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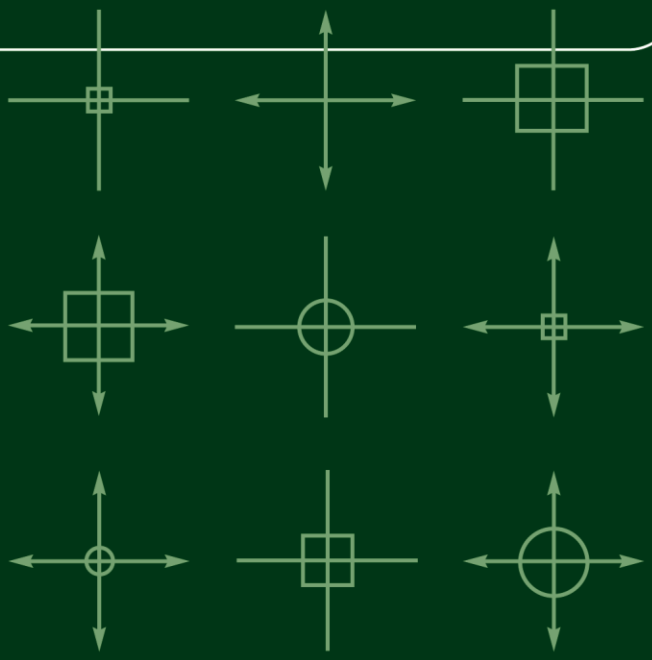
Monumental Computations
Digital archaeology of large urban and underground infrastructures

Proceedings of the 24th International Conference on Cultural Heritage and New Technologies 2019.
CHNT 24, 2019

Edited by
Wolfgang Börner | Christina Kral-Börner | Hendrik Rohland



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Photogrammetry and digital twin creation for an ancient urban physical model

Giorgio VERDIANI, Dipartimento di Architettura dell'Università degli Studi di Firenze, Italia
Gilbert SOETERS, Municipality of Maastricht, The Netherlands

Abstract: During the CHNT 2017, while attending together one of the social events, Gilbert discussed with Willem Beex the possibility of scanning the famous maquette of Maastricht from 1750. Willem suggested a collaboration between his agency and the Dipartimento di Architettura (Architectural Department) in Florence, Italy, to start what clearly was a nice, involving, not easy and fascinating research and work, centred on a large maquette (about 6 × 7 metres) representing the old town of Maastricht in 1750. The Maquette was under restoration in Lille, France, at the Palais des Beaux-Arts, during the reorganization of the specific maquette room in that museum. A very good condition for a survey intervention. In the middle of 2018, the project was going to be supported financially by the Maastricht Municipality and soon there would be the need for an operative proposal and an effective presence in place to bring on the survey and the following post-processing. Willem announced the possibility to start the surveys in June 2018, it was the start of an interesting adventure with a very specific cultural heritage subject. The large size, the high level of details and the high expectations about the quality of the results needed a proper set of smart and technical solutions. The creation of a digital twin of the "Ancient Maastricht Maquette" was undoubtedly the first step to bring this heritage into the new information technology age, but also an excellent occasion to bring back the precious data from the past to match with the contemporary city, rising the value of the main building but also the precious witness of the old urban pattern and the past relationship with the territory. This paper will tell the story, methods, procedures of this last work with Willem Beex, completed without him, and here presented in his memory.

Keywords: *Architecture—Cultural Heritage—Digital Survey—Structure from Motion—Image Matching.*

CHNT Reference: Giorgio Verdiani and Gilbert Soeters. 2021. Maastricht, the city, the maquette and the collection at the Palais de Beaux-Arts in Lille (France). Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum. doi: 10.11588/propylaeum.747.

Introduction

Cultural Heritage is art, objects, part of human works connected to history and events. It is a puzzle of ideas and ideals. In it, complex issues, aims and wills brought to apply intelligent thinking to amazing solutions. Managing the territory, understanding the shape of the world is one of these cases. It comes with the efforts of the mind to reach the proper understanding and developing the needed abstractions. With the aim of reading, presenting and planning the use of the territories.

The realization of a maquette representing a city with all its surrounding territory, like those collected at the Palais de-Beaux-Arts in Lille (Tapié, 2006), was, in its time, a systematic and accurate process to gain the control of areas and guarantee a specific and (at all the effects) strategic knowledge of the towns and their surrounding territories. To allow such a result, two main elements entered the scene: the work of artisans and the best skills and practices about the cartography and territorial representation of that time. These two elements were coordinated to create a detailed model, a clear representation of the state of knowledge about the territories and their assets. The result replied to the need of combining the information gathered in place from maps, drawing, explorers, spies and visitors.

Each maquette in itself was not intended as an artwork. Thus the attention to details was a fundamental factor to allow the recognization of the use and features of buildings and structures. The artisans built these models with simple materials and then painted them to reach a realistic aspect. This was not a matter of innovation, while it was a quite common solution for the old architecture models (Knoll, 2007). The final result and effect brought it to be an admirable application of clever solutions. What arrived in present times creates a valuable impression. These models even after losing their original uses remain a unique witness of the past.

The "Plan Relief" room at the Palais des Beaux-Art in Lille

The so-called "plan-relief" collection at the Palais des Beaux-Arts in Lille, France (Fig. 1), is a precious archive of maquettes hosted in a specific hall of the major Lille museum. At the time of their making the purposes of these exemplary artisan works were military at the one hand and on the other side they were prestige objects of the French King. The high level of details, the accurate representation of each building, of all the walls and fortifications, with great attention to the countryside, with all the trees, terrains, rivers, waterways, channels, stones, roads and paths, was due with the aim of allowing a perfect comprehension of the areas. All the cities and towns represented in this rich archive were settled in a geographic area with very complex borderlines, were the traveller was continuously passing (as it still happens now a day) between the borderlines of Netherlands, Belgium and France. Such a neuralgic area was not far from possible military operations and possessing such a collection of models was equal to possessing a clear knowledge of all the strategic issues and possible troop movements around these territories. The physical tridimensional model was then intended as a tool for planning "virtual" intervention of soldiers, armies, cannons, it was a reproduction of the reality aimed not to plan urban or architecture transformation (Carones, 2017), but for operating military-strategic interventions. In the time of peace, in the age of the European Community, the collection became a patrimony to protect and exhibit because of its incredible artistic value, it took then place in the Museum of the Palais De-Beaux-Arts allowing to the visitors to admire the skills of many artisans who realized each piece. A special set of models capable to tell a rich story about countries, past aspect of the cities with their former relationship with the territory. In between the numerous maquette: Lille (itself), Namur, Calais, Oudenaarde, Maastricht. A total of 14 cities, (six from French, seven from Belgium, one from The Netherlands). Composed of wood, printed or painted paper or cardboard, silk, tissues, sand and wires, on the scale of one to 600 (Warmoes, 2006). The models depict their subjects as they were from the 17th to the 19th centuries. Such use was not a special behaviour of the army divisions in this complex part of Europe (Pollak, 2010),

creating models for military planning is well documented in other collections arrived in our days (Warmoes, 2012), the use of large and well-detailed maquette was a common tradition from that period, a state of the art technical solution aimed to give proper tools to the military planning. In the present time, the collection is not only a rich group of artefacts, a special set of artworks rich of details, but it is also always the witness of a former condition of the urban landscape (Constant, 2008). The collection allows admiring the significant transformations of these towns: all the maquettes present a clear separation between the urban area and the countryside, the limit of the urban centres are sharp, well defined. The town is contained inside its walls, and its limits quickly fade across a series of fortifications between the main walls and the land. The territory all around is mainly dedicated to agricultural activities, then it is represented in fields free from trees and bushes. All the networks of roads, streets and paths are accurately represented and modelled, to make possible the planning of routes for soldiers, horsemen or carriages.

The ancient Maastricht maquette

In the specific, the Maquette representing Maastricht is made of 13 pieces, some of them representing the countryside out of the city area, some others with a detailed description of the fortifications and facilities all around the town and then a group of two large parts representing the town centre with all the walls, the main monumental buildings and all the urban tissue (see table 1 for details about each part). The structure of each part is based on a series of robust wooden beams. They cross beneath the surface of the “terrain” and exit from the inner upper borders to allow connection and blocking to the other pieces. The external border is characterized by a flat blue border. It is underlined with an upper and lower framework giving a “limit” and a graphical conclusion to the whole asset. The materials are not reflective, the paper and most of the details are well preserved or restored and there are few missing parts (small frames from the windows, some arches, some trees) or spots (like what is said to be a large wine spot on some buildings in the nearby of the Cathedral). All the pieces have a high level of details. The parts dedicated to the town centre as well as those representing the countryside show particulars, minor roads, divisions in the agricultural lots, minimal details from houses and fortifications. The River is well represented in all its morphology, complete of minor deviations and islands. This accurate description of the riverside is done with the same accuracy both in the urban and in the countryside areas. There are very few written indications directly on the model, like the name of the river and the arrow indicating the sense of flowing and, just in the sector number 9, two labels with a brass frame and covered with glass. One is larger and brings the indication “MAASTRICHT, Sur la rive gauche de la Meuse (Pays-Bas) 1752, échelle du 600 Rép 1803”. The other, smaller and circular one, presents a compass indicating the North.

The survey, techniques and operations

The first tasks in this part of the research were all pointed to the creation of a digital twin of the Maastricht maquette. The maquette, unmounted in its 13 pieces, was a quite complex subject, in need of different approaches accordingly to the various sizes and level of details. In the group of parts those representing the old town centre, with a very dense urban tissue, were two. All the other 11 were dedicated to the external fortifications of the city and the surrounding countryside. The ongoing restoration at the time of the survey was making things easy, while all the parts were separated

and easily accessible. Defining the best digitalization solution took an accurate reflection: the choice between tools, their practical issues, results and following post-processing needs, was quite strategic before moving to Lille for some early test. The past case studies about the digitalization of a maquette are quite significant (Guidi et al., 2006), like the one about the large "Gismondi's Ancient Rome Maquette", an almost experimental work coordinated by Bernard Frischer and started from a 3D Laser Scanner survey (Guidi et al., 2008), or the survey of the maquette of the Gavi's Arch (Guerra and Vernier, 2011) operated on a wooden model using a pattern projection system. The accuracy of the survey tool was a fundamental aspect, thus, the extreme density of the urban pattern of some parts of the Maastricht Maquette, as well as the intention in having a well detailed and fully textured result, were two points pushing away from the hypothesis about using active survey systems based on lasergrammetry or pattern projection. Willem Beex was looking for the best possible result (Fig. 3), but it was clear that time was influencing the costs, and transportability of the tools for the survey was not a secondary factor. It was then decided to proceed by S.f.M./I.M. Photogrammetry (Guidi and Gonizzi, 2014) using a high-resolution medium format camera, a Fujifilm GFX-50s equipped with a Fujinon 32–64 mm zoom lens, so to have one of the best top choices about image quality at the time. The medium size sensor (33 × 44 mm), the high resolution (50 Megapixels), the quality of the lens and the extremely versatile and professional configuration of the controls were ideal for obtaining the best possible result. One of the possible issues was the minimum focus distance. The Fujinon 32–64 mm zoom lens has a minimal operative distance of 55 centimetres, perfect for close-up photography (Luhmann, 2011) but not strictly a "macro/micro" lens (Erlewine, 2011). At the same time, the angle of field (81° on the diagonal at 32 mm focal length, similar to a 25 mm on a full-frame sensor camera) was giving good options about coverage and creation of images with a proper perspective helping the reconstruction process (Linder, 2016). The light conditions were quite a doubt until the first test, so it was decided to use two remote flash units controlled by a remote trigger on the camera. The flashes were asked to be quite compact and powerful. With such requirements the Godox Witstro Pocket Flash AD200 was a good choice, it has a "Guide Number" (GN, the value expressing the strength of the light emitted by the flash unit) of 60 at 100 ISO sensitivity using the "bulb" naked head. This particular headlamp, projecting light in all the direction allows to have soft shadows ideal for photogrammetry, to make even more "shadowless" this light a specific dome diffuser by Godox was mounted on the flash unit, so to allow a very soft artificial light all over the scene. Two Godox Wistro Pocket Flash AS200 comes out as a well-working choice. The need for artificial light was double: creating proper exposure conditions in case of low light and filling the shadows from the available lighting. A first shooting test was made in July 2018 (Fig. 2), it was operated on two significant pieces, one mostly characterised by a dense urban pattern and the other with the countryside, hills, walls and fortification interventions. In this first test, all the picture were taken moving around each piece, using a very stable tripod and remote control (the Fujifilm App from a smartphone) to trigger the camera. Then, after seeing the final quality of the results and getting well satisfied with it, the second campaign was planned in September 2018. In this second phase, the final strategy was well refined, obtaining the authorization from the Museum about "hanging" the camera over the maquettes. In this way a specific tripod was organized, using two robust stands with a long horizontal bar. The camera was fixed on the bar using a photographic clamp, then the camera plus clamp unit were secured with additional steel cables and safety hooks to the bar (Fig. 4). This

system allowed to move the camera parallel to each main sector of the maquette, taking pictures firmly, quickly and with the desired overlap, which was from a ¼ to ⅓ accordingly to the complexity of the sector.

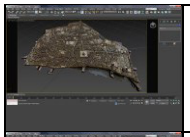
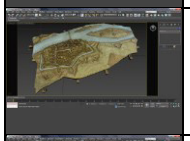
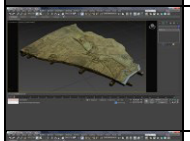
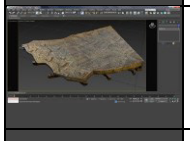
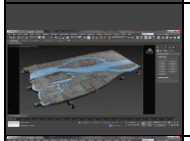
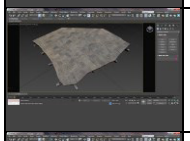
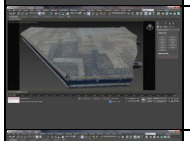
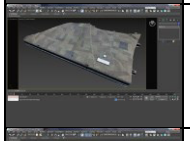
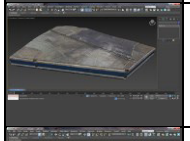
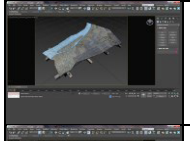
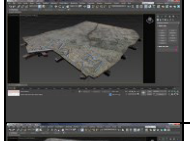
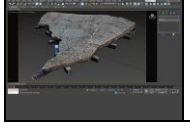
Sector	Number	Description	number of top shots	number of side shots	date
	1	Central part of the city	325 L1 +75 L2	553	09/2018
	2	Walls, river and walled town expansion	0	357	07/2018
	3	Countryside and fortifications	270	81	09/2018
	4	Countryside and external fortress	242	91	07/2018
	5	Countryside and fortifications	267	116	09/2018
	6	River, countryside and fortifications	167	143	09/2018
	7	Countryside	0	302	09/2018
	8	Countryside	0	134	09/2018 + 01/2019
	9	Countryside (part with label and compass)	81	177	09/2018
	10	Countryside	0	192	09/2018 + 01/2019
	11	River, countryside and fortifications	147	224	09/2018
	12	Countryside	245	118	09/2018
	13	Countryside	0	160	09/2018

Table 1. The parts of the maquette and the data about their photogrammetry (© G.Verdiani, G. Soeters).

For the central portion, the part numbered as “1”, representing the main settlement of the city, the shooting from the bar was done at two different heights, keeping the same focal length and similar overlapping. This was done with the purpose to have two different results at different resolutions, with the one taken from higher aimed to produce a more “light” version of this very detailed central part. For all the other sessions it was used a single height. This solution was adopted only for the sectors with a high level of complexity, with many variations in the vertical articulation, buildings and complex terrain modelling.

For the sectors representing quite flat parts it was preferred a simple “turning around series of shots, so to accelerate the overall duration of the operations. To complete the coverage of all the details and streets, a specific sequence of shots taken moving in a circle around the sector was planned for all the parts. The data about the full photographic campaign (final shots effectively used) of each sector are enumerated in Table 1.

When all the pictures were processed and the 3D model done, a final session of shooting, to integrate the existing datasets was accomplished in the middle of January 2019. But at the end of January 2019, Willem Beex left us. The sad event happened suddenly and immediately after the completion of the third, integrative photogrammetry campaign. The work in Lille was completed, it was time to bring to end the photogrammetric processing. The work was brought on and to its end without him, still feeling his strong guide to bring on seriously and tirelessly the project with a proper level of quality.

Data treatment

The processing of the sectors composing the large maquette started immediately after the very first test campaign. It was important to find solutions capable to keep a proper level of details and at the same time create still manageable 3D digital models. The data treatment remained the same since the beginning, while the results were immediately so good that there was no need to take again pictures for the parts used during the test.

The first step was the Image selection, removing all the pictures afflicted by a case of shaking blur, non-accurate focusing, or simply the redundant ones (almost the same point of view). Thus the number of pictures to be removed was very minimal, about 10 to 20 for each sector. Most of them were simply the same shot taken without firing the flashes: in facts, during the second campaign, it happened to have some overheating issue from the flashes, solved with a reduction of the operative speed, taking pictures at a slower pace, waiting a little longer time between each shot. This procedure turned out as the best solution to avoid this kind of stops. The smooth, uniform light, practically shadowless for all the shots, turned out to be so homogeneous to allow direct use of the JPEG images. The extremely high quality of the sensor was well completed by the minimal destructive compression applied to the final images by the Fujifilm camera: the resulting JPEG images ranged from 34 Mb (pictures with urban tissue/textured terrain on all the frame) to 22 Mb (pictures framing a large portion of the floor around the maquette).

The whole processing was then brought on using the Software Reality Capture, using a classic production workflow starting with the alignment of the pictures; followed by the polygonal mesh creation (Fig. 5). At this point, after a first archiving of the photogrammetry project, a new copy of the model

received the process of decimation to reduce the number of triangles composing the mesh. For each sector, the decimation was set with a polygonal model mesh target value of 15 million of triangles. The simplified result was then edited to solve some minimal defects, like isolated triangles and holes. All was done using the internal functions in Reality Capture[1]. The simplified model was then the base for creating the texture. This was generated using the resolution at the value of 16K, equal to 256 Megapixels (Fig. 6). The last step of the process was the exporting of the final model in OBJ/MTL+JPG (mesh plus texture with an MTL file containing the parameters for the texture) formats.

The OBJ model was then imported into Autodesk 3D Studio Max[2] (Fig. 7). The following step in this program was to put in scale all the sectors using measures gathered directly on the objects, annotated and kept for this passage. Each part was prepared in a single MAX file and put in a specific folder with all the images needed for texturing. For each part there was the preparation of a dedicated animation rendering, exploring with a perspective view the single part in its main features and characteristics. The setting of each animation got a duration from 45 seconds to one minute and a half according to the complexity and articulation of the part. This was done to create a first (difficult to repeat) visit to the unmounted parts of the maquette.

The completion of this phase took some times and the first version of the digital twin of the Maquette from Lille was presented in Maastricht on the 14th March 2019, a date defined time before with Willem, just in coincidence with the re-opening of the “Plan-Relief” room at the Palais-des-Beaux-Arts which took place on the 16th March. This was a key event for the completion of the model preparation tasks as well, while at that time the whole model was put back in its unity and with new lighting setup. So, it was extremely interesting to take a look and check the final result, take some pictures of the new setup and define the final calibration of the colours of the textures accordingly to the exhibition appearance.

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Optimization of the alignment between parts

After the reopening of the “Plan Reliefs Room” in Lille, the work on the digital model was ready to be completed. The first task was to optimize and bring to a final version the alignment between the digital parts. This was obtained in Autodesk 3D Studio Max, checking, moving, rotating, aligning and

[1] RealityCapture: Mapping and 3D Modeling Photogrammetry Software - CapturingReality.com

[2] 3ds Max | 3D Modeling, Animation & Rendering Software

using the specific Maxscript "3-Point-Align 1.2" by M. Breidt[3]. No deformation tools were used on the starting models, this was a possible option, but it was preferred to avoid this kind of solution (Fig. 8). This alignment was not easy for two main reasons: for first every single part was not necessarily placed in the same horizontal plane than it will reach when combined with all the others. Secondly, the beams and connections were probably subject to some bending and movements when connected all together. The digital version is a "rigid" representation of elements with a certain level of elasticity. Thus, after a generous series of tentatives, a realistic and efficient alignment came out.

Recalibration of the global colour palette

Once the alignment between parts was completed, it was time to finish the processing with a final colour calibration of all the textures. In facts, the slightly different lighting conditions at the moment of the photogrammetric survey produced a certain number of unbalanced colour dominances between parts (Fig. 8). The correction was done in two steps: a first global colour balancing between textures and a second passage on the single textures balancing the colours about the colour scale appearing in the final setup at the Palais des Beaux-Arts in Lille. All the colour balancing work was done using Adobe Photoshop[4]. To have a very fast and practical intervention on these textures, it was preferred operating directly on the images produced during the export of the model, the maps where easily corrected and balanced, checking little by little the progress with a series of rendering from Autodesk 3D Studio Max.

Future perspectives

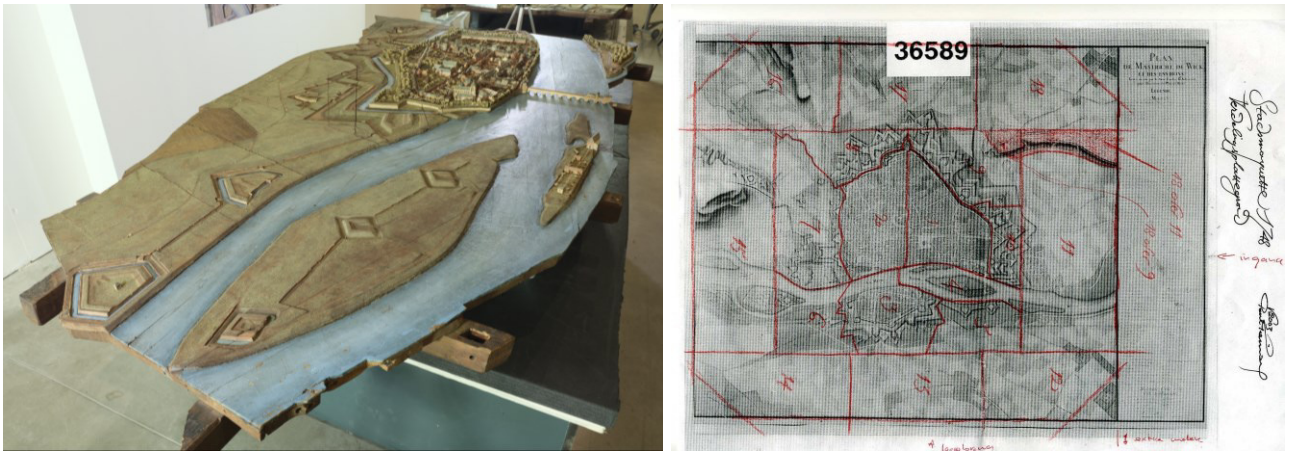
Some testing for 3D printing from the final digital model was a part of the final data treatment at the Dipartimento di Architettura in Florence, the resulting model simply based on white monochromatic resin, was produced using a Formlabs[5] Form2, a 3D Printer using SLS Technology (Selective Laser Sintering), the needed material was an amount of 90 ml for every single part of the model and a printing time of about 10 hours for each part. Both the tests were done on the digital model of the piece number one, the one dedicated to the old town centre. Beyond these very early tests, the digital twin of the maquette is a versatile and accurate model, open and available to the Maascrticht Municipality for digital application and create ideas. After obtaining the data from Firenze, the Municipality of Maastricht organised an inspirational session with several stakeholders to decide what to do with this data in the storytelling of the history of Maastricht. One of the participants, Rob van Haarlem, saw multiple possibilities and his firm Tijdlab, together with the firm Dutch Rose Media, arranged a substantial grant to start a new project. in this project there are a few goals: to render the data to a more realistic level, to use volumetric video to tell the stories in a very vivid way and to give a realistic image of life in the city of Maastricht in 1750. 30 students of the Breda University of Applied Science came up with several ideas of stories to tell. These ideas will be further analysed in the next months and decided which stories to tell and how to perform them. The digital model has brought the possibility to share and use the large ancient maquette to new and creative conditions, making

[3] Freeware, available at http://www.scriptspot.com/3ds-max/scripts/3-point-align (Accessed: April 2020).
[4] Adobe Photoshop webpage: https://www.adobe.com/products/photoshop.html (Accessed: April 2020).
[5] https://www.3dsystems.com/ (Accessed: April 2020).

possible to “bring” this part of the history of the town back to its original place after 270 years since its realization.

Figures

Fig. 1. Lille (France), Palais De Beux-Arts, Plan Relief Room, today (© G.Verdiani).



a *b*

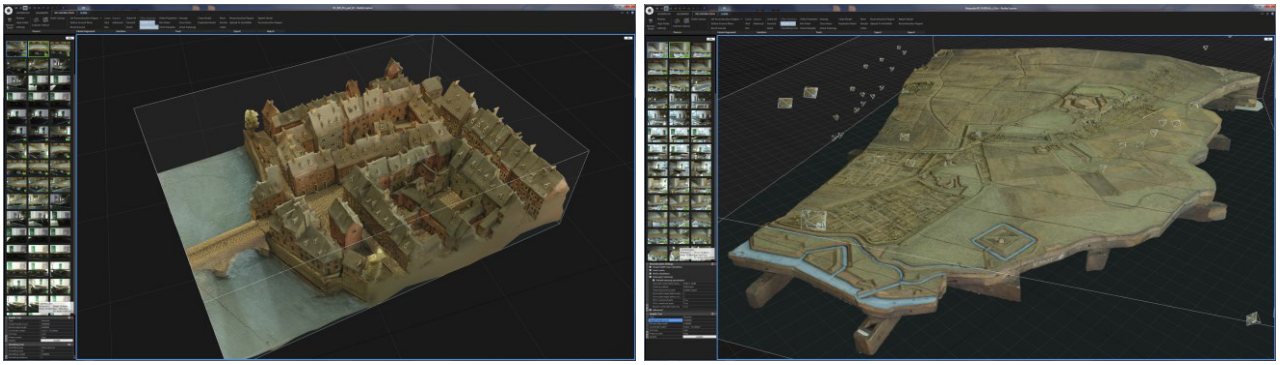
Fig. 2. Starting the photogrammetry in Lille: a) one of the sectors used in the first test (© G.Verdiani, G. Soeters). b) old map with the original subdivision of the sectors (© Archive of the Palais des Beux-Arts in Lille)

Fig. 3. Planning and operating in Vienna and Lille with Willem Beex (© G. Soeters, CHNT Wien).

Fig. 4. Photogrammetry operations at the Palais des Beux-Arts in Lille (© G. Verdiani).

a *b* *c*

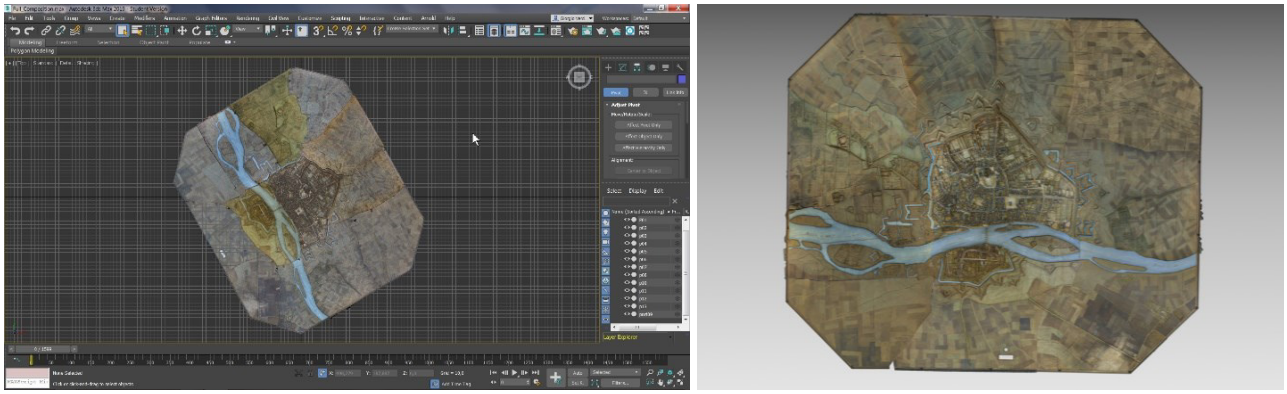
Fig. 5. a) b) c) First results from the Photogrammetry of the sector number one, representing the main town centre (© G. Verdiani).



a b

Fig. 6. Photogrammetry processing: a) a portion from the urban fabric b) a sector completely modelled and textured (© G. Verdiani).

Fig. 7. Photogrammetry processing: final result from the central sector (part 1) (© G. Verdiani).



a b

Fig. 8. Reunion of all the parts: a) before the colours balancing. b) after the colours balancing (© G. Verdiani).

Fig. 9. Detail from the final digital model (© G. Verdiani).

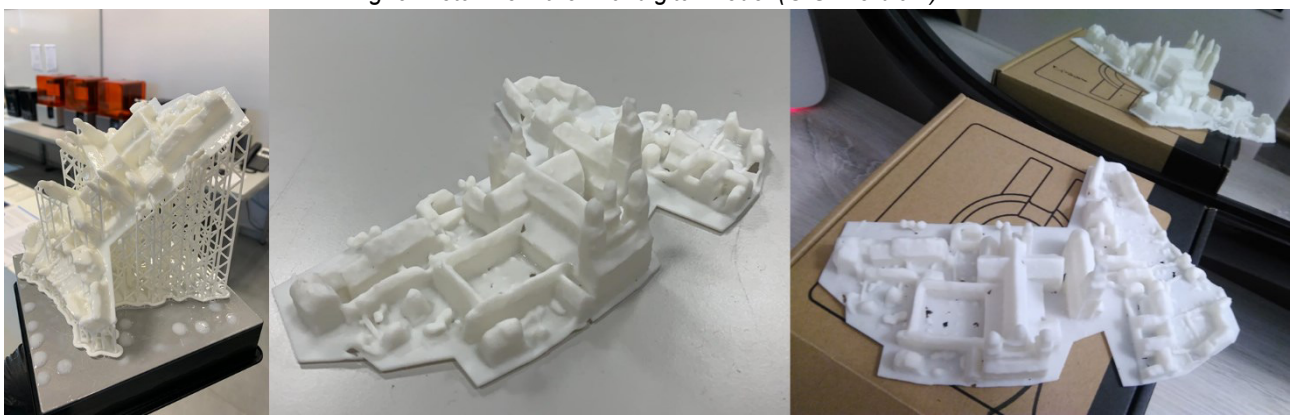


Fig. 10. 3D Print tests from the digital model (© G. Verdiani, LMD DIDALABS, DIDA Florence).

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A descriptive video about all the photogrammetry of the Maastricht maquette is available at https://www.youtube.com/watch?v=hTKb8nZ0WJk&t=49s

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