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Psychological study on the evaluation of transparent space grid roofs

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Abstract

At the IASS 2007 the concept of a sustainable and transparent roof construction was presented. These transparent space grid structures base on a double layer grid in which all bars in the upper layer, the compression layer, are replaced by glass panes. The glazing is part of the primary load bearing system and transfers significant in-plane forces. At the IASS 2008 a presentation on the effect of structure geometry on producibility, economy and aesthetics was hold. [1] In the last year this investigation was extended by a psychological study of 325 people on their evaluation of such transparent space grid strcutures. Basis for the study were 30 sec film sequences that show the walk in a courtyard of 15 m by 15 m covered with a transparent space grid structure of different geometries. Former studies [1] proofed the advantages of grids with sqauared or triangular panes in the upper layer. A total of four structure geometries was chosen and rendered in short film sequences. A semantic differential of 27 adjective-couples helped the observers to describe their impression of the roof. Personal attributes as experiences with spatial structures, personal feeling or performance at 3D-tests were put into consideration. The result of the psychological study showes the aggregaton of 27 adjective-couples into four groups (originality, attractiveness, openess and structure) and the evalutation of each structure with regard to each group. The effect of personal attributes, especially experience with spatial structures completed the study.

Keywords: Glass, Space Structure, Roof, Structure Geometry, Transparency, Psychological Aesthetics

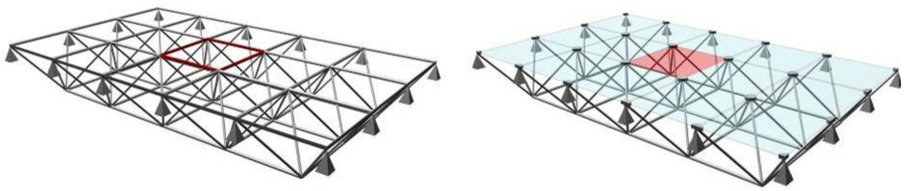
1. Introduction

Since 2006 Technische Universität Dresden has been decisively involved in the development of transparent space grid structures. These structures should combine the advantages of steel space grid structures, e.g. the column free wide spanning and sustainability, and the transparency of glass roofs. The crucial idea of transparent space grid structures is the activation of the glass layer as primary load bearing element. Using the example of a double layer grid the utilisation of the glazing as compression layer, roof stabilisation and roof covering is proven. The structure is material-efficient as the glazing fulfils a double function: it serves for the primary load transfer and as roof covering.

In the last years different structure geometries were realized as life-size mock-ups and extensive testing conducted at them. [2] Beside the experimental and design progress investigations relating to the effect of different geometries on technical feasibility and on transparency has been started. [1] This studies will be extended by a psychological study on the evaluation of double layer grids and their effect on bystanders. The results of this study are presented in this contribution.

2. Spatial geometry and structural system of transparent space grids

In the broad variety of steel space grid structures double layer grids, consisting of a compression and a tension layer, are the most common structures. The assembling of glass panes as compression layer limits the number of economically appropriate geometries. The entire structure is defined by the grids of compression and tension layers.



Figures 1a and 1b: Compression elements in the upper layer of a steel space grid structures and in one with glass panes (structure half-octahedron plus tetrahedron)

One of the most efficient structures in the Mengeringhausen morphology [3] is the space structure half-octahedron plus tetrahedron that was chosen for the mock-up realization. At this structure the compression and the tension layer have the geometry of equal sized square grids and are dually situated to each other. The connection of both layers is achieved by diagonal bars between their knots. The derivation to efficient transparent space grid structures, with regard to the material behavior of glass is detailed described in [1, 4].

3. Appropriate Structural Systems

Recent papers [1] already have described the way to identify appropriate structure geometries for transparent double layer grids. The most economic grids are plain homogeneous grids consisting of one polygon type only. Only three homogeneous grid geometries exist. The elementary shapes are squares, hexagons and equilateral triangles.

The broad variety of different structure geometries [2] is limited by the properties of the building material glass. The glass panes in the compression layer require a glass-appropriate grid. The most economic cut of glass panes are squares, rectangles and equilateral triangles.

In [1] eight of most efficient and economic transparent double layer grids were listed. The structures were named using Mengeringhausen's morphology. In the following these eight structures were compared against structural-constructive parameters. From these studies the following four double layer grid geometries were chosen for aesthetical investigation.

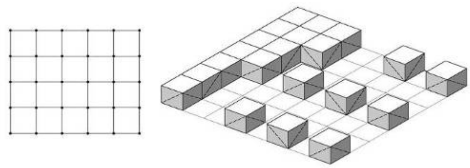


Figure 2: Structure cube (C)

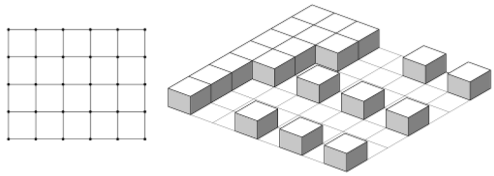


Figure 3: Structure half-Vierendeel (C-HV)

The structure cube is built of hexahedrons located between the two congruent square grids. The glass panes are situated in the compression layer, while the tension layer consists of steel bars. Vertical posts connect both layers. Diagonal braces ensure a stable structure. Another structure built of hexahedrons is the structure half-Vierendeel that is similar to the cube. The stability is achieved by restreint bar connections in the tension layer.

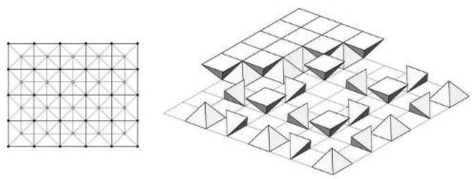


Figure 4: Structure half-octahedron plus tetrahedron (½O+T)

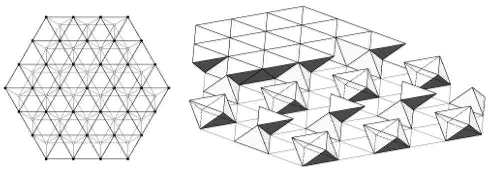


Figure 5: Structure octahedron plus tetrahedron (O+T)

The structure half-octahedron plus tetrahedron consists of the two types of elemtary bodies that completely fill the space between the two layers. The square grids are dually situated to one another. This structure is stable and possesses significant redundancy. At the structure octahedron plus tetrahedron the compression and tension layer grids consist of equilateral triangles. Both elementary bodies and the structure are stable.

The conducted aesthetical study of the four plain double layer grid structures used a fictive inner courtyard of 15 m x 15 m. The grid element length is 1.25 m; therefore 12 x 12 elements built the structures. The structural height is 884 mm. The dead load resulted from an identical glass thickness and the bar dimensions. The snow load was defined by the building codes. The dimensions of the knots were the same at all structures. Results of the design process are member sizes.

Parameter	**Value**
Size structures	15,0m x 15,0m

Assembling height	15,2 m (upper edge)
Supports	quasi-linear at every outline knot
Roof sloping	2,0 %
Size glass panes	1250 mm side length (square and triangular grid)
Structural height	884 mm
Knot dimension compression layer	ø160 mm
Knot dimension tension layer	ø 80 mm
Size vertical bars	ø 30 mm (cube) 90 mm x 90 mm (half-Vierendeel)
Size diagonal bars	ø 16 mm (cube) ø 32 mm (half-octahedron + tetrahedron) ø 26 mm (octahedron + tetrahedron)
Size tension bars	ø 16 mm (cube) ø 18 mm (half-octahedron + tetrahedron) 100 mm x 50 mm (half-Vierendeel) ø 26 mm (octahedron + tetrahedron)
Width joint sealing	15 mm

Table 1: Characteristics of the roof examples above the inner courtyard

The buildings around the courtyard are approximately 15 m high. The architecture of the courtyard remembers at the Gründerzeit ("founder's epoch") around 1900s. These types of inner courtyard similar sizes were frequently built in Germany at those times.

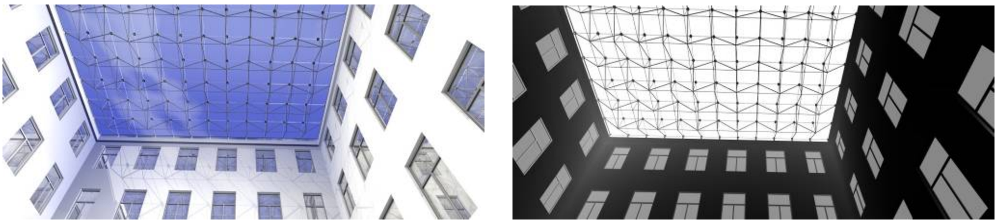


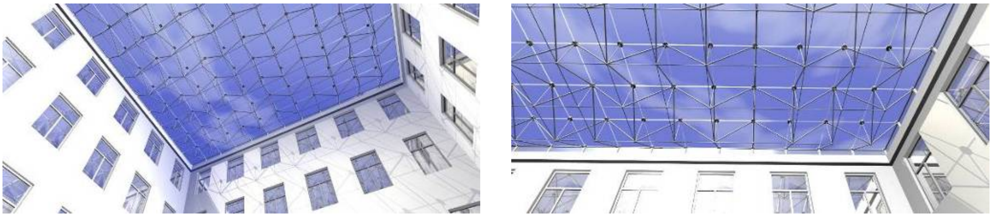
Figure 6a and 6b: View in the visualization and contrast picture (structure cube)

In a histogram of a imaging software the results of the contrast pictured were valued. The overall result gives the structure cube as most transparent followed by the structure half-octhedron + tetrahedron. Both structures octahedron + tetrahedron and half-Vierendeel possess the worst transparency in this investigation.

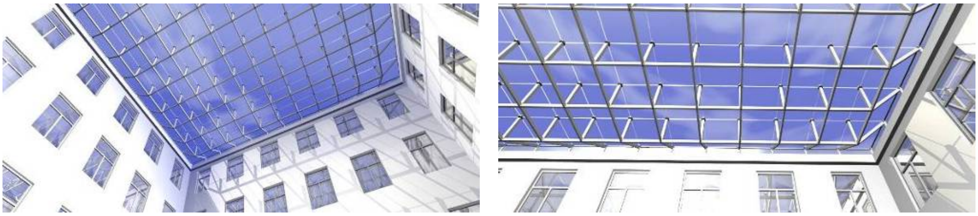
4. Objective of the psychological study

Main objective of the psychological study [5] is the confirmation of the named results of the aesthetical investigation using contrast pictures.[1] Transparency is one of the most important criterions in the modern architecture and not only the physical attribute of a building material. It is a measure how can be seen in a structure that consists of transparent, translucent and solid parts. [6] The glass panes are transparent elements, the bars and the joints and the knots solid parts of transparent space grid structures.

Basis for the psychological study are 30 sec film sequences of the four structure geometries, showing a walk through the visualized courtyards.

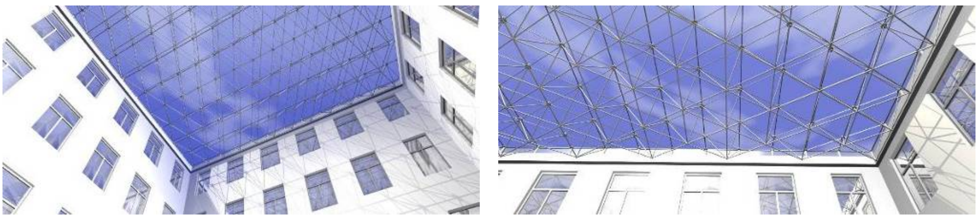


Figures 7a and 7b: Pictures of the film sequence with structure cube



Figures 8a and 8b: Pictures of the film sequence with structure half-Vierendeel

Figures 9a and 9b: Pictures of the film sequence with structure half-octahedron + tetrahedron



Figures 10a and 10b: Pictures of the film sequence with structure octahedron + tetrahedron

5. Tasks

The conflicts in the comprehension of design between constructors or architects and their clients lead to accretive research in the psychological aesthetic. What nice design means belongs to the main goals in this area.

In this study, we investigated the differences in aesthetical judgment concerning four different space constructions half-octahedron + tetrahedron, cube, octahedron + tetrahedron and half-vierendeel. In addition, we examined the influences of stable, changeable and current personal variables on this judgment.

The results of this study should contribute to the arrangement and improvement of the environment.

The secondary task of our study is to develop an appropriate and economic questionnaire to capture the aesthetical preferences.

6. Theoretical Background

What is beauty? In the psychological research of aesthetics this question has been given a wide variety of answers. Many theorists have tried to identify the critical contributors of beauty.

One of the primary goals in this area is to identify and understand those features of an environment that lead to pleasurable responses. Their identification and understanding should support the design of the environment. However, aesthetics and nice design are not the only causes of pleasure. There is evidence that aesthetics may be important in determining behavior [7].

Aesthetical judgment concerns three levels of the human processing of information and is influenced by many different personal characteristics such as expertise and experiences, sex or emotions. Figure 11 shows the perception as well as cognitive and affective components as three stages in the formation of aesthetical reactions. Those stages interact with each other and are additionally influenced by the properties of the environment and the personal characteristics of the observer.

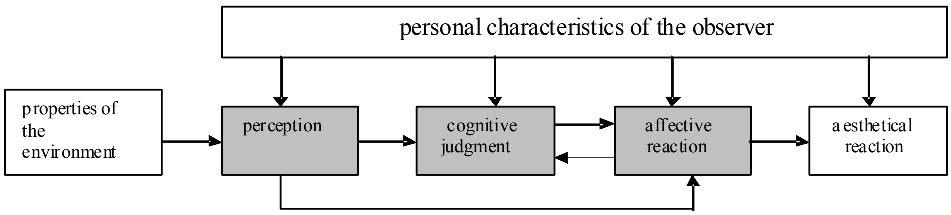


Figure 11: Model of the aesthetical reaction [7]

We suggest that each of the space structures half-octahedron + tetrahedron, cube, octahedron + tetrahedron and half-vierendeel will be judged as different aesthetics. The reasons for this suggestion are based on the model of aesthetical reaction and will be described in the following.

The objective properties of an environment determine how objects are judged. According to Nasar's review [7] the primary formal variables include: enclosure (for example openness or spaciousness), complexity (such as diversity, visual richness or information rate) and order (unity, order, clarity). Because of the different physical properties in the space structures, it is to assume that these structures will be judged as different aesthetics.

The first level of a human's processing of information is perception. How the perceiver sees, smells or tastes something determines how he judges it. Perception is not a stable process, but changes all the time, influenced by experiences and knowledge which are developed by interacting with the environment.

Additionally the cognitive reaction influences the aesthetical judgment and depends on many different personal variables. One of such variables is fluency. According to Reber, Schwarz and Winkelman [8], the more fluently the perceiver can process an object, the more positive is his or her aesthetic response. This means that the aesthetic reaction is influenced by special individual skills of the perceiver.

The design of architectonical objects can lead to specific affective reactions. Thüring and Mahlke [9] showed in their study about usability, aesthetics and emotions in human-technology interaction that a well-designed system of digital audio players was experienced more positively than the ill-designed version. That means that the properties of an object can evoke different kinds of affective reactions and influence the experience of pleasure. These emotions can determine the aesthetical judgment.

The perception as well as the cognitive and affective reactions belong to the process of aesthetical reaction and depend on experiences and knowledge about the environment. We suggest that the judgment towards the four different space constructions in the following study will be influenced not only by their physical properties but also by the personal characteristics of the perceivers.

The personal variables are categorized into three groups which all differ in their stability. One of the stable personal variables is sex. It influences the personal preferences with regard to the environment, such as likeness of certain colors [10], clothes or designs. In this study it is expected that the aesthetical preferences will differ depending on the sex of our subjects.

Not only stable, but also changeable personal characteristics can influence the behavior and thus the aesthetical reaction. The first of such characteristics that was tested in this study was the degree of expertise. We propose the education and profession in the architectonical and designing area as one facet of expertise. The knowledge about architecture, design, and building materials that mediate in the architectonical or construction sciences education should influence the aesthetical judgment of the subjects. The next facet of expertise represents space intelligence. We suggest that this skill leads to better orientation and recognition of details in the environment. It means that people with better space intelligence perceive and process information more precisely, compared to people with lower space intelligence. The third facet of expertise in this study represents the frequency of interaction with 3-dimensional reality in computer games. The reason is that the space structures in our study were presented in the form of 3-dimensional computer simulations. The main requirement was to enhance the ecological validity. Compared to subjects without any experience with such computer games, subjects with more experience should be more sensitive to the details showed in the 3-dimensional simulations. It is expected that this kind of exercise in the 3-dimensional reality will influence the aesthetical judgment concerning space structures.

The third group of personal characteristics which are changeable and influence the aesthetical judgment are the emotions. People in a positive emotional stage activate more positive experiences from the memory. In the aesthetical process this leads to the comparison of the activated positive experiences with the perceived objects or situations [11]. This means, that the positive experiences with the perceived object in the past lead to a positive final judgment.

To summarize, we assume that the four different space structures will differ in their aesthetical judgment, because of their different physical properties, such a complexity. Additionally we suggest, that aesthetical judgment varies depending on the personal characteristics of the subjects such as sex, expertise, space intelligence, frequency of interaction with 3-dimensional virtual computer games and momentary emotional stage.

7. Method

7.1. Equations

The investigation took place in lectures and courses as well as in team meetings of the coworkers of the Building Construction Institute at the Technische Universität Dresden. The space structures were presented in the form of 3-dimensional simulations, by means of a power-point-presentation. The subjects had the possibility to perceive every one of these structures for a time period of 20 seconds and judge it after that.

After the aesthetical evaluation the personal variables sex, expertise, space intelligence, frequency of interaction with 3-dimensional computer games as well as momentary emotional stage were captured.

7.2. Experimental procedure of the subjective evaluations

The experiments took place during June and July 2008. Each of these experiments lasted about 30 minutes. The technical settings for the presentations were prepared before each data collection.

At the beginning of the experiments the participants were informed about the unspecific goals of the study. After the presentation of each space-structure they were asked to evaluate it by means of a semantic differential. After this evaluation they were instructed to fill in the remaining part of the questionnaire, in which the personal variables were investigated.

This study was based on a within-subject experimental design so every participant evaluated every space structure. Each group of participants was presented a random order of the structures. This manipulation of order was used to enhance the internal validity of the experiment. A total of 325 participants took part in the study. 35 people did not fill in the questionnaire completely, so their data was sorted out from the evaluation of the results. The rest of the sample (290 participants) consisted of 151 women and 139 men. The age of the participants varied between 19 and 61 years. The level of education was the basis for the assignment of the participants to the four different groups of expertise. The first group (139 participants) consisted mostly of psychology students. The second group consisted of students of architecture or construction science who were at most in the fourth semester (100 participants) and the third consisted of students who were at least in the fifth semester (34 participants). The last group of expertise was made up of 20 coworkers of the Building Construction Institute.

For the investigation of the aesthetical evaluation we developed a semantic differential. It contained 23 questions using seven-grade bipolar scales. The statistical analysis of the correlation between the answers confirmed four qualitative factors of the aesthetical evaluation, which were named (f1) originality, (f2) attractiveness, (f3) openness and (f4) structure. These factors were used throughout the statistical analysis of the results.

Figure 12 shows 8 of 23 items of the semantic differential, which were related to the four factors originality, attractiveness, openness and structure.

	very	**quite**	**rather**	**neither nor / as well as**	**rather**	**quite**	**very**	
(f1) originality								
interesting	O	O	O	O	O	O	O	boring
modern	O	O	O	O	O	O	O	traditional
(f2) attractiveness								
beautiful	O	O	O	O	O	O	O	ugly
attractive	O	O	O	O	O	O	O	repulsive
(f3) openness								
light	O	O	O	O	O	O	O	heavy
constricted	O	O	O	O	O	O	O	open
(f4) structure								
clear	O	O	O	O	O	O	O	tangled
structured	O	O	O	O	O	O	O	chaotic

Table 2: Items of the four factors of the semantic differential

The performance criteria of the semantic differential were analyzed. The results of this analysis concerning the discriminatory power, reliability (Cronbachs Alpha) and the difficulty of the items confirmed the appropriateness of the semantic differential for the research of aesthetical judgment.

8. Results

The subjective ratings of the semantic differential were analyzed by using statistical tests in the SPSS 16.0 software. Four one-factor analysis of variance (ANOVA) were used to evaluate the differences between the space structures for the factors originality, attractiveness, openness and structure.

An analysis of the ratings of aesthetical evaluation showed significant main effects for the factors attractiveness (($F\ (3,276) = 3.055,\ p = 0.029,\ \eta^2 = 0.032$) and openness ($F\ (3,276) = 2.653,\ p = 0.049,\ \eta^2 = 0.028$). For the factors originality ($F\ (3,276) = 1.467,\ p = 0.222,\ \eta^2 = 0.005$) and structure ($F\ (3,276) = 2.391,\ p = 0.069,\ \eta^2 = 0.025$) no statistically significant main effects could be identified.

The Bonferoni-test for multiple comparisons between the space constructions showed statistically significant results for the factor attractiveness between the constructions half-octahedron + tetrahedron and half-vierendeel ($p = 0.000$), half-octahedron + tetrahedron and octahedron + tetrahedron ($p = 0.050$), half-vierendeel and cube ($p = 0.002$) and half-vierendeel and octahedron + tetrahedron ($p = 0.015$).

The multiple comparisons for the factor openness resulted in statistically significant differences between half-octahedron + tetrahedron and all three other structures ($p = 0.000$). Similar to these results statistical significant differences between half-vierendeel and cube ($p = 0.000$) and half-vierendeel and octahedron + tetrahedron ($p = 0.004$) could be observed.

In summary, each of the space structures half-octahedron + tetrahedron, cube, octahedron + tetrahedron and half-vierendeel was evaluated positively in consideration of the originality, attractiveness, openness and structure. The average answers of this evaluation were mostly arranged in the positive half of the scale from -3 to +3.

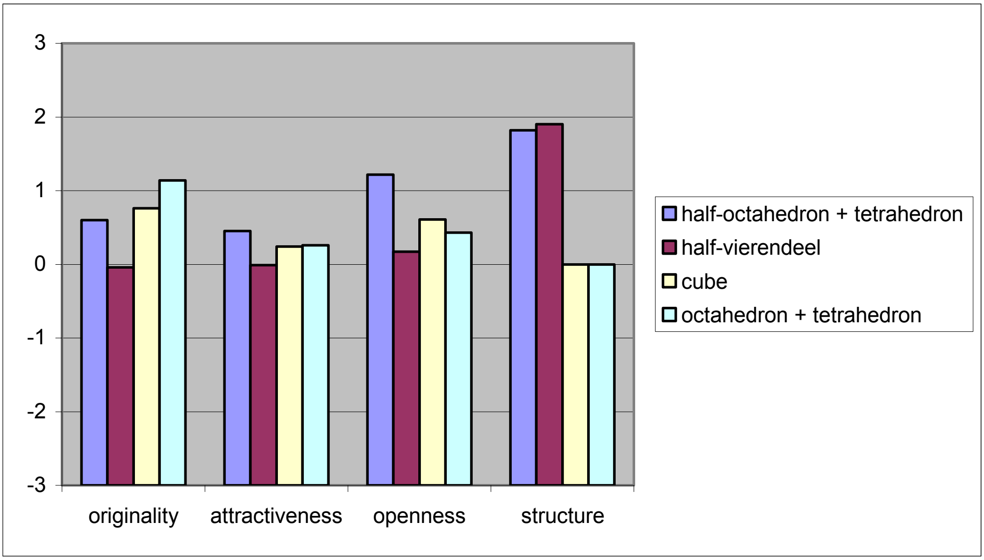


Figure 12: The average evaluation of the factors originality, attractiveness, openness and structure for the space structures half-octahedron + tetrahedron, half-Vierendeel, cube and octahedron + tetrahedron.

An analysis of the overall judgment depending on the degree of expertise showed significant effects for the factors attractiveness ($F\ (1,278) = 2.789,\ p = 0.041,\ \eta^2 = 0.029$) and openness ($F\ (3,278) = 2.955,\ p = 0.033,\ \eta^2 = 0.031$).

We found a significant interaction effect between the variable kind of space structure and space intelligence for the factors originality ($F\ (1,278) = 4.855,\ p = 0.002,\ \eta^2 = 0.014,\ R^2 \leq 0.025$) and attractiveness ($F\ (1,278) = 9.940,\ p = 0.002,\ \eta^2 = 0.035,\ R^2 = 0.027$).

The results showed no statistical differences between women and men in their aesthetical evaluation for all the factors ($p \geq 0.367$). Similar to this result no statistically significant differences could be recognized for the variable frequency of interaction with the 3-dimensional reality in computer games ($p \geq 0.068$).

9. Conclusion

Part of a 3 year lasting research project with the main objective to develop transparent space grid structures is the investigation and evaluating of appropriate grid geometries regarding to their aesthetical appearance. A psychological study of 325 people was conducted to fulfil this task. Stimulus material was 30 sec film sequences of four transparent double layer grids above a visualized inner courtyard. The results of the semantic differential were summarized to four factors originality, attractiveness, openness and structure. In total the structures half-octahedron+tetrahedron, cube and octahedron+tetrahedron possess a similar value of the first three factors but are assessed as less structured. The half-Vierendeel got opposite assessments.

Acknowledgments

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