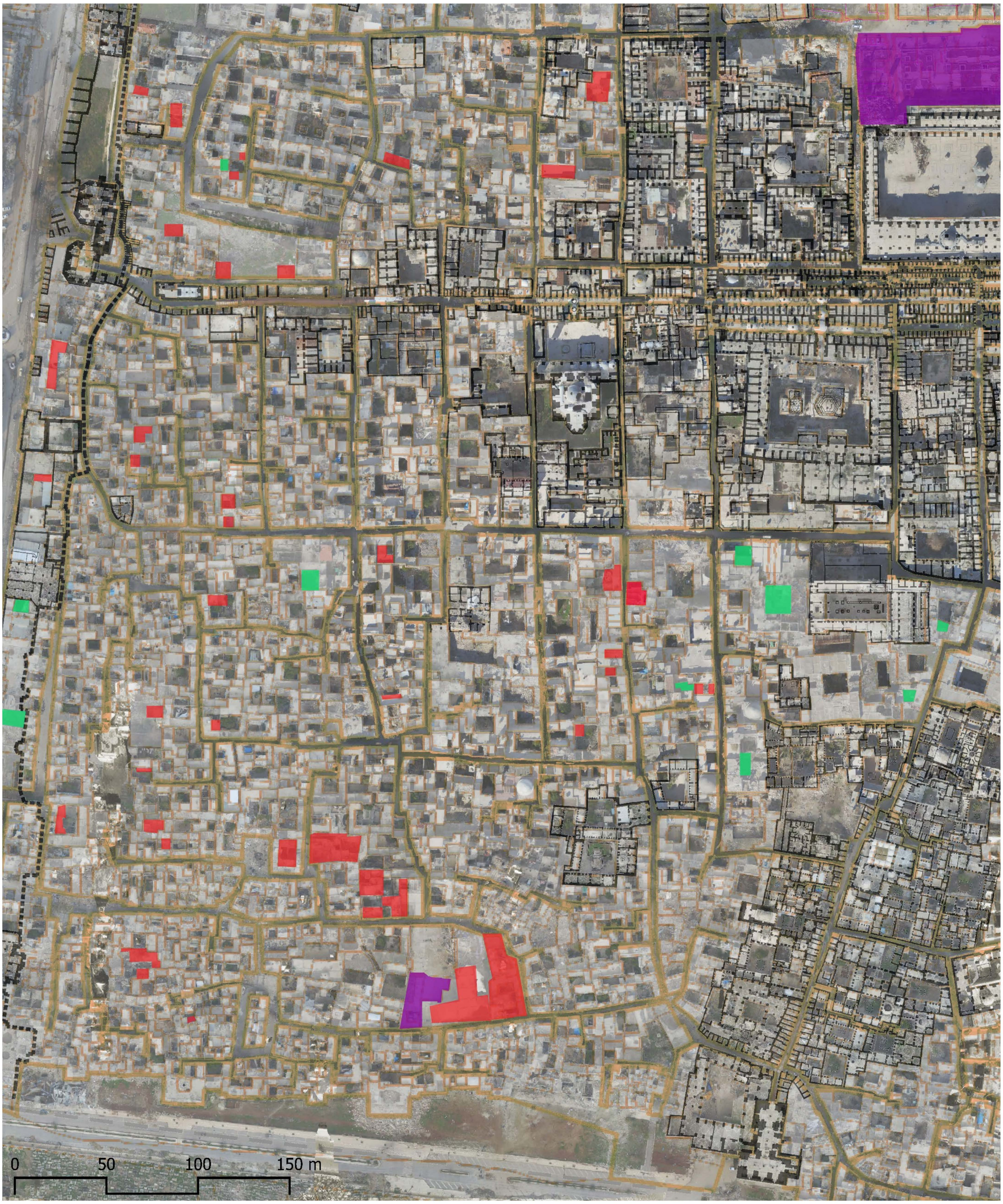


Figure 8. The orthomosaic from the survey superimposed on the BTU map and the map of the 1930s, exported from QGIS, created and designed by the author. The red color represents the removal or division of a courtyard. The light green represents courtyards not visible in other maps. The purple color represents open spaces that were created by removing sections or complete buildings.

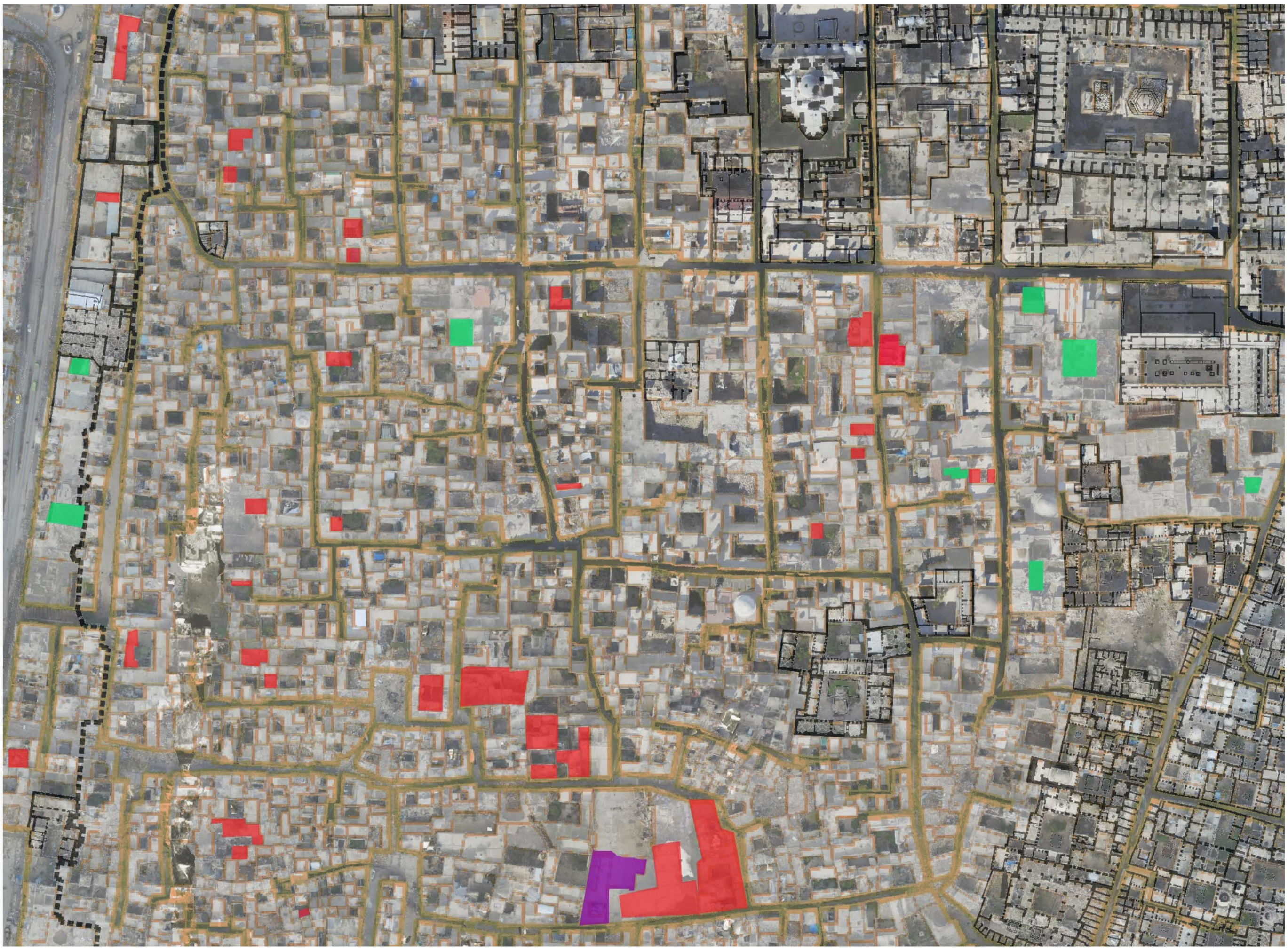


Figure 9. An enlarged section of Figure 8 showing the changed parcels. The red color represents the removal or division of a courtyard. The light green represents courtyards not visible in other maps. The purple color represents open spaces that were created by removing sections or complete buildings.

5. Discussion

Historical maps improve the understanding of the growth and development of a city. In the case of Aleppo, the integration of the Ottoman map within a GIS environment, along with more recent maps—both before and after the war—provide a contribution to the collaborative database of studies of Aleppo.

Despite the previously discussed distortion of the Ottoman map, it provided information about the urban changes and elevation information (Figures 1a and 3). The comparison between the combined cartographic maps with the 3D survey revealed additional courtyards that were not included in all the previous maps.

We can discuss the urban changes in terms of the historical and social aspects. The addition of new streets and cul-de-sac streets can be viewed as an outcome of the division of big courtyard–houses to allow children of the family to have an independent residential unit. It can also be attributed to the change in the function of the city walls. After the revolutionary advances in artillery technology expressed in the cannon, city fortifications were transformed [35]. The use of heavy artillery made walls less important [35]. In Aleppo, this could have caused the residential function to replace the obsolete walls and bastions of the city. Parts of the defensive wall started to be separated into smaller parcels and transformed into other functions; accessing those new functions required new streets and cul-de-sac streets.

The change in size and the alteration of open spaces can be attributed to the repeated division of big courtyard–houses, which was the beginning of the change in mass and void ratio. The high-rise concrete buildings followed the urban masterplans, especially in al-ʿAqaba and to the west of the studied area, amplifying the existing problem and causing more abandonment of the houses due to the loss of privacy [20]. As residential parcels were sold to commercial enterprises or storage facilities, they had to be adapted to such a change in use. In cases where the residential use continued, new stories were added to accommodate either the growth of the family or the owner's intention to increase leasing revenues. But more importantly, adding additional stories can also be viewed as an act to claim back the privacy of the residential building by elevating the height advantage of the new concrete buildings. Overall, the analysis and comparison suggest low to moderate-level alterations in terms of the 2D layout.

Finally, old cartographic representations are valuable evidence of a point in time in the life of an urban fabric, especially when they are prepared with a scale reference. However, depending on the technique of acquisition, they can include errors or deformations. The methodology presented in this article attempted to address those issues of accuracy for the specific case of the Ottoman map of Aleppo. The pipeline is easily replicable by scholars from different disciplines, e.g., urban planners, architectural historians, and archaeologists. Each attempt can lead to new knowledge depending on the area of expertise of the researchers. Future research will attempt to examine the urban development of the studied area in the 3D dimension and explore the possibility of comparing the point cloud of the city with a 3D model based on the Ottoman map.

Nonetheless, one size does not fit all. There will be a continuous need to develop new approaches to implement old maps in digital studies, not only as a witness of a certain time period in the development of a city but also as an artifact in themselves. Airborne photogrammetric and laser mapping will continue to be the primary facilitator of the process.

6. Conclusions and Outlook

Reality capture technology has gained increased importance as an urban analysis tool. It is capable of giving insight into the past while at the same time informing future decisions about conservation, preservation, and restoration projects. Through the combination of historical maps and orthomosaic, new urban details are revealed. In this study, the digital pipeline enabled the identification of large-scale transformation, such as loss of public space, as well as small-scale transformation, such as the changes in cul-de-sacs and occasionally of courtyards.

The case study of al-Jallūm and al-ʿAqaba sets a proof of concept for combining 3D tools in the analysis of the evolution of historic centers. It can also be further developed for the evaluation of the state of conservation of the city as well as the risks and threats that face the historical fabric, especially during and post-conflict. Future research will focus on examining these 2D changes in the third dimension to attempt to identify the vertical growth of the city through the use of point clouds.

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