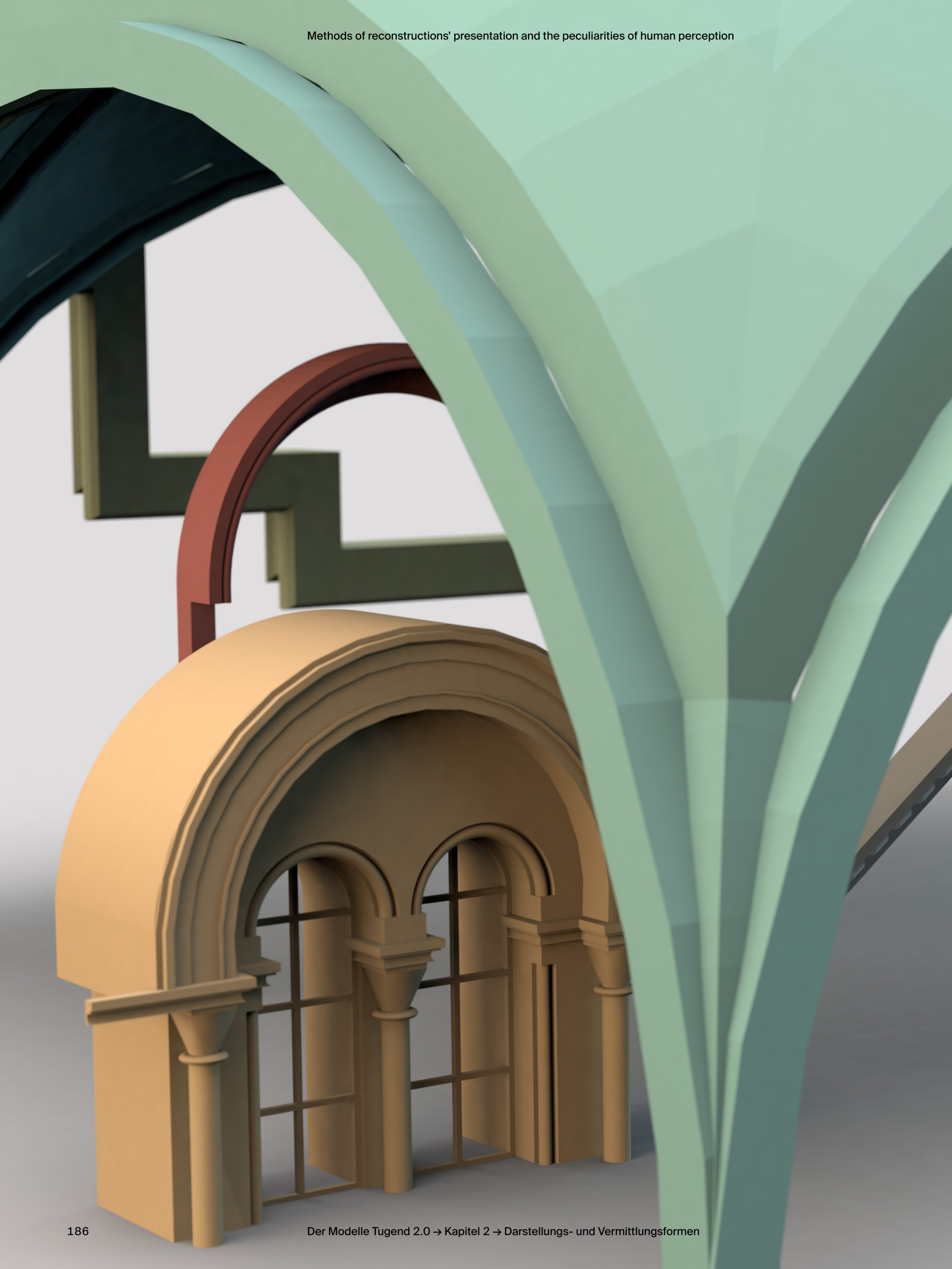
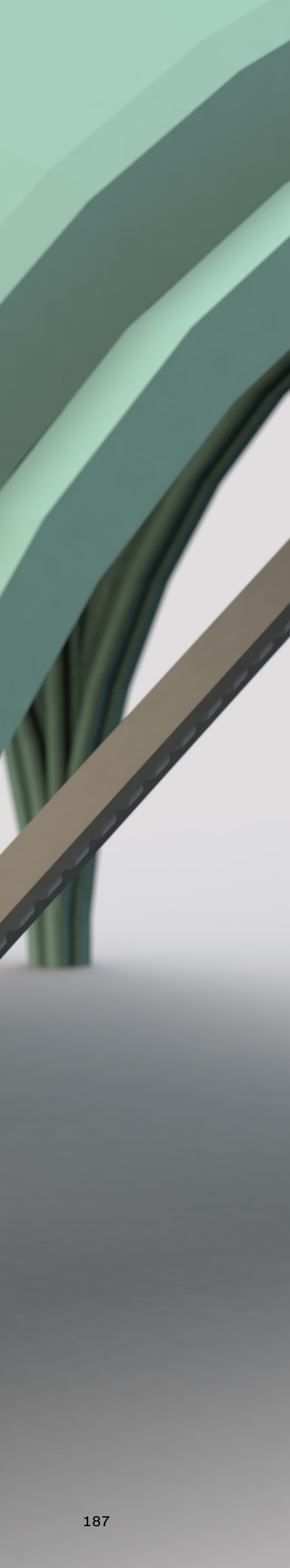




Dmitry Karelin, Maria Karelina

H. Methods of reconstructions’ presentation and the peculiarities of human perception

→ 3D reconstruction, angle of view, architecture, methodology, perspective, plane of projection, presentation, Rauschenbach, viewpoint, visualisation

The paper is dedicated to the methods of presentation of 3D-reconstructions from the human viewpoint. Due to the type of presentation its methods have to change. Several peculiarities of presentation and visualization are discussed in the paper. First of all it is the angle of view which depends on the type of presentation and the features of the reconstructed monument (its size and configuration). This point is strongly connected with peculiarities of perspective’s construction: different surfaces of image projection and usage of the third focal point. Secondly it is the character of a viewpoint, argumentation of its position. In this case the historical knowledge about the monument is very important. Furthermore the creation of viewpoints’ system which shows the argumented trajectory of movement is also possible and could show the historical character of the monument and its perception by the viewer. Thirdly it is important to examine the characteristics of visualization’s composition — direction of its development, the interaction between the background, the midground and the foreground which creates the depth of composition. All the features are important for the perception of the reconstructions’ depiction from the human viewpoint and it is advisable to note them in the reconstructions of historical heritage.

H.1 Introduction

This work develops and continues the paper be several authors made for the Conference on Cultural Heritage and New Technologies, November 2–4, 2015, and the article, which was published later and based on it. The article was dedicated to the methods and approaches of the visualization of 3D reconstructions 01. In the paper we've mentioned we considered the criteria of applying either orthogonal / axonometric images or real points of view, as well as a number of other aspects. There were made the following provisions:

- → The methods of visualization mainly depend on the aim of reconstructions and images which we create. If we need to show the architectural features of an object (planning, structure, constructional peculiarities or type of structural organization and building phases) the best way is to use axonometric views, orthogonal projections and perspectives from the high viewpoints. If we need to show peculiar architectural features of the monument, if any, some viewpoints, which could be important, or show the impression which the building could make on spectators, one could suppose that the perspective views from a real viewpoint with real light and so on is the best way to do it.
- → Criteria as ones used in photography or art should be used for the reconstructions too. In modern studies on historical reconstructions the main idea is to show the authentic features of a building (details, materials and architecture) and to express the impression which the monument could produce upon the viewer using realistic light, comfort angle of view and it is of no less importance that we understand which visual methods should help us 02.

The aim of this work is to focus on the peculiarities of presenting visual information in the case of using static perspective views from real points of view. Before we proceed to the main topic of the work we need to establish some fundamentals on which we are going to base our study.

We can single out several ways of presenting a scientific reconstruction:

1. A drawing on paper (in a book or an article).
2. An image on the computer / smartphone screen (in a book or an article, on a website).
3. A video sequence (on a website or web article).
4. Virtual reality headsets and some other technologies of the same kind when the image is shown via interactive pre-rendering rather then complete rendering.

In this work we will analyze only static images on plane surface (points 1 and 2), as virtual reality headsets and other new technologies are still used indirectly especially in presenting information on scientific reconstructions; nowadays it is mainly publications in scientific and popular literature and on websites.

■ 01
Dmitry Karelin, Serjey Klimenko, Julia Klimenko, The methods and approaches of the visualization of 3D reconstructions, in: Proceedings of the 20th International Conference on Cultural Heritage and New Technologies 2015, Vienna 2015, http://www.chnt.at/wp-content/uploads/eBook_CHNT20_Karelin_etal_2015.pdf

■ 02
Karelin et al. 2015, p. 10.

Besides, when we see an image on plain surface an interesting thing happens which is of a special interest, in our opinion, and which is actually the subject of our article. A human brain has to perceive a plane image as a 3-dimensional one, and there occurs the phenomenon when a person is able to consider the part of the image, which is on its periphery, in the area where peripheral distortion emerges. When dealing with natural eyesight we never see a peripheral area distinctly. While wearing virtual reality headsets it is also unlikely because when we use such equipment we actually emulate natural human eyesight; besides, when we turn the head in such a headset we look at the point we need and the periphery of the image becomes not important.

It is very probable that using devices which create the illusion of virtual reality generate and will generate more different problems connected with human perception. Although in this case we arrive to the conclusion that a human brain does not have to perceive an image on plane surface constructed according to the rules of linear perspective, and this is what makes it difficult to perceive something, and even more difficult in case the laws of constructing perspective and human perception are ignored. Considering that nowadays a flat image is the major way of presenting information in scientific reconstructions, we should pay a special attention to this problem.

H.2 Boris Rauschenbach studies

The essential breakthrough in this field was made by the Russian scientist Boris Rauschenbach. In one of his first works he thoroughly examined the problem of perception of human vision with regard to the rules of constructing perspective [03]. He composed the differential equation of a human brain's work at visual space perception and gave all mathematical calculations. In his further research paper he considered this problem from a different point of view and applied it to the criteria of evaluating works of art, without the already published mathematical part [04]. He also showed what a great meaning axonometry has and proved that ancient and medieval art, which, in general opinion, didn't use perspective, was not primitive, and explained obverse (inverted) perspective from mathematical point of view. The part of our work about perception of human vision is mainly based on the research of Boris Rauschenbach.

However, in Europe and the US there have been done a lot of research on visual perception of space [05]. It is necessary to note some of them which are of a particular interest to us. First of all, the works of J. J. Gibson [06], one of the apologists of the theory of visual perception in the US and the scientist who created a new ecological approach to visual perception. This author paid special attention to the problem of connection between motion and visual perception, which we do not cover in this article, because Gibson began his researches as a visual perception psychologist in U. S. Air Force, so he mainly worked on training of pilots during World War II, although in his works he singled out and gave a thorough description of the criteria of **ground surface.**

■ 03
Boris Rauschenbach, Systems of perspective images in art: general theory of perspective, Moscow 1986.

■ 04
Boris Rauschenbach, Geometry of picture and visual perception, Saint Petersburg 2002.

■ 05
Harold A. Sedgwick, Visual space perception, in: E. B. Goldstein (Ed.), Blackwell handbook of perception, Oxford 2001, pp. 128–167.

■ 06
James J. Gibson, The perception of the visual world, Boston 1950a; James J. Gibson, The perception of visual surfaces, in: American Journal of Psychology, 63, 1950b, pp. 367–384; James J. Gibson, The senses considered as perceptual systems, Boston 1966; James J. Gibson, The ecological approach to visual perception, Boston 1979.

He pointed out that more detailed surface of the ground could improve human visual perception of scale and dimensions [07]. If in an image we see the elements we can recognize — any details or textures or objects — it can help us to assess the distance between those objects as well as their size.

We should also note the work of Jennifer Polack [08], where she carefully examines geometrical systems of constructing perspective on cylindrical and spherical surfaces of projection, both from the point of view of their geometrical basis and the peculiarities of their perception. Having conducted a lot of tests and surveys, the author comes to the conclusion that perspective with Cylindrical surface of projection is better from the point of view of visual perception than planar and spherical ones [09].

The keystone of the problem examined in the article is the fact that a human brain transforms a real image created on the retina, so a person would perceive a mathematically correct perspective relocated in a flat surface and made from the same viewpoint in a different way. The rest of our work will be dedicated to the following task: how we can achieve the maximum similarity of a scientific reconstruction, made on a flat surface from real view points, to human perception.

For a long time the perspective invented by the artists of the Renaissance served as a standard to other artists. However in the 20th century the scientists doubted that renaissance perspective took into consideration the work of a human brain which substantially changed the image when it was created on the retina [10]. Many artists instinctively broke the rules, trying to make a painting or drawing look more similar to how a person actually saw it. According to Rauschenbach's theory [11], we can describe the process taking place in a brain in the following way:

→ There exists an object or space (A).
→ The optics of a human eye creates its image on the retina (C), and the image is close to the one which is constructed according to the rules of geometrical perspective (E).
→ On the basis of the information it gets the brain creates an image (B) in the head, using which an artist can draw or paint a picture (D). If the artist is talented and / or understands the rules of human visual perception, then a different person, when they see the picture (D) they will get an image that looks like a real object (A).

It is important that when making planar scientific reconstructions of the real views an author has to create an image which is as close to the one perceived by a human brain as possible. However, as Rauschenbach prove [12], it cannot be done if the methods of geometrical perspective are used, because as the author corrects mistakes [13] and distortions, there emerge other mistakes. In his work he gives several variants of scientific perspective constructions and three common types of mistakes:

■ 07
Gibson 1950a.

■ 08
However we should note that the author's statement that she created a mathematical model of constructing perspective on cylindrical and spherical surfaces of projection sounds very strange (See Jeniffer A. Polack, Perception of Images Using non Planar Perspective, PhD dissertation, University of South Florida, Tampa 1997, p. 132), as a model of constructing perspective on any kind of surface is included into many text-books on descriptive geometry.

■ 09
See Polack 1997, pp. 132–135.

■ 10
Rauschenbach 2002, p. 8.

■ 11
Rauschenbach 2002, pp. 15–17, fig. 1.

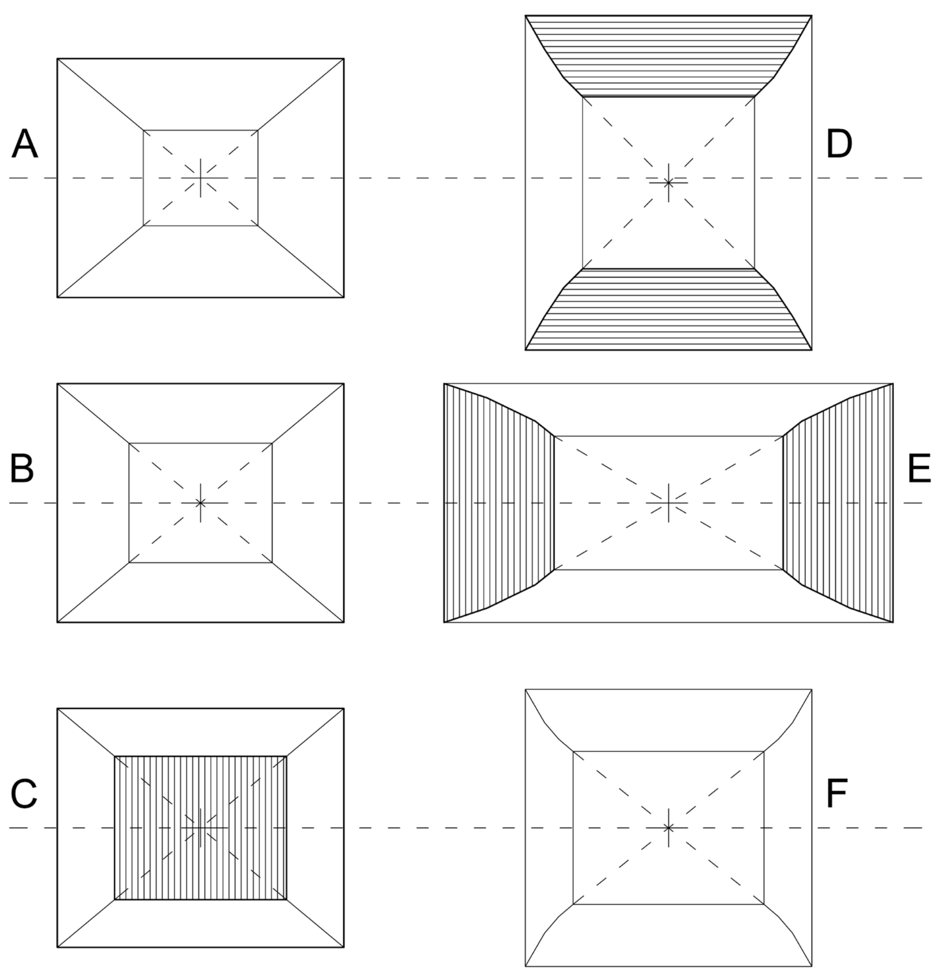
■ 12
Rauschenbach 2002, pp. 22–28, 34.

■ 13
We should point out that by the term »mistake« Rauschenbach does not mean a mistake literally, but the difference between real perspective and its image created by the brain (Rauschenbach 2002, p. 48).

■14
Rauschenbach 1986, p. 53, figs. 8–9.

Six main views 14 01 that depend on the distance between the scene and the viewpoint (L_0) and its position relative to the depth of the scene (L) and the surface on the basis of which the perspective is constructed.

- → Renaissance perspective (A), L_0=L, gives a correct similarity of objects (the shape and the characteristics of an object, that is, a square looks like a square).
- → Linear perspective (B), L_0=2L, gives a correct similarity of objects and the depth of the space.
- → Linear perspective (C), L_0=4L, gives a correct scale (the distance between foreground, midground and background objects). There are problems with giving the correct depth of the scene.
- → The variant which considers (D) that the retina of the eye is not flat. The projection plane of the perspective has cylindrical shape with a horizontal axis. This variant shows some floor and ceiling which helps to paint them better, but it distorts the similarity and scale of vertical elements.



☐01
The main variants of interior perspective. The planes that are not distorted are marked with hatching (Rauschenbach 1986, fig. 9)

→ The variant which considers (E) that the retina of the eye is not flat. The projection plane of the perspective has cylindrical shape with a vertical axis (a panoramic view based on the same principle that used in panoramic cameras when filming some scenery). This variant shows more of the borders, but distorts the similarity and scale of horizontal elements. We should point out that, so as to paint a visually correct image of a floor and ceiling an artist needs to show them in two contradicting ways, which cannot be used in one picture 02.

→ The variant (F) which combines the last two variants. But it still distorts similarity.

All these variants help to avoid one type of **mistakes** but at the same time lead to making other ones. All **mistakes** can be divided into three general types [15]:

→ **The mistake of showing depth** [16], as a rule, is made when using a too narrow or too wide angle of vision and the image looks either too flat or too deep.

→ **The mistake of wrong scaling** [17] is usually made due to the difference of scales between foreground, midground and background. It occurs when a too narrow or too wide angle of vision is used. We must point out here that human vision tends to enlarge objects that are further and to diminish those that are nearer to the observer [18].

→ **The mistake of showing similarity** [19] occurs because of distortion of perspective at the borders of an image at angles wider than 30 degrees. The origin of this **mistake** is the phenomenon of constancy of shape due to which a human brain corrects all distortions of the image of an object trying to make it ideal [20].

■ 15
Rauschenbach 2002, pp. 36–44.

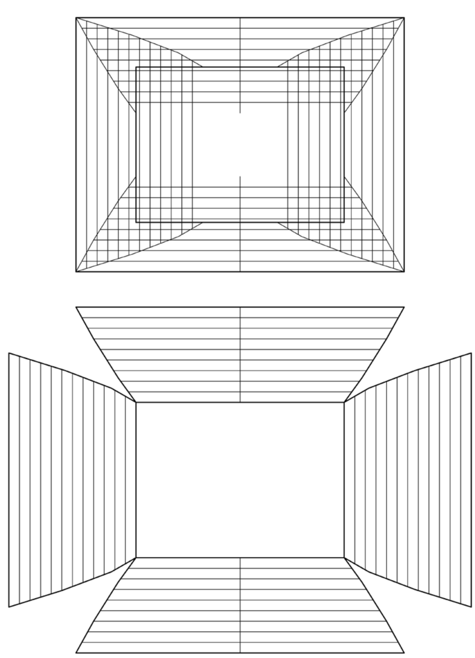
■ 16
Rauschenbach 2002, p. 49.

■ 17
Rauschenbach 2002, p. 50.

■ 18
Rauschenbach 2002, p. 17.

■ 19
Rauschenbach 2002, p. 52.

■ 20
Rauschenbach 2002, pp. 22–31. This is vividly demonstrated by the example with the stool (Rauschenbach 2002, p. 22).



☐ 02
Scheme of undistorted depiction of floor, ceiling and walls in interior (Rauschenbach 1986, fig. 8)

H.3 Methods and Rules for Views from real Viewpoints

It is true that if we look at the same architectural monument showed at different angles 03 we will see that at an angle of 100 degrees the image appears too deep, the difference between the scales of its foreground, midground and background is not natural, the elements at the borders (the capitals of columns) are painted with mistakes of showing similarity. At an angle of 60 degrees we see less mistakes and the image looks more natural, but there are still some distortions at the borders of the frame which demonstrate the mistake of wrong scaling. The image shown at an angle of 30 degrees is, probably, the most natural in this very case, and at the angle of 15 degrees we can see the mistake of showing depth — the image is not deep enough — and it again leads to wrong scaling: the foreground and the background are hardly different from the midground. Having made constructions like this B, Rauschenbach arrived to the conclusion that the most natural angles of vision range between 40 and 20 degrees.

The most important conclusion we can make is the following. As it is impossible to get an ideal image (from the point of view of human perception) we need to choose the variant with the minimum mistakes that distort the most important and typical features and elements of an object. If we speak about painting, then, for example, Paul Cézanne became one of the first artists who deliberately stretched the objects of the foreground and midground in his landscapes (as if he were looking at them from a viewpoint which was situated higher) [21]. It is quite acceptable in reconstructions as well, for instance, if we are making the reconstruction of a building with a mosaic floor. We can either use the algorithm of constructing perspective on a curved surface, to show the floor, or deliberately raise the viewpoint so that it was a little higher than human eye level [22]. If we deal with a lengthy object it seems right to use a panoramic view or zoom the viewpoint out.

■ 21
Rauschenbach 1982; Raucshenbach 1986, pp. 77–85; Rauschenbach 2002, pp. 61–73.

■ 22
It is quite possible in this situation to give an objective and unreal axonometric view from the top, which will tell the specialists more than a perspective image from a real viewpoint (Karelin et al. 2015, pp. 2–5).

100°

60°

30°

15°

☐ 03
The example of difference in perception at the different angles of view (100, 60, 30, 15). Perspective views of Via Praetoria at Dionysias fortress (D. Karelin, T. Zhitpeleva, M. Karelina)

Analyzing the methods that could allow us to consider peculiarities of human visual perception when making scientific reconstructions we need to point out an important thing. An artist can quite easily break the rules of perspective on the canvas, but when one works with a computer model it is much more difficult, as the image is built with the help of mathematical algorithms set in the program, and they are based on linear perspective. Only two main ways are possible in this case: either to use the peculiarities of linear perspective considering all the aforementioned factors, or look for the algorithms that will make it possible to distort perspective constructions according to our needs.

We can single out several basic principles which seem important:

- → Not to use visual angles that do not fit into the range of 60–20 degrees unless it is absolutely necessary. Thus one can avoid gross **mistakes** of showing scale, depth and similarity.
- → Not to use the third vanishing point except the cases when an observer is rather looking up than down, because if the third vanishing point is not very distinct a human brain always ignores it. It can be done both in 3D-programs and raster graphics editors.
- → If it is necessary one can deliberately narrow down the visual angle (zooming it out in one's mind), or slightly distort foreshortening. We can find a lot of examples like this in art [23]. If the viewpoint is situated inside the interior (when painting the interior), according to the rules of perspective, the distortion becomes too noticeable and the depth is shown incorrectly. We have already given the example which demonstrated that this method can be used in making reconstructions [24]. This example 04 shows that if the angle is too wide, it isn't good for the perception of the object either, and we think that it is possible to correct and narrow down the angle by ignoring some objects of the scene. For example this is the real and geometrically correct view from this viewpoint 04 (a, b), and because of a wider angle there are very significant distortions at the borders of the frame. Also the spectator could perceive the proportions incorrectly. If we move the viewpoint back and ignore the wall we will create a geometrically incorrect view 04 (c, d), though it is more comfortable for the viewer. It is important that our eyes percept the picture not by the rules of geometrical perspective, but differently. Usually we turn our head and then our brain corrects all these distortions. Thus the second frame must be closer to the picture which our brain creates. It is important that in the case of using the actual viewpoint (an observer standing at the doorframe), we can not only show similarity in the wrong way (the capitals in the corners of the picture), but we will also distort the visual depth of the space and correspondence between scales — the gate in the background seems too small and lose its architectural meaning, and the image looks very unnatural.

■ **23**
Rauschenbach 2002, p. 56.

■ **24**
Karelin et al., p. 6, fig.6.

→ It is necessary to consider J. J. Gibson's recommendation on depicting the context, that is, the surface of the ground. It should not be too in contrast with the image and distract the attention, but it must be painted accurately enough to serve an appropriate background for the image. One should also keep in mind that the texture of the ground and the textures and character of other objects in the picture are able and should give some idea about the scale [25]. Using wrong textures and objects will distort the scale.

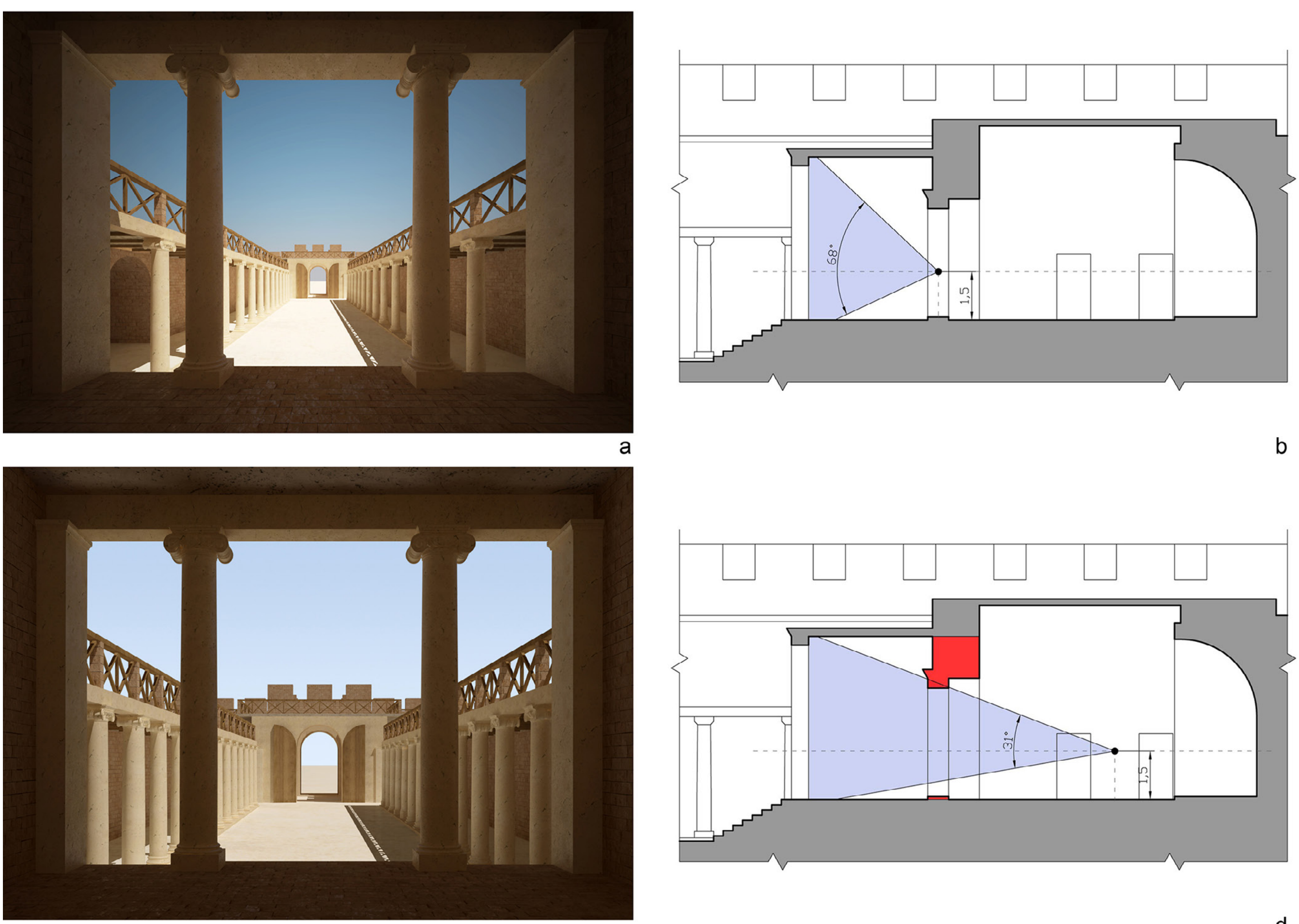
→ One should not make composition mistakes, for instance, those connected with optical contact [26], when objects that do not contact physically touch each other's contours. This can make a wrong impression that they are actually adjoining objects.

→ If necessary, it is quite possible to use the algorithms of construction perspective where the image is built not on a flat surface, but on a cylindrical, spherical and other projections.

■ 25
Sedgwick 2001, p. 133.

■ 26
Sedgwick 2001, p. 137.

☐ 04
The possibility of narrowing down the angle of view along with ignoring of some elements of the building in order to create a more comfortable view for human vision. Views of Via Praetoria at Dionysias fortress from the chapel (D. Karelin, T. Zhitpeleva, M. Karelina)



a b c d

The last point needs to be analyzed in particular. In the case of 3D reconstructions created by the method of computer camera modeling modern 3D editors cameras, as a rule, have all technical characteristics of real photo cameras. They can regulate the angle of vision, focal length, exposure time and film speed, which allows to create a physically correct image. They are also able to construct a geometrical perspective not only on a projection plane but on a surface, for example, a surface of revolution [27]. Besides, we have a number of possibilities of constructing not a physically realistic perspective, but the one having artistically justified distortions.

As we have already mentioned, if it is impossible to provide necessary borders of vision at an adequate angle of vision from the given position of an observer 03. The simplest method of correcting it would be moving the camera back till we reach the position where an adequate angle of vision can be achieved, and applying the so called **clipping plane** which is possible, for example, in V-Ray [28] — that is, some plane which can be adjusted to a particular camera. The objects situated nearer than it is would be ignored by the camera at calculating.

The correction of the third vanishing point appears very relevant in visualizing architecture, and this is the reason why there exist both automatic and non-automatic tools (e. g. **camera correction modifier** and **camera vertical shift** in V-Ray).

Among physical cameras in V-Ray [29] there is also a number of cameras which project the image not on a plane but on a surface of revolution.
Usually this type of cameras is used for creating panoramic views, but they can be also used for creating different variants of perspectives 05. This is the so called **spherical camera** 05 (b, e) which projects rays of light coming from its centre on a spherical surface. It can serve as the example of variant F 01. Cylindrical (point) camera 05 (c, f) builds an image by projecting it on a cylindrical surface with a vertical axis in the viewpoint, which allows one to create the perspective of variant E 01. Apart from that, V-Ray makes it possible to construct fish-eye perspective with a visual angle of 180 degrees. However we must note that this type of perspective is not natural at all and should be used only when a visual angle of 180 degrees is absolutely necessary.

■ 27
In theory, it is possible and interesting to use different surfaces such as an ellipsoid or others (Polack 1997, pp. 132–134).

■ 28
We show some methods and peculiarities of perspective correction (the so called »clipping plane« or using of different surfaces of projection) on the example of V-Ray 1.5 for 3DMAX 2010, however the same possibilities could be given by the other programs, which we didn't use. All the renders in the article (fig. 3–5) were made on V-Ray 1.5 for 3DMAX 2010 for Windows.

■ 29
VRay for 3ds Max Manual. Camera Examples. https://www.vray.com/vray_for_3ds_max/manual/vray_for_3ds_max_camera_examples.shtml.

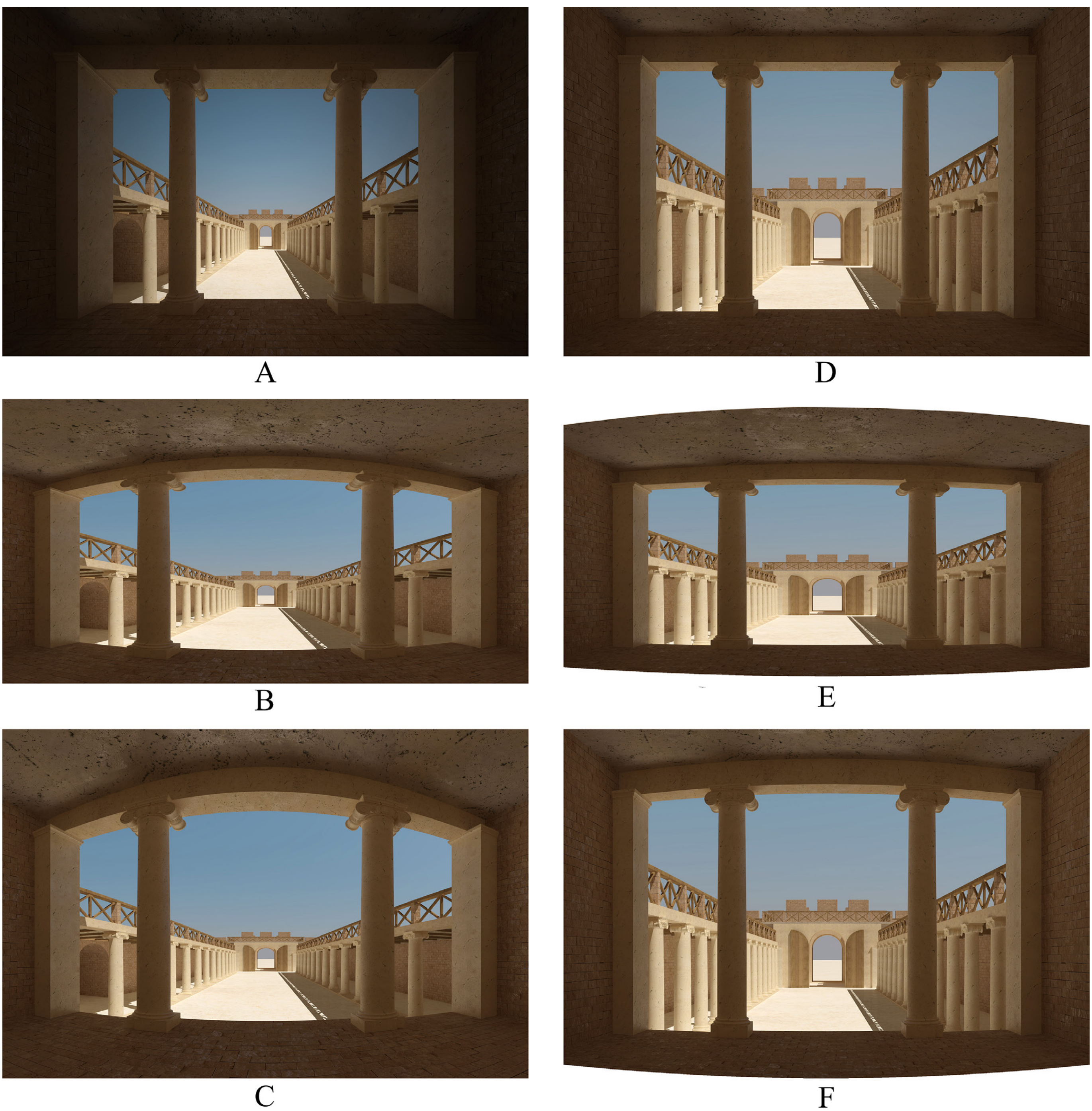
Visual perception of the perspective systems we have described is demonstrated in the pictures below 05, and we can make the following conclusions:

- → The observations we have made about zooming out the viewpoint when dealing with a too wide visual angle seem quite relevant.
- → A spherical camera distorts (diminishes) vertical size, as it was pointed out by Boris Rauschenbach (see 01) and the image looks the least natural.
- → The images taken by cylindrical (point) camera look more natural, and notwithstanding the mistakes of similarity, when the lines which are straight in reality appear not straight on illustrations, seem as natural as planar perspective. Jennifer Polack's conclusion 30 that such perspective is more natural than the other two are quite well grounded, though this statement will be always subject to doubt in relation to planar perspective due to the aforementioned mistake of similarity of the straight lines.

■ 30
Polack 1997, pp. 132–135.

In our opinion, the examples we give allow us to recommend cameras with cylindrical surface of projection for the visualization of reconstructions of architectural monuments, in cases when it is necessary to show the borders of the interior and when geometrical distortions are irrelevant for perception.

☐ 05
Types of perspective with using of planar (a, d), spherical (b, e) and cylindrical (c, f) »plane« (surface) of projection from the real point of view (a, b, c, see fig 4b) and the moved back point of view (d, e, f, see fig. 4d). Views of Via Praetoria at Dionysias fortress from the chapel (D. Karelin, T. Zhitpeleva, M. Karelina)



All the aforesaid shows that when creating images with perspective from real points of view one must very carefully choose a viewpoint and a visual angle, and also take into account a number of factors like avoiding the third vanishing point, perspective distortions, the mistakes of correlation between the scales of foreground, midground and background and even choosing the system of constructing perspective in general. Rauschenbach told about it a lot:

»It is possible that the illustrations will attract the attention of architects who prefer to construct images strictly keeping to the rules. Now they will have the opportunity to choose the variant of the system of perspective that will help them to emphasize the features they consider the most important.« [31]

■ 31
Rauschenbach 2002, p. 60.

H.4 Conclusion

The facts we have examined let us to make some conclusions. In the previous article [32] we made an assumption that when creating and presenting reconstructions it is necessary to follow the criteria applied to art, and it seems reasonable and well grounded as in this work we confirmed it from the point of view considering peculiarities of human visual perception and the perception of things we see by our brain.

■ 32
Karelin et al. 2015, p. 10.

However, at the moment the authors could only formulate several general recommendations relating optimal visual angles, a number of details and the possibility of shifting a viewpoint if necessary. It is quite improbable to give exact recommendations that would work in every case and contain exact figures. It seems that the best possible way is to take into consideration all peculiarities of an object and attract to making reconstructions not only specialists in 3D modeling, but also professionals who specialize in graphic presentation and space design, architects and designers [33]. Boris Rauschenbach gave a very good definition of this problem:

■ 33
It is worth mentioning that this problem is more widely and commonly expressed than the absence of any idea of how human vision percepts space. For example, technical specialists often do not pay any attention at how different textures look in the places of joining or changing the shape of a model, while an architect would immediately notice that masonry or brickwork cannot exist in this way physically.

»Aesthetics intruded into, as it seemed, strictly mathematical field where nobody expected it. It determines the choice of an appropriate variant of constructing perspective. It is aesthetics that help to find that very option which is the best for solving the artistic problem among other numberless ones that are offered by mathematics. No wonder that artists looking for the most perfect way of conveying the idea of spatiality can prefer different variants«. [34]

■ 34
Rauschenbach 2002, p. 54.

We can only add that those aesthetical criteria are primarily based on scientific researches that explain how a human brain works, so they are at the very least justified. But considering that studying a human brain is one of the most mysterious fields in science we understand there cannot be any definite and explicit formulae here.

Moreover, it is known that in his studies Rauschenbach relied on **experimental data by psychologists for some ›average‹ person** [35]. But every person is unique and the specialists for whom, first of all, these scientific 3D reconstructions are created — architects, historians and archaeologists — usually have some professional deformations when it comes to perception of space.

■ **35**
Rauschenbach 2002, p. 9.

All the aforesaid points out that the problem of considering human perception of space at presenting scientific reconstructions is very complicated and not thoroughly studied. It demands further research with the help of cognitive science and the theory of composition in visual arts.

H.5 Acknowledgement

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