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Paper: **Designer's controlled and randomly generated moiré patterns in architecture.**

Topic: Architecture

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Abstract:

The paper presents graphical and formal possibilities of moiré patterns in architecture in different contexts. The paper distinguishes between randomly generated and designer's controlled (influenced) moiré patterns. Some mathematical methods can predict, under certain limitations, the geometric properties of moiré. Those 2D Fourier transformation-based methods would not be considered in the paper, but the basic notions, could be taken from strict mathematical theory of the moiré phenomenon. A short, straightforward, vector-based explanation is given at this point.

In the first group of patterns paper presents carefully selected cases of moiré generated by various periodic and not periodic gratings, grids and dot patterns using the examples from recently completed buildings. Stiff, rigid superposed layers like screen-printed glass, or perforated metal sheets do produce predictable results in a greater extent, while the soft, distortable layers, like fabrics, canvases, loose meshes generate the shapes that are almost impossible to estimate. A link between the images of component superposed layers, their frequency, and superposition angle with the resulting moiré pattern is researched here.

In the second group of patterns paper shows the cases where the designer, by the proper arrangement of component image layers, can consciously influence the result of generated moiré pattern. Two basic techniques are described at this point: moiré fringe multiplication, and moiré magnification. The former allows to control the moiré frequency, by regulating the frequency of component layers (e.g. obtained moiré pattern is doubled with the doubling of the reference gratings, dot-screens etc.). The latter describes a special case of the (1,0,-1,0) moiré type, that shows striking phenomenon of blur and magnification of dots of any given shape lying on layer A, by superposition of layer B with tiny pinholes of identical period at a small angle of difference. The moiré image is showed by sampling any-shape dots of layer A, through a holes in layer B. The results could be obtained by superposing white and black dot-screens as well, but the moiré pattern generated depend on the color and could be produced in inverse video.
In addition, this chapter describes a method of obtaining visually appealing moving images (up to 7 frames) by the usage of properly designed component layers A and B. This could be used to obtain the illusion of movement on the facades that do not contain any real movable parts, but are observed in motion (e.g. from passing car, train etc.). The ease of application allows this phenomenon to be used both in public and commercial buildings. A selection of author's designed exemplary façade's patterns is presented in the paper.

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Keywords:
moiré pattern, architectural design, perforation perception, façade

Designer-controlled and randomly generated moiré patterns in architecture

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Premise

This paper presents graphical and formal possibilities for the use of moiré patterns in various architectural contexts. The paper distinguishes between randomly generated and designer-controlled (influenced) moiré patterns. Under certain limitations, some mathematical methods can predict the geometric properties of moiré patterns. However, in consideration of the recipients of this paper, a straightforward, vector-based explanation will be provided.

In the first group of patterns, the paper presents carefully selected cases of moiré randomly generated by various periodic and aperiodic gratings, grids and dot patterns using examples from contemporary architecture.

In the second group of patterns, the paper discusses instances of designers' conscious influence on a generated moiré pattern by properly arranging component image layers. A link between the images of component superposed layers, their frequency, and the superposition angle with the resulting moiré pattern is researched here. In addition to describing the conditions of excellent moiré visibility, the complex cases of moiré fringe multiplication and moiré magnification are also presented.

The paper then presents a method of obtaining moving images that are visually appealing (up to 7 frames) through the use of properly designed component layers followed by a selection of author-designed exemplary façade patterns. It concludes with a discussion of the influence of the physiology of the human eye on the perception of moiré patterns.

1 Introduction

Although one cannot determine the beginning of the conscious recognition of moiré, a detailed examination was carried out by Lord Rayleigh in 1874. The name of the effect can be traced back to the 1800s, when French craftsman weavers produced thin silk fabric by passing the cloth “through rollers that have a rippling pattern which resembles a large series of water stains” [13]. Superimposed layers of watered cloth called moiré produced an additional rippling illusory pattern absent in the component textiles. The name of this very popular fabric became the name of the phenomenon.

From a strictly scientific point of view, moiré patterns are produced when “repetitive structures (dot screens, gratings or grids) are superposed or viewed against each other.” [2]. Moiré patterns show great sensitivity to the slightest change, such as distortion or angle rotation. This means that even a very little modification of the position or rhythm of component repetitive structures produces striking changes in the resulting pattern. This is why this phenomenon is widely exploited in many fields, such as optometry, metrology and counterfeiting protection (securing documents). Once processed by the appropriate software, moiré fringes can provide accurate spatial data relating to any subject (e.g., historical objects, artifacts, physical evidence in court cases).

Aside from the above examples, moiré patterns are considered to be an undesired byproduct of two or more superposed repetitive structures. Destructive results of this phenomenon might be found in a color picture reproduction (where dot screens are superposed under specified angles) or in various applications of perforated or meshed surfaces (where unintentional moiré patterns can easily destroy the desired formal results). Over time, certain mathematical approaches have been applied to the understanding and avoidance of the appearance of moiré patterns. The most recent is an application of Fourier theory that began in 1960s and 1970s.

2 Scope of this paper

This paper presents the formal possibilities of the use of moiré patterns in different architectural contexts. The paper distinguishes between randomly generated and designer-controlled (influenced) moiré patterns. The attitude presented in this paper is strictly visual (as the aspects of an image are most appealing to architects), thus some mathematical rules expressed graphically must be explained to understand how the patterns are created.

3 Moiré patterns in architecture – conditions of formation

The concept of moiré fringes is associated with the phenomenon of overlaid repetitive structures. In its literal, mathematical sense, moiré means an arrangement of fringes formed by two overlapping periodic or aperiodic structures rotated at an angle or subjected to deformation. This phenomenon can be associated with optical interference – local strengthening and weakening of the electromagnetic wave – though its mechanism is different. That is why moiré and interference phenomena are often confused.

Moiré fringes in architecture can result from various circumstances: superposing repetitive structures with different frequencies (rhythms), imposing grids (shutters, grilles, perforated steel sheets) or arranging repetitive structures layers (e.g., in curtains and drapes). In specific cases, moiré can only be observed when the structures involved are positioned along the observer’s line of sight (e.g., corners of buildings where there is an imposition of grids located perpendicularly; see Fig. 3). Moiré patterns can emerge even when the repetitive structure is laid over its virtual image or the shadow it casts (shutters over a glazed façade, or over a smooth wall). See a detailed description in chapter 6.

The special case of a transparent surface with periodic overprint (such as silkscreen) could also be considered a repetitive structure with all the resulting consequences, including the potential for creating moiré by way of superposition. Depending on the specific case, a repetitive structure can be a flat or three-dimensional physical object (such as bridging grille bars, railings or the warp and weft of fabric).

4 Randomly generated moiré – case studies

The occurrence of moiré patterns can be predicted; however, their appearance on a building is often random, undermining the visual effect intended by an architect. The prediction of moiré formation is difficult at the design stage. Resulting optical effects are therefore equally surprising for architects and investors. Thus, it is important that designers know the mechanism of formation of moiré patterns to use this knowledge consciously.

Randomly generated moiré patterns occur commonly in architecture, but only in selected cases do they enrich the aesthetics of the architecture. These exquisite examples require a detailed discussion.

Fig. 1. Rue des Suisses Housing, Paris (arch. Herzog de Meuron, 1996-2000). Photo by author.

Subtle moiré patterns are visible on the façade of a 7-story residential building located at the Rue des Suisses in Paris [Fig. 1]. The outside envelope of the building is designed as a system of screens-shutters covering the full height of the building. The individual elements are 412 mm in width and one story in height. The folding screens are made of aluminium sheets perforated with square holes. Screens in a folded position are placed perpendicular to the plane of the façade, thus creating clearly defined, though irregular vertical divisions. Unfolded screens "(...) create the impression of several compressed layers of materials: shutter, balustrade, the space of the balcony and the dark aluminium glass wall of the dwellings (…)", thus creating a delicate but visible moiré [12]. Looking closely, we see the detail – continuous perforated pleated sheets that "ripple like corduroy; fully unfolded" [6].

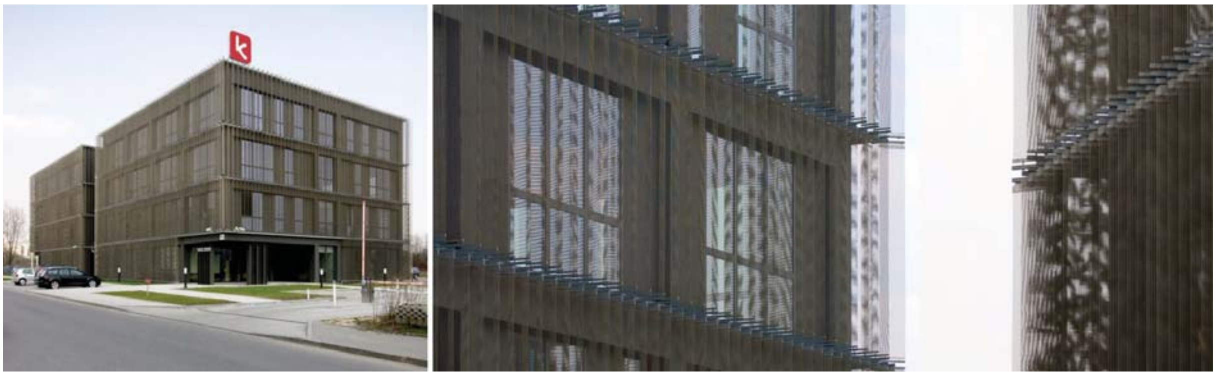

Fig. 2. Headquarters of the Technology Incubator in Krakow (arch. ns moon Studio, 2007). Photo by author.

Clear moiré fringes that appear on the Headquarters building of the Technology Incubator in Krakow were not planned by the architects as part of original design. Instead, they were the result of budgetary constraints. Strips of stainless steel mesh were mounted perpendicular to the façade by the means of two supports cantilevered from the façade. Moiré patterns are formed where multiple layers of the mesh are superposed on each other [Fig. 2]. A zone of dynamically changing transparency and flickering moiré is created around the building. Due to the different configuration of the meshes, moiré patterns change with every step the observer takes. The fringes on the building appear to move, though they are known to be immobile [11]. The results are spectacular when the layers of mesh are seen through the windows against the sky or when a strong wind tugs and deforms the meshes. The envelope of the Technology Incubator in Krakow is undoubtedly one of the most creative façades built in Poland after 2000.

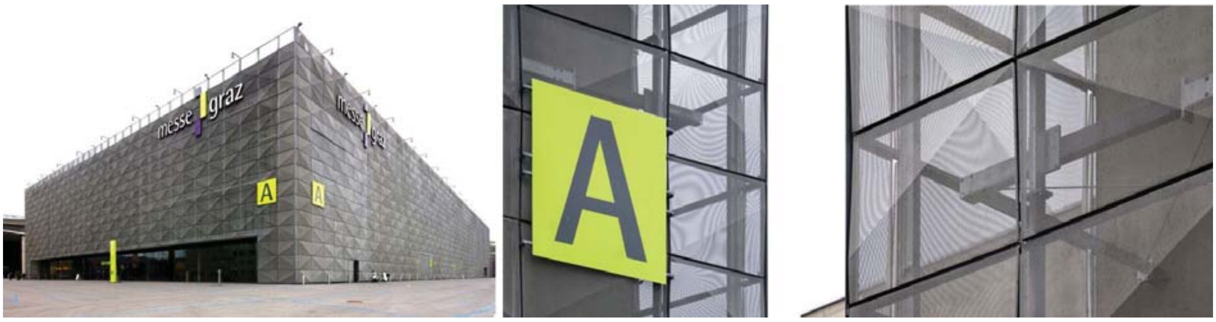

Fig. 3. Messe Graz Halle A (arch. Florian Riegler, Roger Riewe, 2002). Photo by author.

To reduce the large volume of the newly erected, two-story exhibition Halle A of Messe Graz [Fig. 3] and to emphasize its spatial independence, a nearly 300-m concrete wall of the building was covered by the envelope of delicate mesh panels. This technical decision resulted in a unique “(…) gleaming, silver shell, which is very different in its monochrome homogeneity (…)” [4]. The unintended moiré is most visible from the corner of the building where the meshes from the perpendicular facades interact. The rectangular panels of shell are manufactured from diagonally pre-pressed steel mesh. Because panels are not planar but diagonally divided into two independent planes, the resulting moiré is even more diverse and flickering [10].

5 Designer-controlled (influenced) moiré patterns

In contrast to the previous examples of random generation, fringes of moiré can also be “planned” to some extent. The designer can consciously influence the result of the generated moiré pattern by properly arranging component image layers. These layers might include grating, square grids or dots, or they might be composed of different periodic structures (like grating and circular patterns that produce square-like moiré patterns).

In the case of an individually designed moiré, the preparatory phase usually requires an extended design-check stage including the construction of reduced-scale models to verify if the desired moiré pattern appears or not. An excellent example of a properly conducted design phase is the Center of Creative Arts Elementary School for Girls in Brisbane, a building that attracted worldwide attention for a façade that generates unique moiré fringes [5].

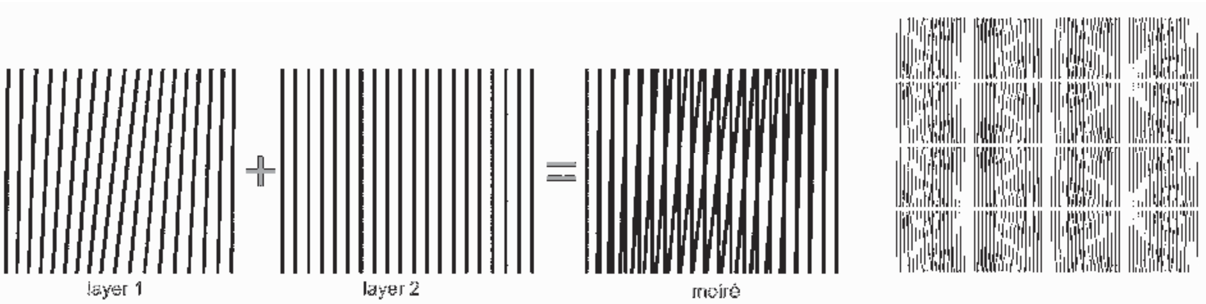

Fig. 4. The principle of moiré generation at the Center of Creative Arts Elementary School for Girls in Brisbane (arch. m3architecture, 2007). Illustration by author.

The school’s western double façade is windowless, with only black vertical stripes painted on a white wall. The solid wall provides a background for the shading screen made of black-coated aluminum slats. The elements lean from left to right at a slightly changing angle, so that the slats overlap with stripes and form a unique moiré [Fig. 4]. With a change of the observer’s position "(...) the building appears to melt and wobble in circular waves as the viewer passes (...)" [7]. A pre-planned motion effect proved to be illusive in that dwellers of neighboring buildings asked the architects and contractors how the elevation is motorized and whether it will make noise.

A prototype of Brisbane’s moiré façade several meters wide was shown at the exhibition titled “Place Makers: Contemporary Queensland Architects” organized by the Queensland Gallery of Modern Art. This large 1:11 scale model was manufactured using two layers of glass with stripes of black adhesive tape. It proved to be a perfect presentation of the project idea as the model involved the viewer in the process of moiré reception.

Due to the expense of model construction, computer simulation can be helpful tool. However, it should be taken into consideration that the effects caused by the screen’s structure itself can cause moiré patterns appear. The moiré patterns on computer screens are caused by the mask (electrical conductors) on the front surface of the LCD interacting with the digitizing of the image. Additional causes of moiré might be a periodic structure of the CCD matrix of the camera or scanner. Therefore, the theoretical prediction of moiré should be followed by practical verification to guarantee proper results.

There are three main parameters that characterize any moiré: **frequency, angle** and **intensity** (also called amplitude) [1]. For the sake of ease, a simple binary (black and white only) grating is used in the following examples.

5.1 Regulating frequency - moiré fringe multiplication

The frequency of moiré is often replaced by pitch (or step). Pitch represents a reciprocal of the frequency and describes the distance between adjacent fringes of the moiré, while the frequency describes how many lines or dots appear per specified unit of length [9]. The parameters given above can either describe the resulting moiré or the features of the component layers.

Moiré fringe multiplication is a technique initially developed for a more detailed analysis of surface deformation This technique originates directly from the principle that changing the frequency of component layers can influence moiré frequency as well (e.g., the resulting moiré pattern might double with the doubling of the component periodic structures).

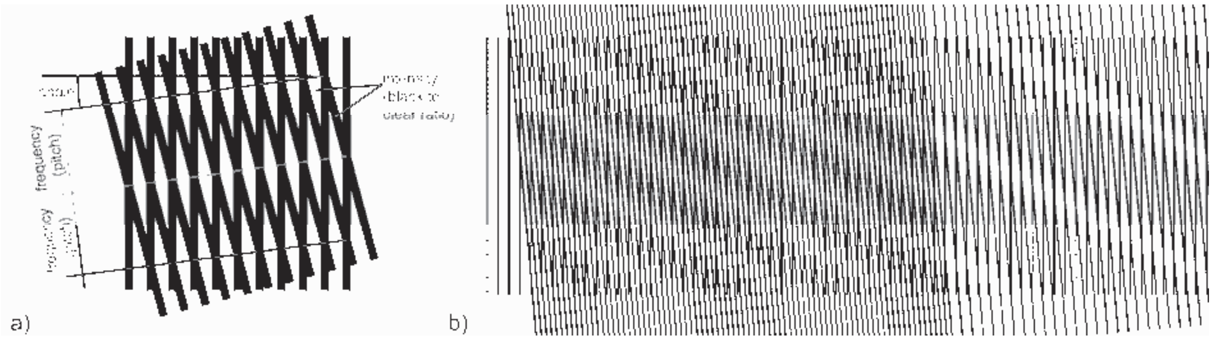

Fig. 5. Example of basic moiré parameters (a) and moiré fringe multiplication (b). Illustration by author.

Moiré fringe multiplication is the simplest and safest way for the designer to influence a moiré pattern. This is not only the simplest method, but is also the most predictable method because the effect of frequency change would be visible from every point of view and every perspective regardless of the shape of the pattern, provided that the component layers superpose.

5.2 Regulating the angle of moiré

Rotating component gratings is another way to create moiré. The resulting angle of the moiré always depends on the angle α between component gratings. If we consider a grid of intersecting lines, a rhomboidal cell net could result from superposition. Space (white fringe, or bright fringe, clear spaces) in the moiré pattern corresponds to the small diagonals of this rhombus; "black" fringe is formed by intersecting lines at the ends of its larger diagonal. As the diagonals are the bisectors of the sides of the rhombus (a, b, c, d), a fringe appears at an angle equal to $\alpha/2$ perpendicular to the gratings of each pattern. "The sharper the angle α, the stronger the moiré pattern becomes" [8].

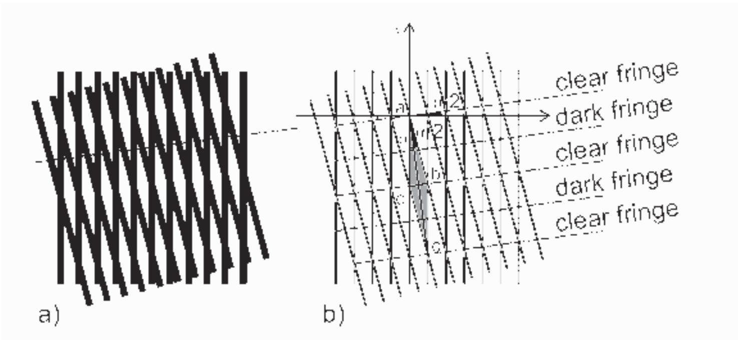

Fig. 6. Rotated binary grating showing the principle of moiré generation. Illustration by author.

A special feature of grating-originated moiré must be mentioned here to complete the picture. It was observed that at certain specific angles, moiré does not occur. This happens when two gratings are positioned perpendicularly to each other to create a square cell net, or when three gratings are rotated by an angle of 120 deg. to create an equilateral triangular cell net. This condition is called a moiré-free state [2]. In selected cases, a moiré-free state proved to be very unstable because "slight deviation of the angle or in the frequency of any of the superposed layers may cause new impulses" [2], causing moiré to reappear. The theory explaining this phenomenon is derived from Fourier's moiré analysis, and its full explanation lies beyond the scope of this paper [2].

Rotating the grating can be an effective method to influence the form of moiré patterns because only a slight rotation is necessary to cause a substantial change in the resulting moiré pattern. This method could also be creatively applied to achieve certain formal results when one or two of the component gratings are curvilinear.

5.3 Regulating moiré's intensity

Intensity is a parameter strongly associated with the ratio of clear spaces to black bars in the component gratings. Intensity is also called amplitude (according to signal theory, the "amplitude" of impulse represents the intensity of that periodic component layer). It should be noted that even when all the component layers are black-white only (binary, with the intensity 0 and 1) …" their moiré still may contain intermediate values" [2]. The local intensity of moiré patterns created by the binary gratings depends on the clear to black balance at given point of the image, the value of intensity "represents the average ratio of white (clear space) per unit area" [2]. In terms of optical phenomena, the intensity of moiré can easily be translated to the reflection coefficient (average reflectance) (e.g., an equal area of white and black in a sample boundary would mean 50% reflectance).

Fig. 7. Local reflectance of moiré is determined by the amount of white (clear space) per unit area. Illustration by author.

If the grating bars and spaces have equal width, bars fully overlap at the point of intersection (two identical stripes are exactly on top of each other). At this point, a bright moiré fringe appears. Where the two bars are side by side, a dark bar fills the white space completely. At this point, a black moiré fringe appears. Between bright and dark fringes, all intermediate stages of the moiré's intensity (or reflectance) are present. The intensity of moiré varies between 0.5, where the bars overlap, and 1.0, where they are located next to each other.

Component layers with various intensities (different black bar to white space ratios) can create moirés of different intensities, but the following general principle can always be applied: the greater the intensity of the component layers, the greater the intensity of the moiré.

5.4 Conditions for excellent moiré visibility

Based on the previously explained general principles and laws of moiré formation, certain conditions may be identified that must be met by the component layers to obtain the best moiré visibility.

The conditions for excellent moiré visibility, based on [9], are as follows:
- the width of the black bars and spaces in component gratings are equal,
- the angle of intersection of the two gratings is small (e.g., 3° or less),
- the ratio of the pitches (frequency) of the two gratings is small (e.g., 1.05:l or less).

5.5 Complex cases of moiré

Complex cases of moiré require strict mathematical analysis and careful preparation of the component layers; in return, unique fringe patterns can be attained. To achieve certain patterns, preparation of complex various curvilinear gratings might be required, such as parabolic- or arg sinh (x)-shaped cosinusoidal grating. Although the superposition of such gratings might create visually appealing shapes, the range of possible designs is limited.

There are few cases of complex moiré in which the results of component layer supposition can be "programmed" with much greater precision by making the desired shapes appear by layer superposition.

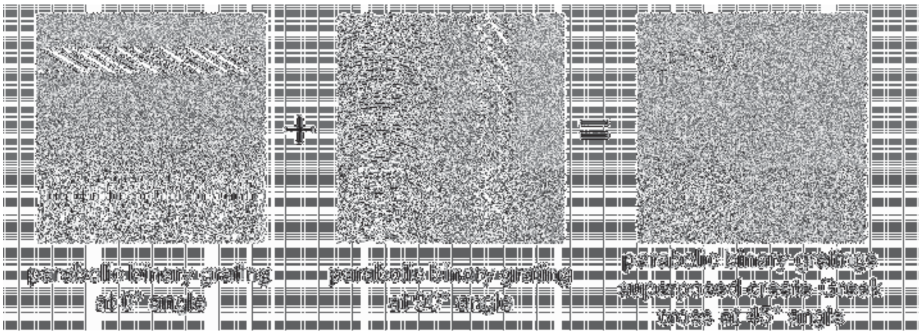

Fig. 8. Superposition of two perpendicular parabolic gratings creates visible moiré in a form of a hyperbolic, cosinusoidal grating that recalls a Greek cross. Illustration by author.

5.5.1 Moiré magnification

A special case of moiré type (1,0,-1,0) shows the striking phenomenon of image blur and magnification. Let us assume that component layer A (located below) consists of regular array dots of any given shape. If this layer is superposed with opaque component layer B that has tiny pinholes of identical frequency as the dots on layer A, the moiré pattern will arise by sampling the any-shaped dots of layer A through the holes in layer B. When layers are superposed with an angle of zero as the starting position and this angle is gradually increased, a magnified and blurred dynamic image of the sample dot is made visible. The ratio of this magnification depends on the angle of superposition. However, a general rule could be formulated that the larger the angle is, the smaller the magnification factor.

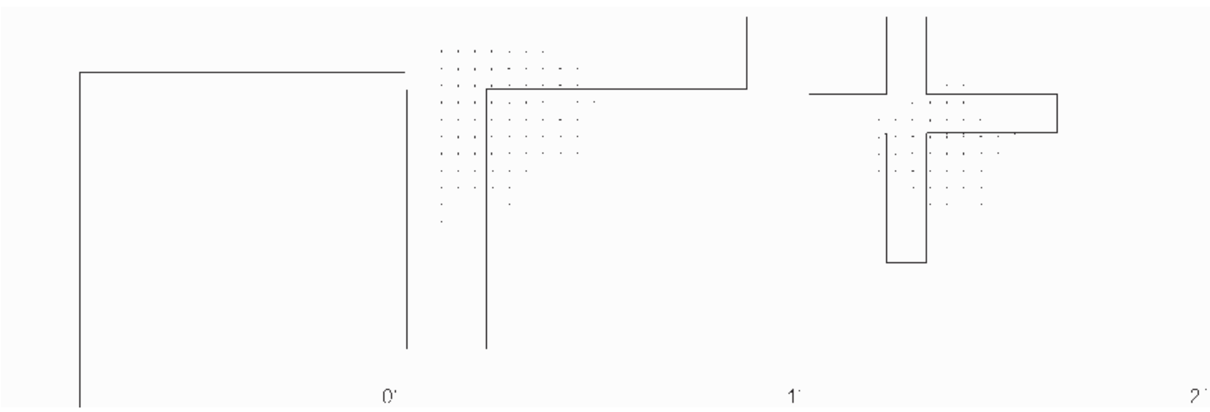

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Fig. 9. Image blur and magnification showed by a special case of moiré type (1,0,-1,0). The sample dot is the shape “+”. Illustration by author.

The unique property of this type of moiré was discovered and described relatively recently with the introduction of computer techniques. Exploring the possible application of this moiré effect, Armidor writes that this “moiré effect can be used in certain applications as a “virtual microscope” for visualizing the detailed structure of a given screen” [2]. There is great potential in the careful application of this technique in architecture. The shape of the so-called sample dots can be custom-specified, which makes this technique a powerful tool of branding or marketing. Using properly designed component layers in a form of optical filter allows the user to display dynamically changing images without actually using any moving parts.

5.5.2 The illusion of motion. Stop-motion by proper arrangement of moiré layers

Stop-motion is a well-known animation technique in which the manipulated object is repositioned or rearranged in small increments and then photographed. Individually photographed frames are played sequentially, creating the illusion of movement. This classic animation technique could be re-interpreted and re-applied using moiré principles.

To achieve the effect of virtual motion, the top component layer should consist of vertical binary grating with the appropriate ratio of dark bars to clear spaces. The ratio is based on the number of frames (e.g., if planned animation is 7 frames, the width’s ratio of dark bars to clear spaces should be roughly 6 to1. The bottom component layer is designed to show successive frames of animation through the gap between the dark bars of the top layer (see Fig. 11). The bottom layer picture is usually obtained by properly cropping successive frames. The process of preparation requires a high degree of precision for which CAD software is an asset.

The illusion of movement is obtainable by passing the top layer over the bottom layer, but similar effects may be accomplished without the use of any moving parts or mechanisms at all. This involves the creative exploitation of the motion's relativity principle. If the two component layers are static, parallel, and positioned at a proper distance, the moving observer would perceive the relevant parts of the further layer through gaps located in the closer layer.

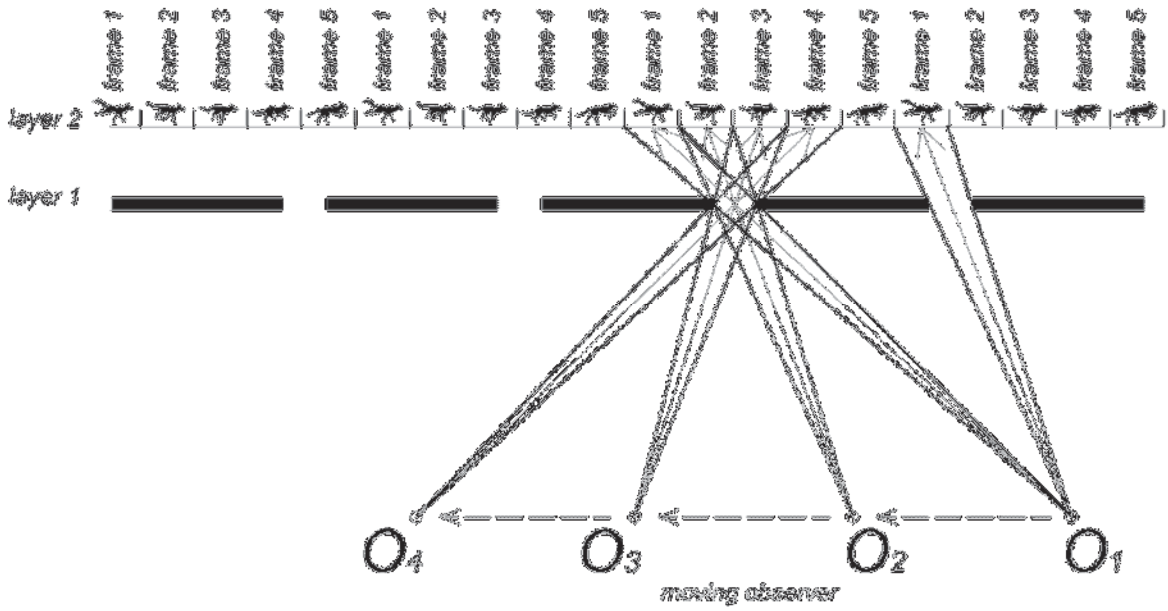

Fig. 10. The principle of the construction of the illusion of motion achieved by proper arrangement of superposed layers. Illustration by author.

The proper speed causes the successive frames to appear so quickly that the illusion of motion occurs. In a design, the reverse logic could also be used by adjusting the parameters of layers to the speed of a moving observer (e.g., traveling in a train or in the car on the highway).

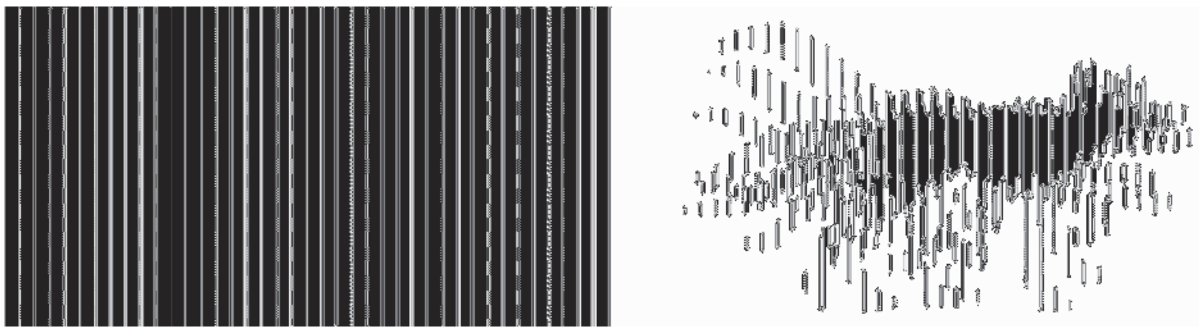

Fig. 11. The samples of component layers: the upper containing binary grating (left) and the lower containing the compiled image of a running wolf (right). Illustration by author.

6 The influence of human eye perception

It is relatively easy to predict the results of component layer superposition in orthogonal projection (as analyzed above). In architecture, however, the issues of moiré must be approached from the position of human perception.

The most distinct feature that differentiates perspective from orthogonal projection is that the objects get smaller as their distance from the observer increases. In this way, two identical periodic structures with the same frequency, which would not create any moiré from an orthogonal point of view, can create visible moiré by perspective projection. A component layer with a periodic structure positioned further away from the observer will be virtually “rescaled”, and its frequency will be changed. The moiré would appear as a result of the interaction with the component layer positioned closer. All efforts made by designers to exhibit moiré should be preceded by an analysis that considers the properties of perspective projection. In practice, the phenomenon may occur in any case of the superposition of multi-layer mesh or perforated panels but also in the case of periodic structures and their shadows or mirrored reflections. The formation of moiré can come as a surprise to a designer, especially in the case of the last two examples listed, and it may have a significantly negative effect on the project. However, it can also be creatively exploited.

The resolution of human sight must also be considered when dealing with moirés on an architectural scale. Curcio et al. [3] derived 77 cycles per deg. (the cycle is a pair: grating and space). This means that in a one deg. segment of a visual field, an observer is able to distinguish approximately 30-70 lines depending on the individual abilities and lighting conditions. Because the resolution is constant, the number of perceived details varies in relation to the distance from the observed object. The farther away the object, the more blurred the details are, and the fine meshes and gratings seem to be more uniform. The periodic structure is indistinguishable and the mesh appears to be semitransparent.

In some particular cases, the observer is located far enough from the superposed objects that the recognition of periodic structures is not possible, but simultaneously close enough that the moiré resulting from their interaction becomes visible. In these situations, moiré fringes appear suddenly, on virtually uniform transparent surfaces.

Another important feature of human vision is sensitivity to light. It is not linear, but, as with human hearing, it is logarithmic. This is verified by the comparison of human reception of brightness with the actual reflectance levels present in moiré patterns and is calculated on geometrical basis (as a ratio of white to black fringe). Both the intermediate stages of the moiré’s intensity and the contrast are perceived differently than indicated by the sole reflectance values [2].

7 Conclusions

The author hopes that with the guidance presented in the paper, architects might change their attitude toward the unique phenomenon of moiré. Instead of regarding moiré as a disadvantage, they could consider the potential of its creative exploitation. The moiré phenomenon should not be thought of as a closed chapter or limited in its range of options. New fringe patterns can be generated on-demand, based on custom-designed component layers and dynamic points of view. The possibilities are endless, limited only by the imagination of the designer and acceptance of the client.

The proper use of moiré in architecture should be thought of well in advance because in select cases, the results are difficult to predict at a reduced scale. The design process requires mathematical calculations, tests, and construction of reduced-size prototypes. Sometimes on-site analysis is required to verify the achieved results. Moiré could easily destroy the designer's original intention but, if properly arranged, could enrich a building with unique artistic quality, exceptional branding, or virtual moving pictures.

8 Acknowledgments

I am pleased to acknowledge Prof. P.W. Fowler's (The University of Sheffield) contribution of conceptual support.

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