Urban Landscape in Circular Images: Panoramas and Cylindrical Anamorphosis

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Abstract

The 'panoramas', painted canvases intended to be exhibited in cylindrical buildings named 'rotundas', were produced by the composition of images portrayed from the same point of view, rotating the direction of the visual axis. The privileged subjects of panoramas were urban areas, usually portrayed from an observation point placed at a high altitude, usually a tower, a bell tower, or the roofs of a building. In panoramas, the city cannot be seen at a glance, as the overall image can be formed only in the observer's memory, as a combination of the partial views of the cylindrical canvas. In order to remedy this difficulty, or simply to help visitors to recognise the depicted places, panoramas were also represented in a synthetic image, produced by the projection of the cylindrical canvas onto a horizontal plane; these images were called 'horizontal panoramas'.
This essay analyses the projective relationship between the cylindrical panorama and the horizontal panorama; unfortunately, as far as the authors know, the two images have been preserved only in two panoramas: the panorama of Constantinople, realised in 1801 by Henry Barker, and the panorama of Thun, realised in 1814 by Marquard Wocher. The analysis of the correspondences between the cylindrical and the horizontal panorama is anticipated by the survey of 17th century treatises that illustrate the problem of the relationship between a cylindrical image and its projection onto a plane. One hypothesis proposed in this study is that the hollow area in the centre of horizontal panoramas may be the base of a cylinder whose surface shows the image of the cylindrical panorama formed by reflection.

Keywords: 19th century panoramas, urban landscapes, catoptric anamorphosis, digital representation.

Cylindrical panoramas (1793-1880)

The term 'panorama' denotes an elongated painting, produced by the combination of several views (usually six or eight) in vertical perspective, that spanning the entire circle and are captured from the same point of view, through the rotation of the visual axis. The first panorama that accomplishes these features dates from 1559, according to the current state of research. It is a view of the city of Constantinople, presumably taken from the hill above the Haydarpasa promenade, looking towards the Bosforo and, beyond it, the oldest part of the city with the Topkapi, the church of St. Sophia and the Blue Mosque [1]; the view shows the painter at work (fig. 1).
The invention of the panorama as a form of mass entertainment [2] dates back to 1787 when the Scottish painter Robert Barker patented this type of pictorial representation and provided instructions for its exhibition in dedicated buildings named 'rotundas'.
Although the great part of them was executed by painters, Panoramas offered a training opportunity for young architects experts in perspective drawing, e.g., Jakob Ignaz Hittorff, designer of the Champs Elysées rotunda in Paris (no longer extant), and Friedrich Schinkel, author of a panorama of Palermo.
The panorama's history spans over a century: after the construction of the first rotunda in 1793, painted panoramas went through a period of success in the entire first half of the 19th century. The spread of photography from 1839 did not undermine panoramas success because, from

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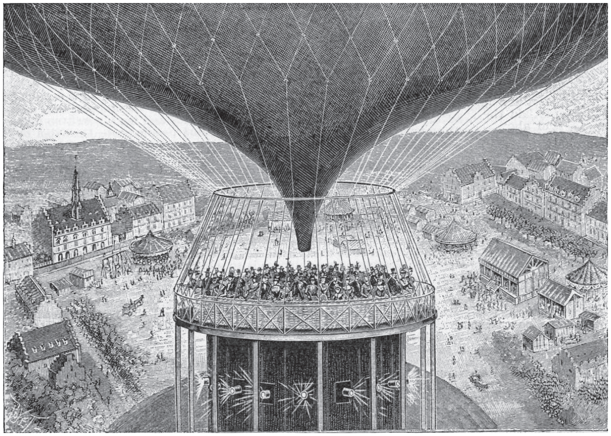


Fig. 1. M. Lorichs, Panorama of Constantinople, 1559. Up: detail of the Panorama of Constantinople. Down: The XI sheet of the Panorama of Constantinople shows the painter himself drawing the view [Solar 1979, p. 63].

Fig. 2. R. Grimoin Sanson, Cyneorama Ballon, 1900 [Bordini 1984, p. 312].

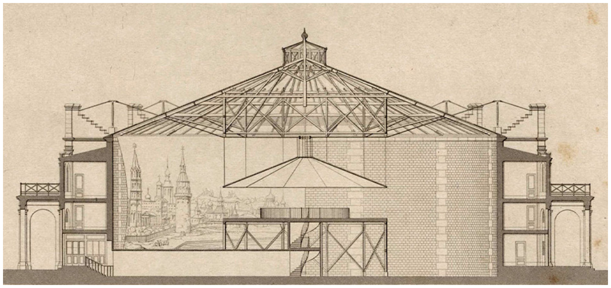


Fig. 3. Section of the Champs Elysées 'Panorama' [Hittorff 1842, Planche 2]

the very beginning, the new technique was also used to produce successful circular photographic panoramas (fig. 2). The very decline of panoramas and rotundas will be caused by the cinema that became the new form of mass entertainment; panoramas will be completely abandoned after the end of the century.
Rotundas were circular buildings, whose diameter ranged from 20 to 30 metres, covered by a conical roof; an elevated platform for the public took the centre of the cylindrical room [3]. The painted canvas was stretched along the inner walls of the building and the platform was placed at a height almost equal to half the height of the canvas, corresponding to the horizon line of the perspective views (fig. 3).
The crucial difference between *veduta* and panorama lies in the fact that the first one, as the term itself suggests, is captured by the eye at a single glance, while the overall image of a panorama can only be formed in the observer's memory; moreover, if in a *veduta* the observer distinguishes the depicted subject from the context in which it is exposed, when watching a panorama the observer finds himself 'inside' the painted landscape, in a condition that today we would call 'immersive'.
Together with panoramas, small images (approx. 40*40 cm) depicting a horizontal projection of the cylindrical panorama were produced; these images were named 'horizontal panoramas'. The aim of these images, where the name of depicted subjects or the description of historical events depicted were often given, was probably to support visitors' orientation in the panorama exhibitions and identify its context and theme; this is why horizontal panoramas were also called 'viewers' key'.
Although it is reasonable to assume that horizontal panoramas were always realised for the exhibitions in rotundas,

the two versions of the same panorama, the cylindrical and the horizontal one, have been preserved only in two cases: namely, the urban panorama of the city of Constantinople, painted in 1801 by Henry Barker, son of Robert, and the panorama of the small Swiss town ofThun, painted in 1814 by the painter Marquard Wocher (fig. 4).
Even if the number of horizontal panoramas that have come down to us is greater than that of cylindrical panoramas [4], the relationship between the two images has rarely been investigated.
The question of the projective relationship between cylindrical images and their projection onto a plane has been studied in numerous treatises of the 17th century on optics, perspective, and direct and catoptric anamorphosis. The analysis of the demonstrations presented in these treatises will provide the reference for the formulation of a hypothesis on the projective correspondence between the two versions of the same panorama.

Horizontal panoramas

Horizontal panoramas were usually offered to visitors together with a small pamphlet that provided information allowing a better understanding of the depicted subject. These images, were at the same time a vehicle for the dissemination and the promotion of the exhibited panorama. Horizontal panoramas are often the only source for the reconstruction of themes and subjects depicted in missing canvases [5].
The artistic characteristics and transformations of horizontal panoramas, and the related pamphlets, have been well summarised by the art historian Denise Oleksijczuk; she observes that, since the first exhibition in 1793 of the panorama *View of the Grand Fleet at Spithead* accompanied by a horizontal panorama: «the Barkers made changes to the pamphlets, experimenting with different pictorial techniques, narratives, and ways of representing space and time» [Oleksijczuk 2011, p. 130]. Oleksijczuk also discusses the evolution of horizontal panoramas, distinguishing the circular format – widespread until 1818 – produced by the projection of the cylindrical image onto a plane, from the later rectangular format, obtained by the development of the cylindrical image on a smaller scale. While the latter presents the extended panorama, often divided into two or more parts, the circular format offers a synthetic representation of the panorama, all at a glance.
The circular format, i.e. the horizontal panorama that is the subject of our study, depicts the ground line in the innermost circle and the horizon line on the outside; the innermost part of the circular image sometimes contains the title of the panorama.
Despite a huge literary production on panoramas, especially developed in the last thirty years of the last century, only a few authors, save Oleksijczuk, have focused their studies on horizontal panoramas and their projective relationship with cylindrical panoramas.
One of these scholars is Stephan Oettermann, probably the most prominent expert of panoramas. In his book on 19th century panoramas, an indispensable reference for anyone approaching the subject, Oettermann dedicates a short paragraph to horizontal panoramas, which he calls 'anamorphic' drawings. The author firmly states that these drawings played no role in the realisation of the panorama, and does not provide a clear explanation of the projective relationship between the two panoramas: «how the anamorphic drawing came to be connected with the panorama is a mystery» [Oettermann 1997, p. 60].
A second outstanding scholar of panoramas, Gustav Solar, focuses his book – dedicated to Hans Conrad Escher, painter of Alpine panoramas – on urban panoramas and on the description of their history and evolution. Solar mentions horizontal panoramas several times, showing many examples, including the Thun panorama analysed in this study. The author states that; «the horizontal or circular panorama […] is based on the vertical projection at a wide central angle. The landscape appears as a circular area, the horizon line as its edge» [Solar 1979, p. 36].
A hypothesis on the use of horizontal panoramas, proposed in this study, is that the hollow area in the centre of the circumference may be the base of a cylinder with a vertical axis, on whose surface the image of the cylindrical panorama is formed by reflection.

Catoptric cylindrical anamorphosis: from Jean Louis Vaulezard (1630) to Kaspar Schott (1657)

The examination of the scientific literature has been directed to the research for studies on the projective relationship between images on a cylindrical surface and their projection onto a plane orthogonal to the axis of the cylinder, i.e. the relationship between vertical cylindrical surfaces and their projection onto a horizontal plane.

Fig. 4. M. Wocher, «Panorama von Thun», 1814. Up: cylindrical panorama of Thun. Down: horizontal panorama of Thun.

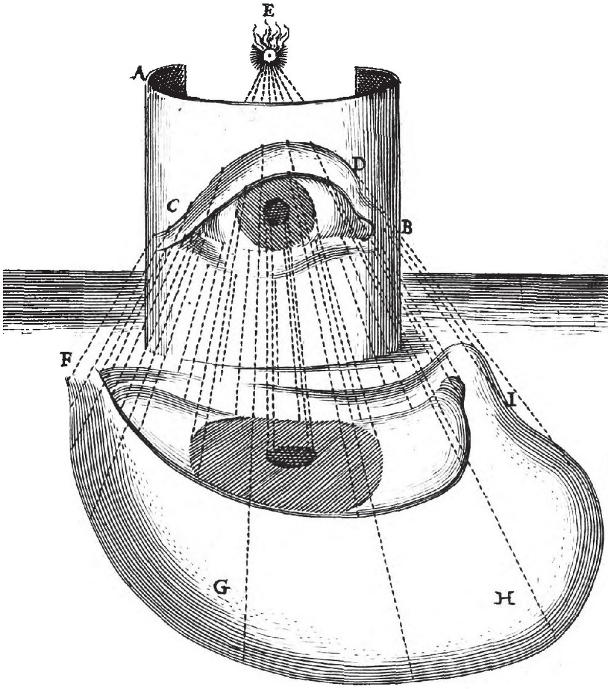


Fig. 5. Depiction of the anamorphosis of a cylindrical figure using a light source, 1642 [Bettini 1642, V, p. 7].

This relationship is analysed in many treatises published in the 17th century, according to two distinct methods:

1. the projection of the cylindrical image onto the plane with the aid of a candle placed inside the cylinder;
2. the projection of the image with geometric criteria, using the optical principles of reflection.

The first method is described in 1642 by the Jesuit mathematician Mario Bettini (fig. 5). In Chapter III of his treatise, Bettini illustrates a method to deform a cylindrical image in a horizontal one: *Imaginem in cylindrica superficiae rectè formatam in plano horizontali ritè deformare* [Bettini 1642, V, p. 7]. The author suggests to place the base of a wooden cylinder on the horizontal surface and to lay on its surface a canvas, or *papyrus*, where the figure to be projected is represented. The canvas is then perforated in correspondence with the lines of the drawing; the wooden cylinder is then removed, keeping the perforated canvas in place. At this point, a candle is placed behind the canvas, in the area previously occupied by the cylinder; the light rays will project the deformed figure, named *dissipata*, onto the horizontal plane. The last step is to place, in the area previously occupied by the wooden cylinder, another cylinder of the same size with reflective outer surfaces. The observer must stand at the same height as the candle but on the opposite side of the cylinder, at a distance from its surface that equals the distance of the candle [6], in order to see the deformed image in a corrected form, *reformata*, on the reflective surface of the cylinder.

The procedure presented by Bettini is extensively reported, recalling the source, by Kaspar Schott in his treatise of 1657. The only difference between Bettini and Schott lies in the judgement on the accuracy of the procedure that uses light rays: while Bettini states that the procedure is flawless, Schott notes that the projection with the candle is affected by imprecision and is not comparable to geometric constructions [7].

The second method, which uses the optical principles of reflection, is described in some 17th century treatises in the chapters dedicated to the phenomenon of 'catoptric anamorphosis', a part of the more general subject 'anamorphosis'. This is not the place for an even short resume of the vast contemporary literature on anamorphosis [8]. Here, it is simply reminded that the term states for a projective procedure that deforms an image so that it can be recognised only from a pre-established point of view. The most diffuse and known anamorphosis, based on the projection of rays onto a surface, is named 'optical' or 'direct', whereas those anamorphoses that use mirrors are named 'catoptric' or 'indirect'. We will limit our attention to catoptric anamorphoses, since they provide an effective reference to study the problem of the projective relationship between the cylindrical surface and its representation on the plane.

Jurgis Baltrušaitis identifies one of the earliest appearances of a catoptric anamorphosis in an engraving by Simon Vouet dated from 1625, (fig. 6) in which the effect produced by a cylindrical catoptric mechanism is depicted. According to Baltrušaitis, this engraving encouraged scholars to investigate this subject, dedicating part of their treatises to the analysis of the catoptric phenomenon.

The first treatise that focuses catoptric anamorphosis is *Perspectif cylindrique et conique* written by the French mathematician Jean Louis Vaulezard and published in 1630. Vaulezard's demonstration stands out among the others, both for its earliness and for the exactness and elegance

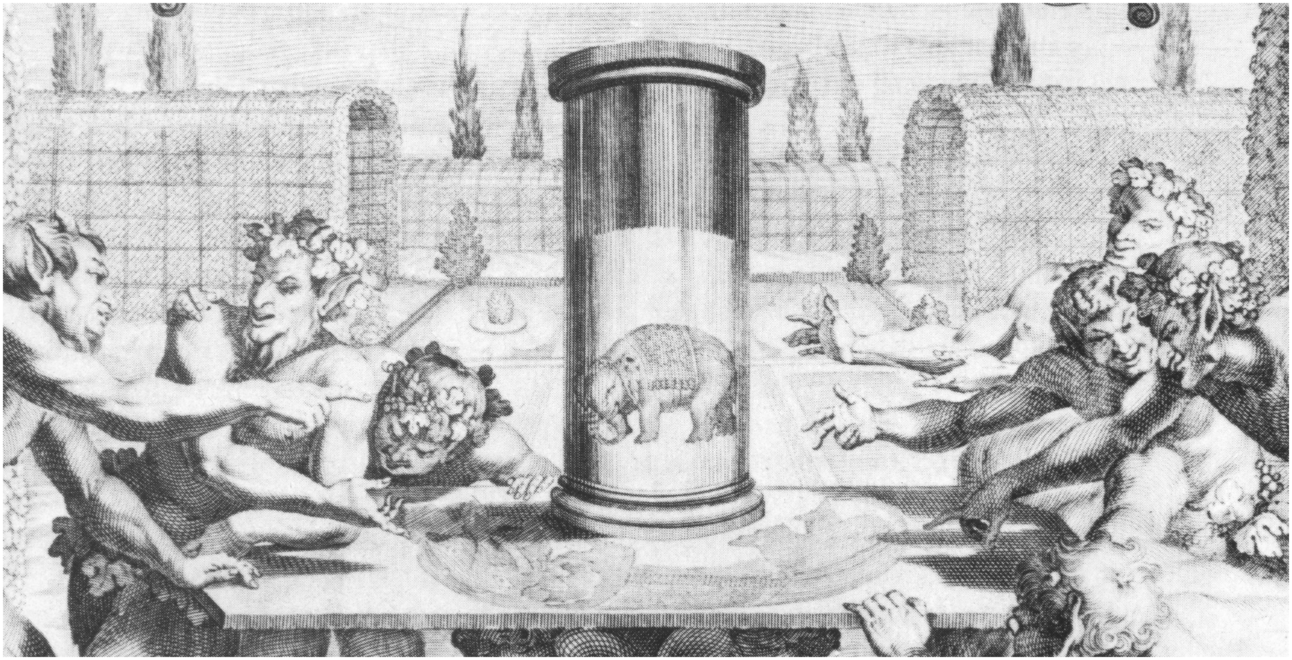


Fig. 6. S. Vouet, Eight satyrs looking at an anamorphic mirror with an elephant, 1625 ca (detail) [Baltrušaitis, 1990, p. 169].

of the demonstration. Later treatises on cylindrical projective catoptric mechanism report rough reproductions of Vaulezard's demonstration [9].

Catoptric cylindrical anamorphosis according to Vaulezard's demonstration.

All the schemes for cylindrical catoptric anamorphosis, published during the 17th century, assume that the flat image to be deformed, named 'prototype', is inscribed in a vertical grid placed inside the cylinder. The prototype is then deformed through two steps: the first is a central projection of the plane grid onto the cylindrical surface; the second 'catoptric' one, uses the principles of reflection to project the cylindrical image onto the horizontal plane; this image, when reflected onto the cylinder, will restitute the correct perception of the initial vertical image. For the purposes of this study, the analysis of the first step has been rejected, and the investigation has been restricted to the second step, i.e. the catoptric demonstration.

Vaulezard illustrates his demonstration with the aid of two images: a double orthogonal projection, which follows a widely recurring scheme in various treatises on perspective, and a an axonometric drawing, which, although aiming to facilitate the comprehension of the demonstration, is quite puzzling (fig. 7).

Vaulezard places the observation point of the reflected image at a considerable distance from the cylinder, at a height from the horizontal plane roughly equal to its diameter.

Given a line *m* that passes through the observation point and intersects the cylindrical surface in *Pr*, Vaulezard illustrates the reconstruction of the reflected line *n* [10] and of the point of incidence *Po* between *n* and the horizontal plane at the base of the cylinder. From the observation point *V*, *Pr* will be the reflected image of *Po*.

It is known that the incident line and the reflected line form the same angle with the reflecting surface; to

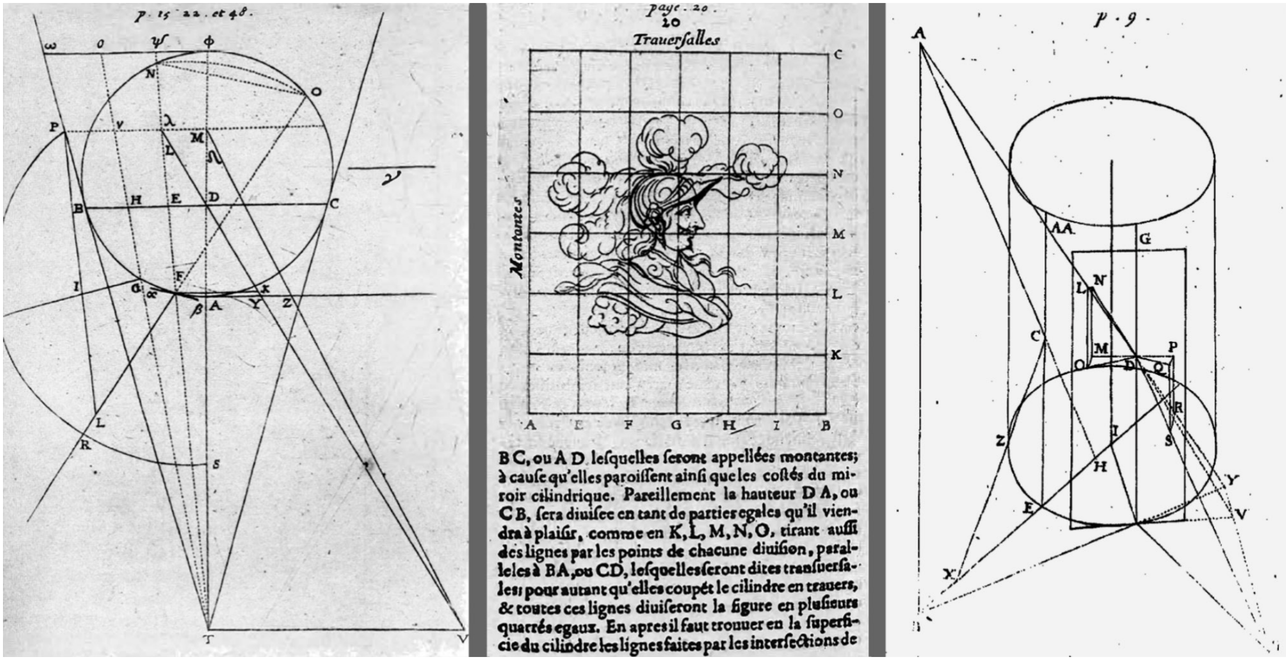
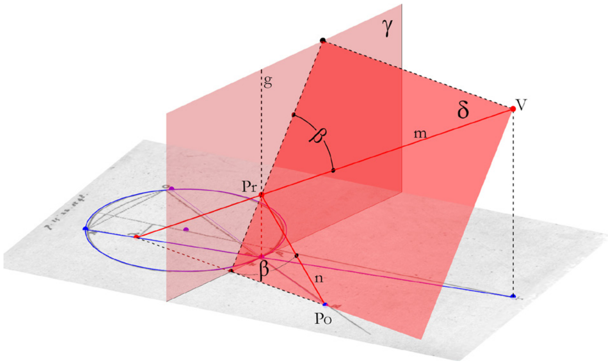


Fig. 7. a) Double orthogonal projection scheme [Vaulezard 1630, p. 20]; b) Prototype figure [Vaulezard 1630, p. 15]; c) Axonometric scheme [Vaulezard 1630, p. 9].

reconstruct this condition it is sufficient to place a vertical plane *γ* tangent to the cylinder along the generatrix *g* that passes through *Pr*; after that, the angle *β* that the line *m* forms with its orthogonal projection on *γ* is measured; *δ* is the plane that projects the line *m* onto *γ*. The reflected line *n* will form an equal angle *β* with the projection of *m* on *γ* (fig. 8). The construction proposed by Vaulezard correctly reconstructs the three-dimensional scheme of reflection.

Thus, given the observation point *V* and a chosen point *Pr* on the surface of the cylinder [11], produced by the projection from *V* of a point *P* of the starting grid plane, Vaulezard draws in plan the line corresponding to the vertical plane that passes through *V* and *P*. This line matches *m'*, the projection of the line that passes through *V* and *P*; *Pr'* is the plan projection of the intersection point between *m'* and the cylindrical surface. Vaulezard draws in elevation both the generatrix of the cylinder through the point *Pr*, named *g*, and the line *m* passing through *V*, *P* and *Pr*.

Vaulezard uses the plan drawing to reconstruct the vertical plane that will contain the reflected ray, simply drawing a straight line that forms with the circumference the same angle of incidence formed by *m'*. To do this, Vaulezard extends *m'* to the second intersection *M'* with the circumference, centres the compass at *Pr'* with radius *Pr'M'*; the arc, thus drawn, intersects the circumference at *N'*. The line *n'* will pass through *N'* and *Pr'*. The chord through *M'* and *N'*, as Vaulezard himself notes graphically, is parallel to the tangent to the circumference at *Pr'* [12]. The last step reconstructs the position of *Po* on the line *n'*; Vaulezard considers that the reflected ray must cover the same distance that separates the point *Pr* from the point *Q* where the line *m* intersects the plane of the cylinder: he therefore imposes the equivalence *PrQ=PrPo*. To find *Po*, Vaulezard represents the second projection of *Q*, i.e. *Q'*, and, from this, the point *Q* on *m'*; he then traces, in top view, an arc of circumference with centre at *Pr'* and radius *Pr'Q* (fig. 9). The point of intersection between the circle, thus drawn, and the line *n'* will be the point *Po* [13].



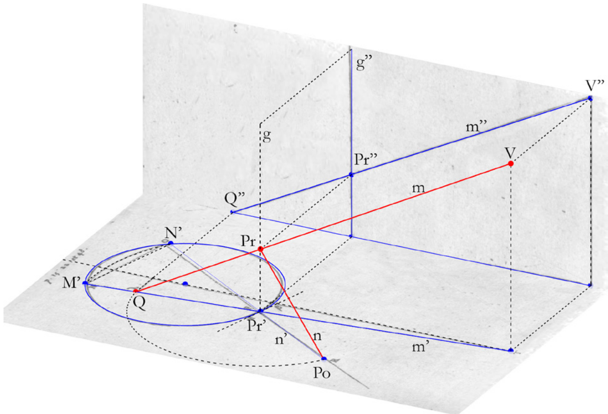


Fig. 8. Explanatory model of the construction proposed by Vaulezard (drawing by the authors).

Fig. 9. Illustration of the construction proposed by Vaulezard with the spatial reconstruction of the projection planes (drawing by the authors).

Digital tools for the photorealistic verification of projective correspondence

Digital representation and photorealistic rendering tools make it possible to verify the operations described by Bettini and Vaulezard and demonstrate the substantial differences in the produced effects.
Both verifications have been carried out by tracing, onto a cylindrical surface, a circumference at a pre-established height; afterwards, the circumference has been projected onto the horizontal plane according to the two mechanisms proposed by the two authors; finally, the correspondence between the starting circumference (our prototype) and its reflected image on a cylinder having the same dimensions has been verified.
The first studied mechanism uses projecting straight lines (light rays): given the cylinder and the circumference to be projected, a point on the axis of the cylinder is chosen, and this point assumes the role of the centre of projection, or light source; from this point the projecting straight lines are then drawn to intercept some points of the circumference, thus identifying their projection on the horizontal plane. As can easily be argued, the projection on the horizontal plane of the circumference onto the cylinder is once again a circumference, concentric to the first one. Following Bettini's instructions, in order to see, on the cylindrical surface, the match between the reflected and the drawn circumference the observer must be positioned at the same height as the centre of projection and at a distance from the cylinder equal to the radius of the cylinder.
Using a digital tool for photorealistic rendering [14], it is possible to assign a reflective texture to the cylinder and position a virtual camera on the previously defined observation point. It is thus verified that the circumference identified on the cylinder and its reflection are perfectly congruent only on the portion of the cylindrical surface closest to the generatrix, at the intersection between the cylinder and the vertical plane through the cylinder's axis and the observer's point. In fact, the digital model demonstrates that, moving away from this generatrix and approaching the apparent contour generators, the two circumferences show slight deviations (fig.10a).
The second verification was performed using Vaulezard's geometric method for catoptric anamorphosis. Given the circumference on the cylinder and the observation point, the incident rays through chosen points on the circumference and their reflections have been identified, thus

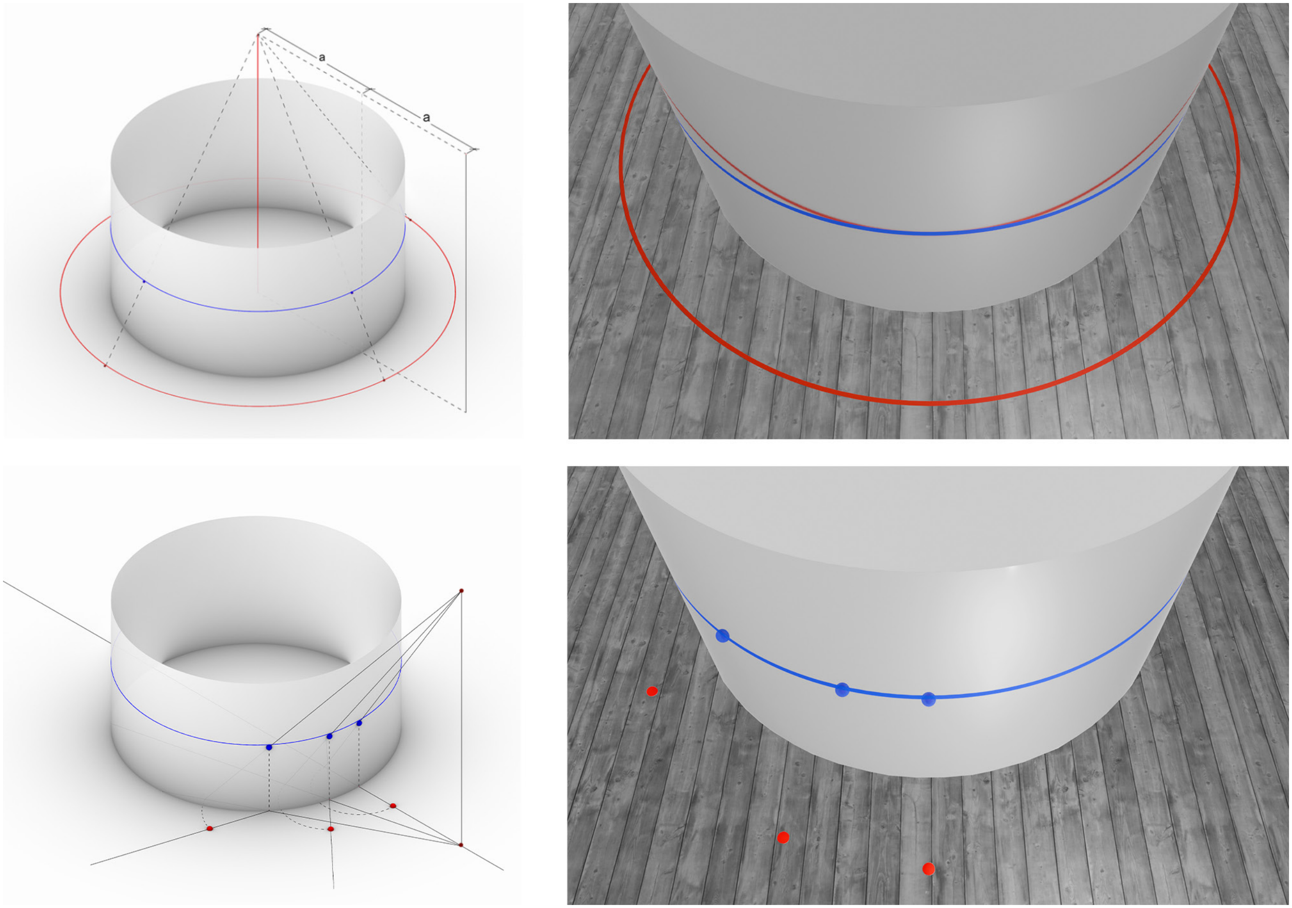


Fig. 10. a) Verification of the light-ray method; b) Verification of the Vaulezard method (drawing by the authors).

obtaining their projection on the horizontal plane according to Vaulezard's method. Assigning a reflective texture to the cylinder and placing a virtual camera on the observation point, it has been verified that the circumference drawn on the cylinder exactly matches its reflection (fig.10b). It is thus confirmed that if the observer is positioned exactly at the predetermined viewpoint, the Vaulezard geometric mechanism has no error.
This test has revealed advantages and weaknesses of the two techniques: while the method proposed by Vaulezard is the most correct, it can be used only for the reflection on the cylinder of an image that takes only a limited area of the horizontal plane, that can be reflected on the portion of the cylinder that is visible from the observation point.
On the other hand, the method proposed by Bettini, which is affected by the deviations described above, allows the catoptric correspondence between plane and cylindrical image to be extended to the entire circumference; these deviations can be considered irrelevant, as Schott has already noted, for an observer who rotates around the mechanism composed of a horizontal plane and a cylinder, i.e. to observe the entire cylindrical panorama recreated by the reflection.

The Panoramas of Thun and Constantinople

As already noted, this study aims to answer two questions:
1. is there a projective relationship that explains how horizontal panoramas were drawn?
2. if this relationship exists, does it allow us to reconstruct, by reflection, the image of the panorama displayed in the rotundas starting from its horizontal panorama?

The previous considerations guided the analysis of the two chosen case studies [15].
The first test was dedicated to find a correspondence between the horizontal and cylindrical panorama. To this end, after mapping the cylindrical panorama onto a surface of corresponding shape, a vertical plane passing through the axis of the cylinder and a remarkable point of the cylindrical panorama was identified; the horizontal panorama was then mapped onto the plane at the base of the cylinder, ensuring that the hollow inner portion of the circumference corresponded to the base of the cylinder; the mapped image was then rotated until the remarkable point of the cylindrical panorama matched the corresponding point on the horizontal panorama.
At this point, the vertical plane passing through the axis of the cylinder was rotated in order to intercept other remarkable points of the cylindrical panorama, in order to verify whether the line of intersection between these points and the horizontal panorama passed through the corresponding point.
This test has revealed a good correspondence between the two images of the Thun panorama, while it showed clear inconsistencies for the Constantinople panorama; it was therefore decided to exclude the second panorama and perform further analysis only on the Thun panorama.
The next step was to verify whether there was a projective correspondence between the two versions of the Thun panorama based on the light ray mechanism.
For this purpose, straight lines passing through homologous points were drawn on the previously identified vertical planes. The research of a convergence towards a common point was successful and showed that, to a good approximation, the lines passing through homologous points intersect the axis of the cylinder (Fig. 11).
In addition, the verification showed that this point of convergence on the axis of the cylinder is placed at a distance from the base that equals the diameter of the cylinder.
The research for the projective correspondence between the cylindrical and horizontal panorama of Thun showed that it corresponds to the method proposed by Bettini.
As far as the second question is concerned, it can be observed that, based on what was observed in the previous paragraph, Thun's horizontal panorama made it possible to recreate the image of the panorama on the reflective surface of the cylinder with an acceptable approximation (fig. 12).

Conclusions

This study focuses a topic often eluded by the scientific literature on the subject: the relationship between cylindrical panoramas and their anamorphic transformation into horizontal panoramas. It has been proposed that a catoptric mechanism could be used to reconstruct the cylindrical panorama outside the rotunda, through the reflection of the horizontal panorama on a cylindrical surface located at the centre of the horizontal panorama. The examination of 17th century treatises focusing the relationship between cylindrical images and their flat anamorphosis has made it possible to verify two different projective workflows that use light rays and reflection

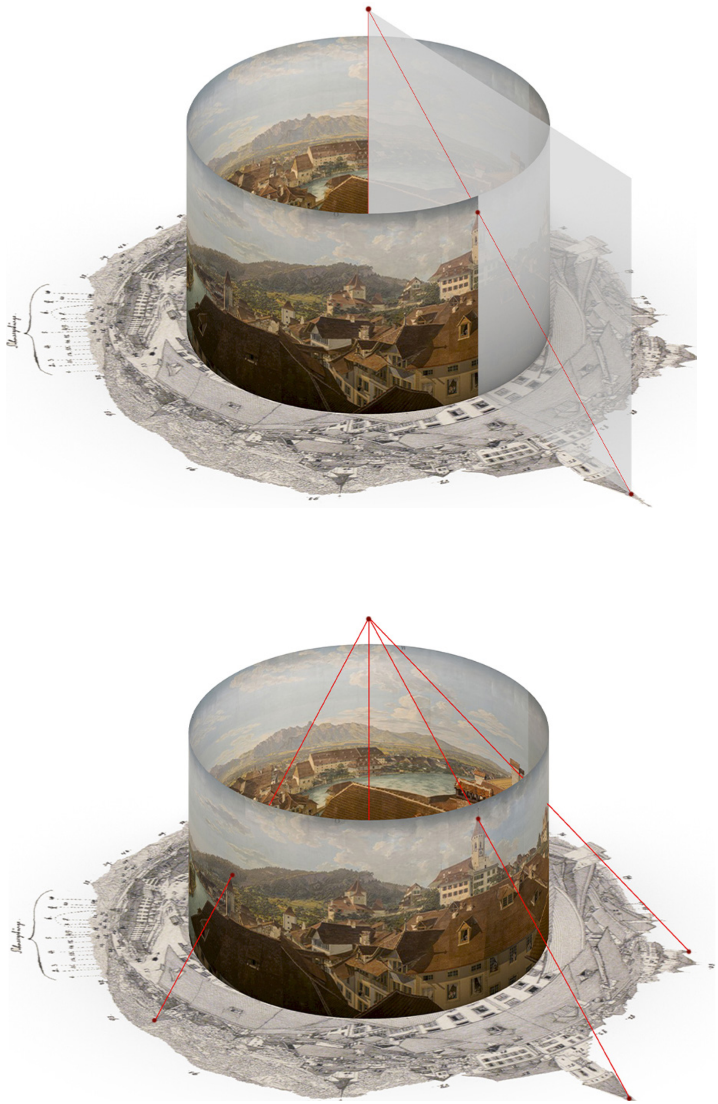


Fig. 11. Steps for finding the projective correspondence between the cylindrical panorama and the horizontal panorama of the city of Thun (drawing by the authors).

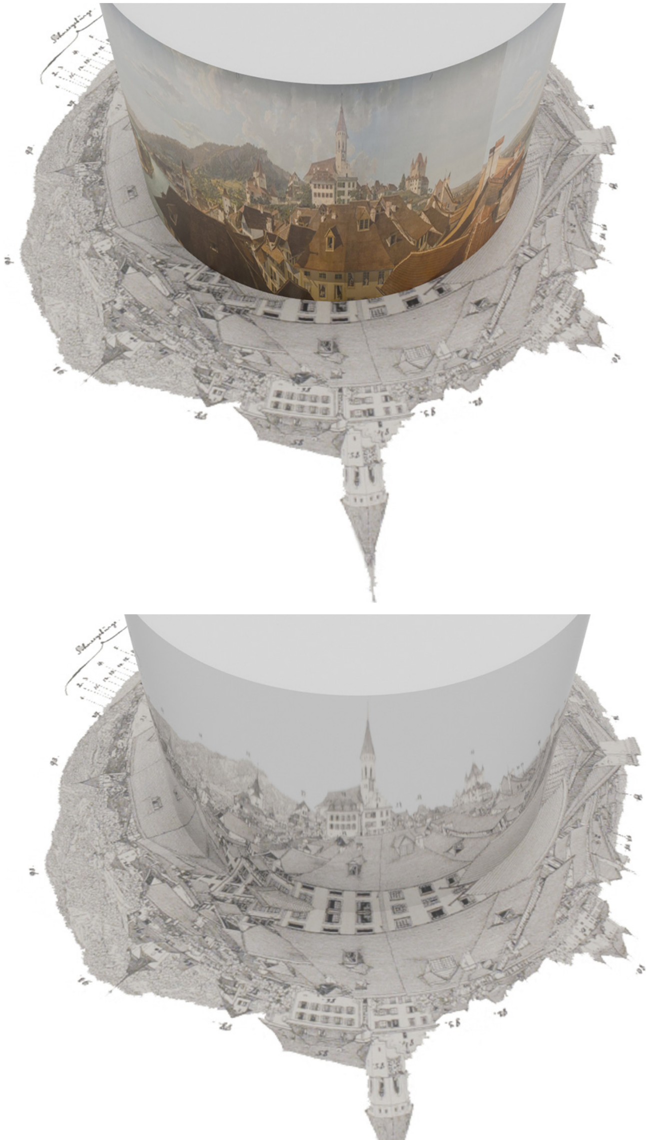


Fig. 12. Comparison between the cylindrical panorama of the city of Thun and the one produced by the reflection of the horizontal panorama (drawing by the authors).

respectively. The analysis, also developed with the aid of digital tools for photorealistic visualization, has made it possible to confirm the hypothesis of a relationship based on projecting lines (light rays) converging at a point on the axis of the cylinder, whose distance from the base equals the size of the diameter. The proposed considerations must be intended as simply hypothetic, because, although many horizontal panoramas and a good number of cylindrical panoramas have come down to us, the double version of the same panorama has been retrieved only in two cases, one of which turned out to be inaccurate; the field of investigation was therefore restricted to a single case study, the panorama of the small Swiss town of Thun.

Notes

[1] The panorama of Constantinople, now kept in the Leiden library, has never been exhibited to the public.

[2] The definition of the panorama as a mass medium was introduced by Stephan Oettermann in his famous monograph on the 19th-century panorama [Oettermann 1997].

[3] In Barker's patent, the rotunda was described as: «a circular building […] lighted entirely from the top, either by a glazed dome […] inside this building there must be a circular stage […] there must be over it […] a shade or roof […] to prevent an observer seeing above the drawing or painting, when looking up; and there must be […] another interception […] so as effectually to prevent the observer from seeing below the bottom of the drawing» [Bordini 1980, p. 13].

[4] The small format of the horizontal panoramas allowed their quick and cheap reproduction, facilitating their preservation even by enthusiasts; on the other hand, most of the cylindrical panoramas made during the 19th century have been lost due to the degradation induced by the repeated transport and assembly operations to which they were subjected.

[5] A proposal for the reconstruction of a lost cylindrical panorama starting from its horizontal panorama was carried out for Schinkel's panorama of Palermo; the study was conducted by Fabrizio Ferro, architect and PhD in Survey and Representation at the University of Palermo, as part of his degree thesis in Architecture, discussed in 1993 [Ferro 1996]. Ferro proposes a graphic procedure that applies Galli Bibiena's method to project a three-dimensional object on double-curved surfaces. Given the considerations set out in the text, the authors state that they cannot agree with the assumptions and procedure adopted by Ferro.

[6] «*Advertendum tamen est (ut exactissimè omnia fiant) lumen, quod collocandum est post cavam papyrum, tantum dem ab ea, et in eadem altitudine distare opporrere, quanta est distantia, et altitudo oculi visentis emendatam imaginem depictam in convexo papyri cylindricè incurvatae*» [Bettini 1642, V, p. 8].

[7] Bettini states that light, as a natural phenomenon, is without error: «*Atque hic prefectissimus deformationis modus est, cui rite facto nullus error subesse poterit, cum naturam magistram in proiectione, ac traiectione luminis sequatur*» [Bettini 1642, V, p. 8]. On the other hand, Schott notes that the accuracy of geometric reconstruction of the reflection phenomenon is superior to projection using light rays: «*Hic obiter observo, lumen non tam accuratè praestare dictum officium designandi in plano figuram*» [Schott 1657, III, p. 162]. A little further on, however, the author states that the margin of error is acceptable, as it does not affect the perceptual experience: «*Sed in similibus praxibus non requiritur scrupolositas geometrica*» [Schott 1657, III, p. 162].

[8] The text that rekindled the scientific community's attention to the projective phenomenon of anamorphosis in contemporary times is *Anamorphosis o Thaumaturgus opticus* by Jurgis Baltrušaitis. Numerous studies on the subject have been conducted in subsequent years by Riccardo Migliari and the academic school that draws on his teachings; two volumes collect the results of a PRIN project in which numerous scholars from different universities participated [Valenti 2014], while a more recent text offers a compendium of theories above perspective and its applications [Migliari, Fasolo 2022]. An important recent exhibition on the anamorphosis of Nicéron and Maignan, curated by Agostino De Rosa, author of numerous studies on the subject [De Rosa 2013], has to be mentioned. A valuable compendium of treatises on anamorphosis is offered by Chiara Capocefalo's PhD thesis [Capocefalo 2014], which deals with optical and catoptrical anamorphosis through the demonstrations set out by de Caus, Vaulezard, Hérigone, Nicéron, Dubreuil, Bettini, Kircher and Schott. In the plates attached to the text, the 17th-century schemes are redrawn by the author to aid understanding and highlight certain approximations.

[9] Demonstrations of the catoptric phenomenon, after Vaulezard, adopt an intuitive approach to bring them closer to the artists' practices. Jean François Nicéron, for example, in the book III of his treatise, published in 1638 and entitled *Perspective Curieuse ou Magie Artificielle des Effets Merveilleux*, proposes an admittedly approximate method, including corrections to be made by observing the image reflected on the mirror. Nicéron does not consider the relationship between the incident and reflected rays and, above all, the position of the point of view for the correct view of the reflected image. Later, in the same volume, Nicéron proposes a scheme based on that of Vaulezard, proposing some simplifications. Subsequent works describing the construction of anamorphic images, starting with Dubreuil's 1642, collect and graphically rework previously published schemes, adopting a practical and intuitive approach.

[10] «*Et il faut décrire en ce plan une ligne, de laquelle l'apparence tombe sur le côté du miroir cylindrique*» [Vaulezard, 1630, Problème I, p. 14].

[11] For ease of reading, the description, while remaining faithful to the scheme proposed by Vaulezard, adopts the annotation of points and lines proposed in the text; in addition, it uses the current conventions on the indication of double orthogonal projections.

[12] «*Du point T, soit menée la ligne droite TF, prolongée jusqu'à la circonférence concave du cercle, coupant icelle au point N; puis du point F,*

comme centre, & intervalle FN, soit décrit l'arc de cercle NO, coupant la circonférence du cercle de la base au point O, duquel par le point F, tirant OFR, icelle FR, sera la ligne requise. Car, si on tire la ligne αβ touchant le cercle ABC, au point F, l'angle OFβ sera égal à l'angle ONF» [Vaulezard, 1630, Problème I, p. 14].

[13] «*En après soit faite la ligne Fκ, parallèle a TV […]; puis tirant la ligne droite Vκλ, coupante la ligne TFλ, au point λ, si on fait FR, égale à Fλ, le point requis sera le point R*» [Vaulezard, 1630, Problème 2, p. 17].

[14] The drawings and models designed by the authors to illustrate the essay were made with Rhinoceros; photorealistic simulations were calculated with Blender.

[15] The first case study is the panorama realised by Henry Aston Barker and exhibited at the rotunda in Leicester Square, London, between 1801 and 1802, called *View of Constantinople from the Town of Galatea*; the panorama shows part of the city and port of Constantinople from the tower of the historical quarter of Galata. The original canvas has been lost but its dimensions are known, and a scale aquatint made by Charles Tomkins in 1813 has been preserved [Hyde 1988]. The aquatint, divided into eight sheets, and the viewer's *key* of the panorama are preserved in the Prints and Drawings Department of the British Museum. The second case study is the *Panorama von Thun*, created by Marquard Fidelis Wocher and exhibited since 1814 in a small rotunda in Basel, Switzerland. This panorama, depicting the mountain landscape of the small town of Thun, is 7,5 m high and 38 m long [Steiger-Bay, H. A. 1950]. The panorama is now displayed in Thun inside a new rotunda, designed in the 1960s by architect Karl Keller.

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