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ISOMETRIC MEASURANDS ON PERCEIVED SPACIOUSNESS:

Exploring volumetric isovist

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ABSTRACT

The isovists are essential hypothetical structures for understanding the visibility in space. Regarding the perception of space, volumetric visibility presents a complicated geometrical volume that may be considered as a polyhedron obtained from the optical arrays of the vantage point. Despite the stated importance of volume, the preference for two-dimensional approach was later emphasized to be highly pragmatic by the prominent researchers of the field considering the non-applicable and complex data analysis of isovist radials and accordingly the polyhedron structure within a three dimensional medium.

Through an experimental case study, the research explores the extension of syntactic and semantic parameters of visual perception and helps to understand the dynamic nature of the volumetric visibility. Research uses semantic and syntactic data analyses based on the fixed vantage points in a medium to expose the differences in the spatial experience of users. Syntactic data obtained from a modified real environment, and semantic data obtained from the vantage point scenes derived from this environment are correlated. The research is based on four founding subjects of study, which are considered as the main factors in understanding the perception of spaciousness and openness. These factors are defined as isovist parameters, graph parameters, radial data parameters, and volumetric parameters.

The selected environment of the case study is a part of a university building. For this study, ground and first floors are abstracted and simplified in the experiment's virtual environment. Selected 16 vantage points from two floors had diverse variations in width, length and height, which are likely to cause different perceived spaciousness levels. Semantic evaluation is examined through an experimental research with 90 students from

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two different universities. The participants are asked to evaluate the feeling of spaciousness and openness in the virtual medium of 16 vantage points on a 5-point Likert type scale questionnaire. The last step of the methodology is composed of multiple regression analyses showing the effects of syntactic and spatial determinants of the virtual scenes and one-way-ANOVA analyses showing the effects of spatial experiences related to familiarity and educational background of the sample groups.

Results of the research indicated that isovist area is highly correlated with spaciousness, meaning that wider spaces are perceived as more spacious. Higher connectivity values, having more possibility of expansions, lead to an idea of perceptual spaciousness. Volumetric visibility indicates that perception of spaciousness is directly related to the z-dimension. The amount of natural light in space has a positive effect on the participants' semantic evaluations. The infinity value increases the amount of natural light, giving a feeling of wideness and providing a visual access to beyond. Previous experiences of students, familiarity with the space and educational background are highly effective on the perception of openness.

In this research the psychological outcomes of visual perception through concepts of spaciousness and openness with three dimensional geometry of visibility are combined. By the help of novel methods of calculating volume, natural light and infinity values, the research presents a quantifiable data of comparison of semantic assessments with syntactic ones.

KEYWORDS

Spaciousness, openness, isovist, volumetric visibility, visual perception

1. INTRODUCTION

The preliminary researchers of Space Syntax mainly concentrate on 2D based parameters and they mainly discuss the importance of concepts like isovist area, isovist perimeter, occlusivity and circularity in the perceptual evaluation of the space (Davis and Benedikt, 1979; Wise, 1985). Although these give an idea about the expansion of space conception, they give limited information on the volumetric space.

Regarding the optical perception of space, volumetric visibility based on a specific or fixed vantage point presents a complicated geometrical volume or an abstract prism that may be considered as a "polyhedron" obtained from the optical arrays from the vantage point. This static polyhedron structure morphologically changes when the organism starts to act. The organism's movement transforms the polyhedron; and throughout the path, in every seconds of movement, the polyhedron changes. The structure of the optical radials along with the location and the angle of the observant are the main reasons in the morphological change of the polyhedron. However, as stated by Turner et.al. (2001) this explanation may also be connected to our daily movements and our pragmatics in terms of our use of space.

This research mainly deals with the change in the structure of the polyhedron based on the location of the vantage points and how volumetric visibility parameters may contribute to space syntax theory in the evaluation of the concept of spaciousness. Through an experimental case study, the research explores the extension of syntactic and semantic parameters of visual perception and helps to understand the dynamic nature of the volumetric visibility. Research uses semantic and syntactic data analyses based on the fixed vantage points in a university building medium to expose the differences in the spatial experience of the actual and observing users. As it will be explained in detail in the following sections, syntactic data obtained from a modified real environment, and semantic data obtained from the vantage point scenes derived from this environment are correlated. The research is based on four founding subjects of study. In a fixed vantage point, these subjects are considered as the main factors in understanding the perception of spaciousness:

a- Isovist parameters,

b- Graph parameters,

c- Radial data parameters,

d- Volumetric parameters.

Therefore, moving from the "a priori" structure of the epistemological base to the acquired "a posteriori" knowledge of the dynamic polyhedron structure, the aim of this research is exploring the relationship of syntactic parameters with perceptions of volumetric visibility and spaciousness in order to contribute to the three dimensional space analysis discussions.

1.1. Theoretical Background

The epistemological base of the cognitive research starting from Immanuel Kant to new Kantians explains the perceptual world in two domains of syntactic and semantic world; however there's a also a behavioural domain. In buildings with complex architectural designs, circulation always requires a certain experience for the user. Barker (1968) and Gibson (1966) examine the human-environment interaction through adaptation to the environment as well as physiological and biological structures. From such a point of view, the process of perception of the individual is related to the criteria such as size, width, spaciousness and height of the space.

The perception of spaciousness is a parameter influencing orientation and wayfinding and it results from the formal features of the architectural space, as width, height, volume, solid /void balance, permeability, angle of view. Therefore in this research the relationship between the perception of spaciousness with syntactic, volumetric and semantic parameters are explored. However, spatial experience is not just a two-dimensional criterion that can be measured by parameters related to the plan. On the contrary, during the process of user experience of the space, factors affecting the spaciousness such as the ceiling height, wall openings, components in different levels of the space; mezzanine floors and gallery spaces also directly affect the spatial perception.

In terms of human-space interaction, it is important to state that the third dimension of the space is an irregular polyhedron which is dynamically changed depending on the movement. The volume of this polyhedron affects the feeling of spaciousness and this is important for the perception of the space as a whole. In this context, the volume and section of the space may present novel syntactic outcomes in relation to spatial experience, perceptual and psychological processes of the users. Although in terms of theoretical assumptions of isovist research and ease of calculation the spatial perceptions of the agents are taken as 360° in the planar view, human horizontal sight has a total angle of nearly 190º using head and neck movements. Because of similar concerns, in this research, the sight cone which is an irregular polyhedron is considered as 180º horizontally and 135° vertically.

The extension of visibility capacity and its effects on the perception of spaciousness is proved by many researchers, who are mainly concentrated on two dimensional shapes or architectural configurations. The development of isovist based researches owes its progress to Benedikt's ambition about the struggle of understanding the scope of experiential aspects of space (Wiener et. al 2007; Dalton et. al. 2015). For example, Davis and Benedikt (1979) discuss the isovist algorithms in accordance with the rules of calculation regarding occluded areas versus visible areas and visual capacity problems. Davis and Benedikt (1979) and Wise (1985) experiment the perceived spaciousness and try to connect this feeling of spaciousness with the location of the observant and the direction of the movement in terms of orientation, body postures and gazing. Davis and Benedikt (1979) and Benedikt (1979), discuss the spaciousness primarily in relation to the systematic formation of objective isovist properties such as isovist area, isovist perimeter, occlusivity and compactness. On the discussion of perceived value of spaciousness, despite Benedikt's and Wise's empirical findings supporting the effects of isovist parameters, Benedikt and Burnham (1985) and Turner (2003), also argue on the dominance of spatial configuration in terms of isovist complexity rather than isovist area.

Benedikt (1979) expresses Gibson's visual perception as an experience that is formed as a result of the agent's self-movement, intentions and curiosity rather than a set of visible physical outcomes. He explored the interaction between space and agent through placing the observer in the centre. By, this quantitative isovist polygon concept, depending on the agent's movement, a number of computational criteria can be set in the horizontal plane, such as isovist perimeter, isovist area, number of vertices, and length of the visible or occluded edges in the space. However, there are also other researches that dealt with the perception of objects and the visual affordance issues. In order to estimate which factors are effective in understanding volumetric capacity and perception of spaciousness in terms of spatial geometry and affordance, the literature expose many experimental researches. Wise (1985) states that in one of the oldest researches it was found that significant results showing high aspect ratios in different areas in rooms point out high perception of spaciousness. Imamoglu (1973) on the other hand, emphasizes the densely use of furniture cause reverse effect in spaciousness, stating that the occlusivity ratio is high in densely used furniture areas.

The shape of the space is an important enclosure affecting our visual capacity, especially the ratio between the dimensions of a space is extremely important in measuring the degree of perception. Referring to Menchikoff's discussion on how rectangular rooms are perceived as having more volume than square rooms, Sadalla and Oxley (1984) also find similar results stating that rectangularity may cause an illusory perception of spaciousness. They emphasize that rectangular spaces reinforce illusion, because optical misconceptions and users perceive more spaciousness in rectangular spaces.

Wise (1985) posits that spaciousness is linked to the perceived size or the extent of the enclosure. His concept of spaciousness may be referred to the movement; in other words the perception of spaciousness exists with motion and movement. Wise (1985) points out the importance of horizontal sections emphasizing the eye level isovist areas, vertical void, depth value adding positive feelings on spaciousness and such. The height parameter as a factor of spatial geometry is often estimated as an error in judgements. Referring to Ankerl in his study, Wise states that perceptual exaggeration of height in relation to area causes errors in the judgements. The concepts of elongation and compactness are other factors that change the perception of volumetric configuration and the limits of spaciousness. For example, as the spaces get more compact and symmetrical, the more they are regarded as not only shortened, but less spacious. According to Wise (1985) boundary wall and distance are other parameters that change the visible areas; high values of isovist area and radial variance and low values of isovist perimeter and occlusivity are correlated with judgements of greater perceived space.

Owing to Turner's contributions, theoretical discussion is oriented to considering two concepts' togetherness as shared roles of visual and volumetric qualities in evaluations. As a continuum of graph theory that is solely based on the permeability graph (Hillier and Hanson, 1984), Turner develops it by adding up the visibility potentials that are systematized in the graph theory (Turner et. al. 2001). Turner emphasizes the importance of visibility and permeability potentials and supports Gibson's (1966, 1979) visual affordance and optic flow of information theory (Turner et. al. 2001; Turner, 2003) by exploring the two potentials based on two questions, *"what you can* *see"* which was referred to the concept of visibility and *"where you can go"* referred to permeability.

The unique contribution from Fisher-Gewirtzman and Wagner (2003) comes with a 3D analysis model on spatial openness called as SOI (Spatial Openness Index), which presents the dominant role of spatial attributes like openness, distant views, natural light and spaciousness. Spatial Openness Index (SOI) shows not only an analytical path about the urban voids and inter-building visibility as openness, but it also argues the conceptual framework of the isovist volume.

On the other hand, Stamps (2010; 2011) have important contributions on spatial elongation. The visual distances arising from the surface permeability of space, in other words, the visual perception of adjacent spaces from an opening increases the spatial elongation. The increase in the permeability and spatial distance are considered as positive parameters for spaciousness however, they may be causing a hesitation problem in wayfinding. Stamps (2010) takes perceived enclosure and perceived spaciousness as two dependent variables in his analyses. According to these, the judgement of spaciousness gains importance in visual permeability of the enclosure. The concept of permeability is related to the amount of light and horizontal area. In his research, amount of light had a positive effect on perceived enclosure given equal boundary permeability and area, lighter environments seemed more open. Similarly, horizontal areas presented effects similar to light. Surface permeability refers to the visible areas around the viewpoint and the visible / open areas surrounding the visual rays (Stamps, 2011). Therefore Stamps (2009, 2011) discusses essential parameters of spaciousness based on experiments of area, light, shape, occlusivity, boundary followed by height in subsequent researches.

The legibility of the spaces is closely related to the amount, type and accuracy of the data obtained by the perception of the environment and the processing of these in mind. In this research, the perception of spaciousness that is obtained from the geometric ratio of the dimensions in the horizontal and vertical planes is discussed in the context of the permeability and occlusivity of the surfaces and the legibility of the space. The ratio of the lateral surface openings observed during the movement of agents in space indirectly influences the kinesthetic experience and route preference of them according to different perceptual criteria. The surface opening ratio offers a mathematical value that explains the levels of openness and occlusion of surfaces. Perception of spaciousness may lead to hesitations in the decision-making process in terms of movements in wayfinding and evacuating situations, while explaining the concepts of surface and enclosedness (Passini, 1996).

Franz and Wiener (2005) correlated the concepts of spaciousness, openness, complexity and order with the isovist parameters. On the other hand, they found a significant correlation between user experience, jaggedness, clustering coefficient, openness and revelation values. In their experiments, the spaciousness value is highly correlated with the isovist area and they emphasized the qualitative works in architectural design experience researches can also be interrelated with visual graph measurands. Franz and Wiener (2005) attach importance to isovist and graph measurands and their effective role in navigation tasks, which may be correlated to perceived spaciousness studies, similar to Wiener et.al.'s (2006) findings that the average isovist area is highly correlated with spaciousness. In recent studies, Bokharaei and Nasar (2016) also found that perceived spaciousness is correlated to spatial area, lighting, window size and the amount of furniture.

The space syntax literature reflects that the spaciousness cannot be isolated from the three dimensional considerations on ambiguous polyhedron structure. The theoretical background of this research, discusses the perception of spaciousness in isovist and graph measurands. The volumetric measurands has been linked to isovist parameters, where the spaciousness criteria are discussed as an extent of radial data arguments. The nature of observer's horizontal and vertical visibility planes, the radial lines embedded in the volume and the nature of enclosure are among the theoretical scope of this research. Including geometrical and volumetric voids, the amount of natural lighting and infinity values; all volumetric measurands mentioned here form and concretize our understanding of spaciousness and they will be discussed in the following section in detail.

2. DATASETS AND METHODS

Before discussing the details of methodology, it should be mentioned that this research is founded on a model experimented within the virtual medium of a modified real environment. The spatial geometry of this environment presents the syntactic and volumetric data of the research, while the participants provide the semantic data. The experiment was executed in four steps starting from the obtainment of virtual scenes and semantic differential tests, final determination of research parameters and statistical correlations.

2.1. The Model

As mentioned before, the research is based on four founding parameters of isovist, graph, radial data and volumetric components. The method of the research proposes a model that is obtained from the syntactic and spatial measurands that help us to evaluate the notion of spaciousness and openness values in relation to specific vantage points. Because of the necessity of using the local (Turkish) language in the experiments, where spaciousness and openness may be used interchangeably in daily conversations, the notion of openness in here is accepted as the subordinate term that linguistically and conceptually supports spaciousness. Within the scope of this research, the independent variables that form the structure of our model are isovist, graph, radial data and volumetric parameters, while the concepts of spaciousness and openness are set as dependant variables of the semantic experiments.

Isovist parameters, or in other words, isometric measurands, are the primary factors in understanding the scope of two dimensional x-y based visibility. As *area, perimeter, drift* and *occlusivity* are the outcomes of 2D configurations, they give information on geometry of space and they explain the spatial potentials about the visibility. On the other hand, *compactness* and *circularity* are isovist extracted terms explaining the enclosure of the volume and the shape of configuration around the vantage points. According to the connectivity or permissiveness of adjacent volumes, these terms denote the shape of configuration in terms of linearity or circularity.

The graph parameters comprise four measurands of *connectivity, mean depth, real asymmetry* and *local integration* values, which show the nature of linkage between the cells. These measurands intend to explain the connections and cellular type of existing building configurations. Radial data parameters of the model, help discussing the visibility potentials along the radial lines according to the vantage points. Radial data of spatial configuration are collected from the sum of the radial rays extending from the eyes and hitting the surrounding surfaces. The experiments of this research are implemented according to the selected radial data parameters of *radial mean, radial variance, radial standard deviation* and *elongation*.

The fourth group of measurands is volumetric parameters; these are not derived from syntactic parameters but they provide an insight about the third dimension as the z-plane. The z-plane which helps the discussions on the scope of visibility, completes the void between the x and y planes and we label this three dimensional void as *volume*. As the research explores the causes of perception of spaciousness and/or openness, it is important to distinguish the level of effectiveness or the degree of strength of the spatial, physical and syntactic parameters. Therefore, acting as a control group, the outcomes of the volumetric parameters also brings out the discussions of the physical, spatial and/or syntactical dominance on the overall effects on spaciousness or openness. Volumetric parameters are derived from spatial and physical environmental control parameters and are considered as *volumetric visibility, natural lighting* and *infinity values*.

These four groups of measurands create an interactive model with the notions of perceived spaciousness and openness. Also, this model underlines the discussion of effective role on syntactic parameters in volumetric calculations. The methodology of this research is structured in order to investigate the correlations of semantic evaluations of the participants with syntactic and image-based spatial values of 16 vantage points.

2.2. Sample Group

Semantic evaluation is examined through an experimental research with 90 students from two different universities in Istanbul where the participants are asked to evaluate the feeling of spaciousness and openness in a virtual medium of a modified real environment. 60 of the participants are students of Özyeğin University who will be mentioned as OZU Students in the research, remaining 30 from Istanbul Technical University who will be mentioned as ITU Students. As it will be discussed in detail in the following section, the experimental research with 90 students is conducted in a virtual interior environment that is depending to the configuration of an actual university building's structure at both horizontal and vertical scales. In this case, 60 OZU students are somehow familiar with the modified virtual environment of the case study while ITU Students are not. However while 30 of the OZU participants are architecture students, along with 30 ITU students, remaining 30 OZU Students are from different disciplines.

Therefore, the total number of the participants consists of three different sets of students forming 30 people within each group that are OZU Architecture Students, OZU Non-Architecture Students, and ITU Architecture Students. The idea here was to distinguish the comprehension of spaciousness and openness as concepts within familiar and unfamiliar environments, as well as the ability of defining these words and identifying them spatially in terms of perceptions.

2.3. Environment

The selected interior environment is a part of Özyeğin University's Business School in the main campus, in Istanbul as seen at Figure 1, that is occupied with classrooms, study rooms and eating facilities for students as well as serving as a transition space especially on the ground floor level. For this study, ground and first floors are taken into account and the interior area's features are abstracted and simplified in the experiment's virtual environment. The reason for selecting this pre-designed interior environment as the case study was its contrasting spatial characteristics such as gallery voids, double height ceilings, deep or shallow corridors and an atrium opening with a glazed covering at the top. These features allowed us to discuss perceptual differences of individuals in terms of volume that is the crucial part of this research.

Figure 1. Case Study Environments with vantage points (Ground Floor on the left, First Floor on the right).

The permanent structural and architectural elements such as columns, beams, fixed ceilings, solid walls, glazing walls, stairs, etc. are kept as they are but some features such as temporary spaces for students, fixed or semi-fixed furniture are not implemented in the virtual environment. The aim was to create an environment that is reflecting these visual varieties in the medium; therefore we selected 16 vantage points from two floors. As the isovists of these 16 points have changing parameters depending on their location and also the shape of the surrounding space, we were also able to differentiate the semantic characteristics of space. The cross-sectional variations and change in volumetric perceptual effect of the individual through eye level which is 150 cm above the floor, have been taken into consideration.

Briefly, the experiment is conducted with the participating students where they experienced this virtual environment through a computer screen with all 16 selected vantage points individually. Each vantage point is seen through PanoVR (2018) software, which provides a 360º of panoramic observation. This individual investigation is combined with an evaluation of each point semantically through a 5-point Likert type scale questionnaire prepared for each vantage point. Rendering this 360º panoramic image also combines images in 6 different angles on a single screen and produces a single image for each vantage point as seen in Figure 3. Through this single image, “Natural Light Index” can be obtained through an algorithm written in Python and also “Infinity Index” can be obtained through the calculation of Alpha Channel Rate that is also known as a parameter of the Vray rendering engine. “Volumetric Visibility” is calculated via Alpha Channel in Python (2018). The syntactic values of 16 vantage points are obtained in three different categories by Syntax 2D (2010). Finally, by using the SPSS (2018) correlations of values obtained from the semantic differential study of 90 participants (dependent variables) and the syntactic (independent variables) values were examined. The following sections explain the experimental research and correlations in detail.

2.4. Virtual Scenes

The space to be analyzed is modelled through AutoCAD Revit and transferred to Sketch-Up in order to take raster sequential images from three-dimensional model. Despite the possibility of misleading the participant's perception, attributes such as color, texture and glossiness are not assigned to spatial components. As the main purpose of the study is to investigate the parameters of spaciousness and openness, glass surfaces on the facades of the building are processed in the model; thus the only light source in the model is natural lighting. The scenes are modelled by standardizing the amount of sun in Istanbul, at 2.00 pm in March, with open air conditions and sharp shadows without any clouds.

PanoVR software, resembling a cube’s expansion, combines images in 6 different view angles on a single screen (Figure 2) which are distributed as follows: forward (e), right (f), left (d), back (k), up (b), and down (h). The remaining angles are dead spaces and do not contain any information (a, c, g, i, j, L fields). These 6 view angles are then combined in a single frame in order to form a T shape allowing a 360º viewing experience. Using the in the Pano2VR’s 360º panoramic observation for the selected 16 vantage points individually, the participants are set to experience the virtual environment.

Figure 2. 360º panoramic image rendered for calculations of volumetric parameters (left); An example of 3D virtual scene from a vantage point (right)

2.5. Semantic Differential Test

While the 90 participants were observing the virtual 360º panoramic scenes derived from 16 vantage points, a 5-point Likert type scale questionnaire was also presented them in order to measure their perception of spaciousness and openness. Participants experienced the panoramic image for each vantage point using the keyboard's arrow keys to the right, left, front, back, up and down. Guided by a research assistant, immediately after they observed the scene, they answered the questions of the semantic differential table for that specific vantage point. As completing one, view of the next vantage point appeared on the screen; therefore, the participants experienced the virtual scenes one by one. In the semantic differentiation experiment, subjective perceptual differences of the participants are explored by assigning values from 1 to 5 to their judgments related to the concepts of spaciousness and openness. Independently of the educational background, or the familiarity with the environment, the drawback of semantic judgments is related with the language used. Therefore, two separate adjectives were set to define both spaciousness and openness in order to distinguish the perceptual and/or linguistic differences. These adjectives are open and permeable for openness and spacious and roomy for spaciousness. Therefore, the participants evaluated the virtual scenes as 5 denoting the most, and 1denoting the least of the mentioned qualities. The numerical answers given to expressions such as “This space is an open space”, “This space is a permeable space”, “This space is a spacious space” and “This space is a roomy space” are summed to obtain the mean.

2.6. Determinants

Syntactic values of the isovist, graph and radial data measurands of the 16 vantage points, which are described in the model, are obtained by Syntax 2D (2010) software (Figure 3). As mentioned before isovist measurands used in the research are *area*, *perimeter, drift, occlusivity, compactness* and *circularity* values, while the graph measurands are set as *connectivity, mean depth, relative asymmetry*, and *integration (n)* values. Within the scope of radial measurands, *radial mean, radial variance, radial standard deviation, radial elongation* values are taken into account.

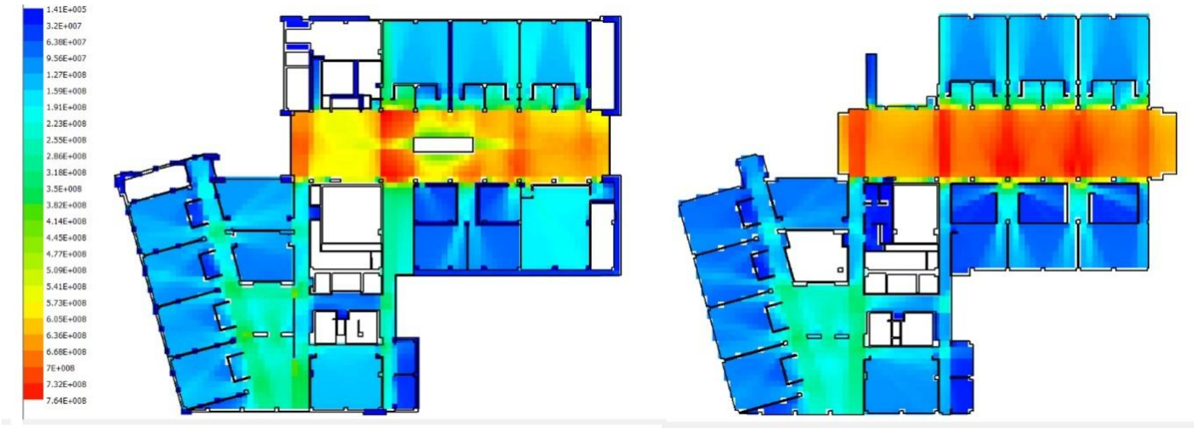

Figure 3. Isovist graphs of the university building (Ground floor on the left, First Floor on the right)

Volumetric measurands are not derived from syntactic parameters but they provide an insight about the third dimension through volumetric visibility, natural light index, and infinity values. Volumetric data which is novel both with its theoretical background and methodology used, demonstrates the unique and significant part of this research.

Natural light index gives us the amount of natural light taken into a space through transparent/semi transparent planes and openings by calculating the intensity of cast shadows. Using PanoVR's virtual scene images resembling a cube's expansion, illumination values of the total pixels on the screen are collected for each 16 vantage points in order to calculate the amount of natural light. For each of the images, an algorithm written in Python was used to find the corresponding value between 0 and 255. The calculation using the Matplot Library (2018) in Python is reported on the screen and visualized in the yellow-red scale (Figure 4).

```
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
import numpy as np
import pandas as pd
import os

os.chdir(os.path.dirname(os.path.realpath(__file__)))
#os.chdir("test5")

def Imj_Anlz(GG):
    plt.clf()
    #İmaj Okunuyor
    img=mpimg.imread(GG)
    ##Tek Kanal Alıcısı (BLUE)
    lum_img = img[:,:,0]
    #Pandas DF'e dönüştürülüyor
    a=pd.DataFrame(lum_img)
    #Kızıl filitre uygulanıyor.
    imgplot = plt.imshow(a, cmap="hot", label="hellop")
    plt.title(str(GG)+", Total : "+str(a.sum().sum()))
    ##imgplot.set_cmap('nipy_spectral')
    plt.colorbar()
    plt.savefig("{}.pdf".format(GG))
##    plt.show()


for k in os.listdir():
    if k.endswith("png"):
        print(k)
        Imj_Anlz(k)
```

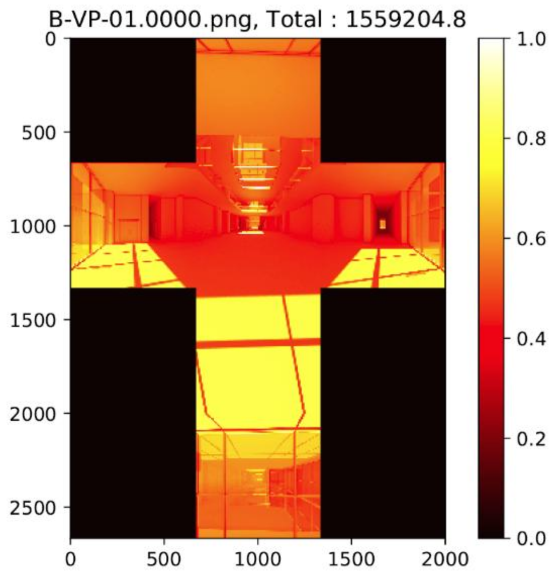

Figure 4. The calculation method of natural light index.

Infinity Index shows us the amount of the sky seen in each vantage point; these comparable values are used to investigate how perception of the sky is grasped in relation to spaciousness. The problematic aspect of this calculation is, even if a small portion of the sky is seen from the vantage point, an infinite distance is produced in the calculation of volume. In order to overcome this problem, a distance limit greater than the farthest interior distance was set where the infinity was detected. In the calculation of this parameter Vray rendering engine (2018), known as Alpha Channel (2018), is used as an additional rendering image. This rendering technique as shown in the left hand side of the left image (Figure 5) defines the infinity value as black, while the solid planes, and walls are visualized as white. Therefore, in relation to the distance set for infinity limit, and the transparency ratio attributed to glass specified as 50%, infinity values of the vantage points are calculated as the sum of variations of grey dots on the Alpha channel.

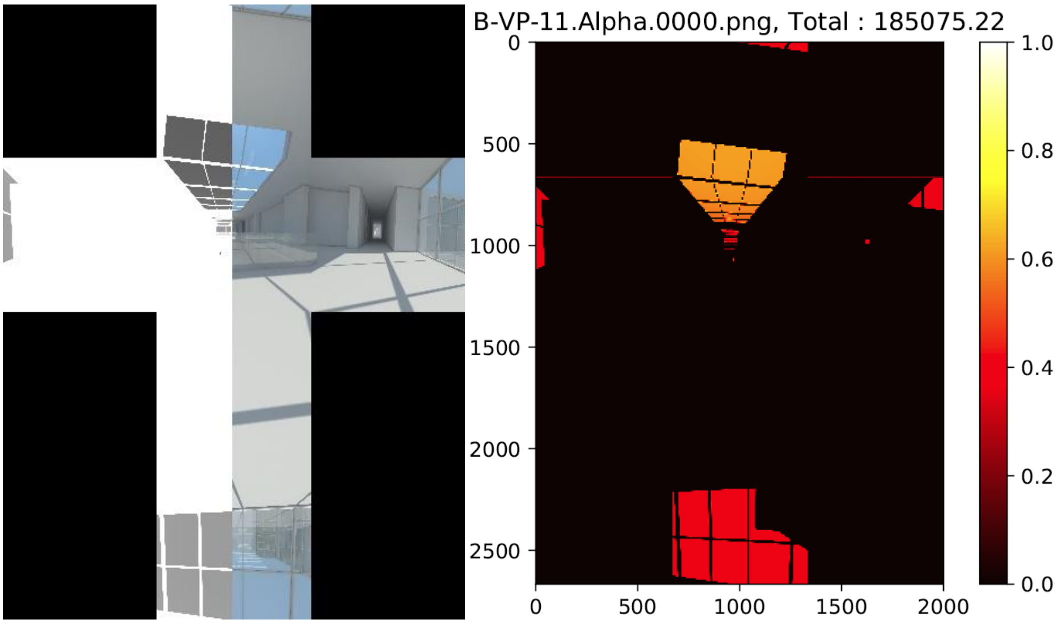

Figure 5. The representational image of calculation of infinity index.

As the volumetric calculation of the isovist polyhedron is one of the most important issues of this research, **Volumetric Visibility** shows the amount of isovist volume on each experienced vantage points. For the calculation of this novel value, 360º of viewing in the x-y axis similar to isovists are set; however for the z- axis on the eye level, an angle of 60º of viewing above x-axis, and 75º below are used. One of the main issues in preparing this calculation method is the camera's setting to resemble the actual spherical structure of the human eye, in order to obtain the least visual distortions. Therefore the pixels converted to individual prisms to form a sphere, scan all angles horizontally and vertically from a viewing point. In this case, using only distance values, visual volumes necessary for comparison of the vantage points can be calculated.

On the basis of this proposed calculation made with the same Python method, the additional Z-Depth rendering channel is used for the distance mapping of the rendering engine Vray (2018). In this rendering technique as shown in the left hand side of the left image (Figure 6) defines and limits the closest and farthest distances to the camera. In the Z-depth channel, as the distance of pixels to the camera increases, pixels whiten; on the contrary closest pixels are the black ones with 0 values. In this calculation the shades of grey present the values of distances linearly, having a value of 50% of greyness in the mid-distance. Thus, as the remote areas are whiter, sum of the values of the pixels will be higher in spaces with larger volumetric visibilities, whereas the sum of pixel values will be lower in the spaces where less volume is seen.

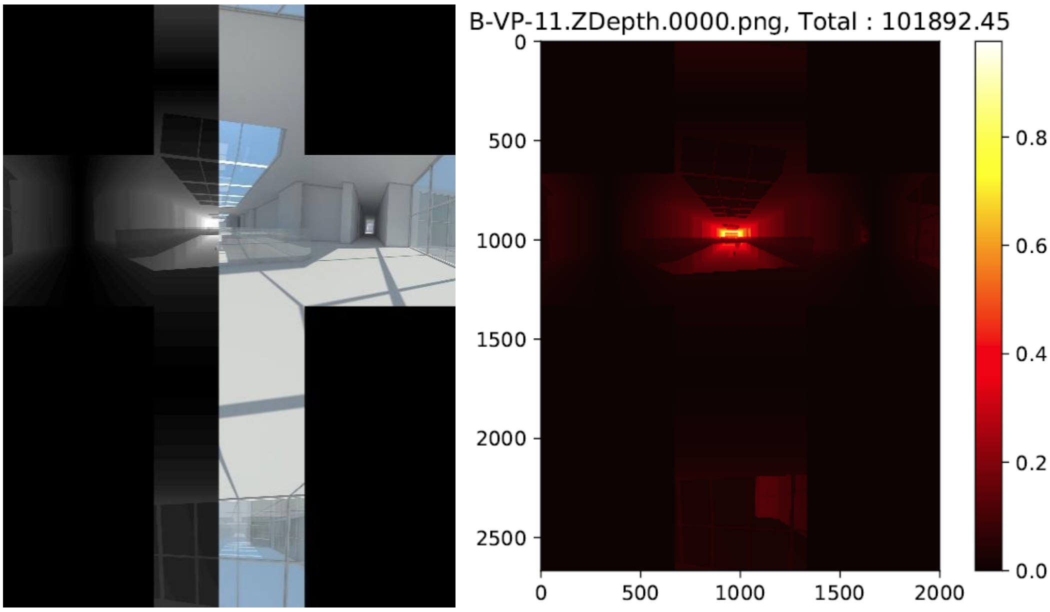

Figure 6. The representational image of calculation of volumetric visibility

2.7. Correlations

The last step of the methodology is composed of multiple regression and variance (one-way-ANOVA) analyses which are performed by SPSS (2018). The outcomes of the regression analyses show the effects of syntactic and spatial determinants of the virtual scenes on the participants' responses. The outcomes of the variance analyses on the other hand, show the effects of spatial experiences related to familiarity and educational background as well as the differences between these three sample groups. As mentioned before values of the semantic differential study, i.e. mean spaciousness and mean openness values, obtained from 90 participants are defined as dependent variables, while syntactic, physical-spatial values of volumetric data and gender and education characteristics of the participants are defined as the independent variables of the research.

3. RESULTS

The results of the analyses can be discussed in two sections; first section deals with the responses of the participants related to effective and significant determinants of isovist, graph, radial data and volumetric measurands in the proposed model through multiple regression tests. Second section deals with variance analyses test to expose the significant results in each group to discuss effects of spatial experience mainly.

3.1. Multiple Regression Tests through Stepwise Method

When regression analysis tests are conducted between the syntactic values and the frequencies of semantic values, the Pearson correlation values were found to be significant ($p < 0.05$) in these binary analyses. So, in this case a new phase of statistical analysis was needed to reduce the effect of multiple independent variables and to increase the rate of expression of dependent variables in multiple regression tests. In order to avoid a multi-connection problem that reduces the value of the established model, there could be two methods implemented; the highly correlated variable might be subtracted from the model or the two variables might be converted into a single variable. In order to test which was the most effective variable, stepwise strategy was implemented in the multi-regression tests. Therefore, using stepwise method, the analysis was repeated in which each variable was added and evaluated respectively to investigate significant values. In this model, all independent variables are retested to assess whether they contribute to the model significantly or not; if the contribution was not significant, the variable was removed from the model.

According to these tests applied, 11 significant correlations found which are shown shaded in Chart 1. When the correlations between isovist measurands and semantic frequencies are analysed, it is found that the *isovist area* is significantly correlated both with the *mean spaciousness* (R^2=0.749(p<0.001); F14,15=41.706; p<0,01; ΔR^2=0,000(p<0.001) and *mean openness* (R^2=0.767(p<0.001); F14,15=46.063; p<0,01; ΔR^2=0,000(p<0.001) response values of the participants. This result, resembling many other previous studies, supports that value of area is highly correlated with the spatial perception in terms of spaciousness, meaning that a wider space is perceived as more spacious or open from a specific vantage point.

When the correlations between graph measurands and semantic frequencies are analysed, it is found that *connectivity* value is highly correlated both with *mean spaciousness* (R^2=0.752(p<0.001); F14,15=38.504; p<0,01; ΔR^2=0,000(p<0.001) and *mean openness* (R^2=0.733(p<0.001); F14,15=42.544; p<0,01; ΔR^2=0,000(p<0.001) response values of the participants. Space syntax theory states that spaces with high connectivity are the ones which have direct permeability to other spaces. When the plan of the case study is analysed, it is seen that the central part of the building is a node where many classrooms are associated, including galleries, mezzanine floors along with transition routes. Thus, also housing many vantage points, this space is large in size and has more connections compared to other parts of the layout. Even though the connecting spaces may not always be clearly visible from the virtual scenes, having more connections may be regarded as having more possibility of expansions, therefore leading to an idea of perceptual spaciousness.

When the correlations between the radial measurands and semantic frequencies are analysed, it is found that *radial mean* value is highly correlated both with *mean spaciousness* (R^2=0.765(p<0.001); F14,15=45.618; p<0,01; ΔR^2=0,000(p<0.001) and *mean openness* values (R^2=0.779(p<0.001); F14,15=49.416 p<0,01; ΔR^2=0,000(p<0.001). The concept of radial mean in the space syntax theory is related with the spatial characteristic of a layout being close to a regular circle or not. In our case study, most of the vantage points have average radial mean values because of the existence of larger halls, compared to the small number of deep corridors. Therefore, the participants' responses to perception of spaciousness for example, on a vantage point located on a long narrow corridor comply with the value of radial mean in the same sense.

When the correlations between the volumetric measurands and semantic frequencies are analysed, it is found that *volumetric visibility is* highly correlated with *mean spaciousness* value (R^2=0.92(p=0.042<0.005); F12,15=45.762; p=0.42<0,05; ΔR^2=0,000(p=0.042<0.005). Therefore, the effect of the volumetric visibility value on the human perception of the research is confirmed. In other words, by going one step beyond the previous studies, which have been exploring the perception of the individual on x-y planes, it has been determined with this research that the perception of spaciousness is also directly related to the z-dimension.

It is also found that *natural lighting index* is highly correlated both with *mean spaciousness* (R^2=0.92(p=0.029<0.005); F12,15=45.762; p=0.029<0,05; ΔR^2=0,000(p=0.029<0.005), and *mean openness* values (R^2=0.907(p=0.026<0.005); F12,15=38.961; p=0.026<0,05; ΔR^2=0,000(p=0.0026<0.005). Confirming an intuitive assumption, this result shows that the amount of natural light in the vantage points has a positive effect on the participants' semantic evaluations of spaciousness and openness. On the other hand, variety in the selection of vantage points, in relation to z-dimension, also helps to analyse the differences of perceptual evaluations. For example, the characteristics of spaces such as the gallery where the voids are located, the places where the transparency of the atrium openings and the transparency of facades are noticed, seemed to be effective on the assessments.

Chart 1. Multiple regression tests

			Significance value	Significance	R	R Square	Adjusted R Square	Std.Error of Estimate
ISOVIST MEASURANDS	**Isovist Area**	Mean Spaciousness	**0.000**	**significant**	0.865	0.749	0.731	0.43744
	Isovist Perimeter		0.709	not significant				
	Isovist Drift		0.346	not significant				
	Isovist Occlusivity		0.747	not significant				
	Isovist Compactness		0.795	not significant				
	Isovist circularity		0.924	not significant				
	Isovist Area	Mean Openness	**0.000**	**significant**	0.876	0.767	0.75	0.41501
	Isovist Perimeter		0.742	not significant				
	Isovist Drift		0.402	not significant				
	Isovist Occlusivity		0.907	not significant				
	Isovist Compactness		0.765	not significant				
	Isovist circularity		0.989	not significant				
GRAPH MEASURANDS	**Connectivity**	Mean Spaciousness	**0.000**	**significant**	0.856	0.733	0.714	0.45058
	Mean Depth		0.117	not significant				
	Relative Asymmetry		0.22	not significant				
	İntegration (n)		0.272	not significant				
	Connectivity	Mean Openness	**0.000**	**significant**	0.867	0.752	0.735	0.42773
	Mean Depth		0.121	not significant				
	Relative Asymmetry		0.267	not significant				
	İntegration (n)		0.211	not significant				
RADIAL MEASURANDS	**Radial Mean**	Mean Spaciousness	**0.000**	**significant**	0.875	0.765	0.748	0.42284
	Radial Variance		0.075	not significant				
	Radial St.Deviation		0.240	not significant				
	Radial Elongation		0.929	not significant				
	Radial Mean	Mean Openness	**0.000**	**significant**	0.883	0.779	0.763	0.40389
	Radial Variance		0.059	not significant				
	Radial St.Deviation		0.172	not significant				
	Radial Elongation		0.703	not significant				
VOLUMETRIC MEASURANDS	**Volumetric visibility**	Mean Spaciousness	**0.042**	**significant**	0.959	0.92	0.9	0.26721
	Natural lighting		**0.029**	**significant**				
	Infinity value		**0.023**	**significant**				
	Volumetric visibility	Mean Openness	0.065	not significant	0.952	0.907	0.884	0.28331
	Natural lighting		**0.026**	**significant**				
	Infinity value		**0.054**	**significant**				

On the other hand, *infinity value* is also found to be highly correlated with *mean spaciousness* value (R^2=0.92(p=0.023<0.05); F12,15=45.762; p=0.023<0,05; ΔR^2=0,000(p=0.023<0.005), while it is almost significantly correlated with *openness* value (R^2=0.907(p=0.054>0.005); F12,15=38.961; p=0.054>0,05; ΔR^2=0,000(p=0.029<0.005). This result, confirms that as infinity value increases the amount of natural light coming to inside, it also gives a feeling of wideness providing a visual access to beyond. Considering one of our most primitive impulses of survival, psychologically, humans prefer visual access more, compared to physical access. Therefore, having atrium openings and transparent façades showing the sky and exterior space, contributes to the perception of spaciousness and openness in relation to a wider visual potential.

In the context of spaciousness-openness model that is specific to this research, Figure 7 shows a concise summary of the multiple regression analyses with significant outcomes. Although these results might be expected from the theoretical background, the model in fact presents an insight to the intertwined and hybrid nature of independent variables especially in terms of volumetric measurands. Even though the z-plane based volumetric calculations expose highly complex shapes that cause them to be ignored in the theoretical base of isovist researches, this research extracts a twofold discussion showing the importance of syntactic parameters such as isovist area, connectivity, radial data, on one hand, and their complementariness like volumetric visibility, natural lighting and infinity, on the other hand.

Multiple regression tests indicated in Chart 1 posits the importance of isovist area that it is an indispensable determinant about the arguments of spaciousness and openness values. It is seen that this finding has not changed since the prominent researchers of the field like Benedikt (1979) and Wise (1985) to the updated works of Franz and Wiener (1985) and Stamps (2009, 2010, 2011).

As the literature suggests (Wise,1985; Benedikt and Burnham, 1985) the isovist area is considered to be in relation to horizontal sections and the larger the area we see, the more spaciousness we perceive; on the contrary low values of isovist perimeter also contributes to the positive perception of spaciousness. In our case study building, we witness low values in the isovist perimeter; the clear geometry of the building configuration that is based on a centrally large void and surrounding classroom spaces present significant perceptions about the volumetric legibility. So, inevitably, the role of isovist area is dominant compared to other configurative parameters such as perimeter, compactness and circularity around the vantage points. Turner et. al. (2001) considered visibility and permeability as two inseparable concepts; the significance of connectivity in our tests both confirms the relation to isovist area and shows the potential of visual depth obtained from the vantage point. Connectivity may also be regarded as a significant element for catching the possibilities of openings on the enclosure that is being viewed.

The vantage point has a potential of measuring the visibility, based on radial lines. In early works of the field from Wise's (1985) horizontal sections of radial lines to Dalton's OmniVista (Dalton et.al.2015), the radial data is considered to be the essence of "visual and mathematical world". Therefore, the significant correlation of mean radial data with spaciousness and openness was another predicted parameter in our tests. On the other hand, the significant correlations in volumetric visibility, natural lighting and infinity values were also predicted due to the proven works of Fisher-Gewirtzman and Wagner (2003) and Bokharei and Nasar (2016). However, our novel method used in this research has much potential to explore the field further.

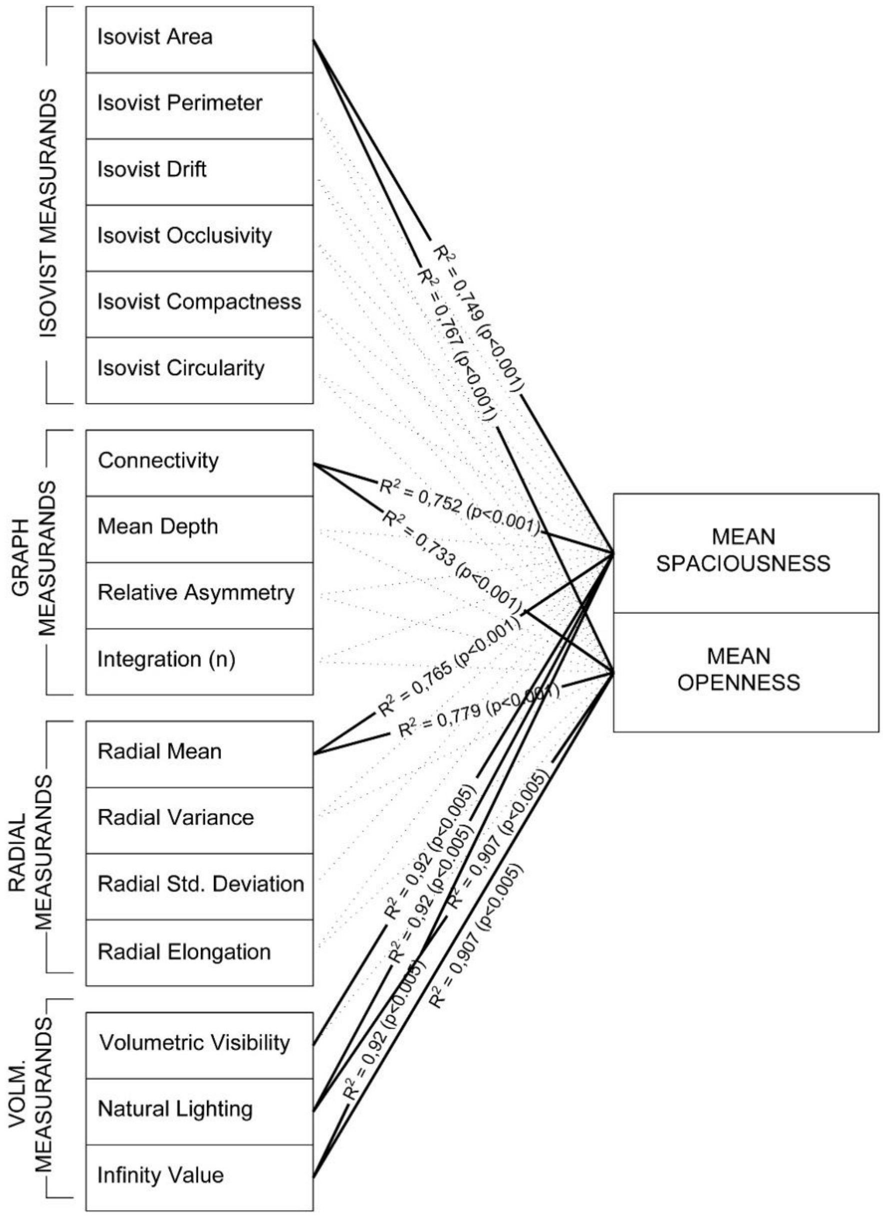

Figure 7. Significant correlations revealed from multiple regression tests

3.2. Variance Tests (One-way-ANOVA tests)

The outcomes of the variance analyses are predicted to show the effects of spatial experiences related to familiarity and educational background as well as the differences between three sample groups from two different universities. According to the one-way-ANOVA tests, it is observed that three independent variables have a significant relationship with mean openness value. These significant correlations are being from which school and department as a whole, being an architecture student or not, and being from Özyeğin University or Istanbul Technical University are shown shaded in Chart 2.

If we take a closer look at the variables, there is a significant relationship between school-department and the value of openness (p=0,02<0,05). On the other hand, correlation between being an architecture students or not and openness presented a value of (p=0,001<0,05), while being from OZU or ITU presented a value of (p=0,007<0,05). Remembering that the school and department variable, consists of three groups with 30 students in each group, the participants are in equal number. At this stage in order to understand which school and/or which department's students have more openness value than the other, an additional test was needed. Therefore, a Tukey Post-hoc test was applied as the clusters are equal in size.

Chart 2. One-way-ANOVA tests

		df	F	Significance Value	Significance
Gender	Mean SPACIOUSNESS VALUE of the Participants	1	0.071	0.791	not significant
School&department		2	1.623	0.203	not significant
Semester		9	0.402	0.93	not significant
Being arch student		1	3.267	0.074	not significant
From OZU/ITU		1	0.612	0.436	not significant
Gender	Mean OPENNESS VALUE of the Participants	1	2.334	0.130	not significant
School&department		2	6.438	**0.020**	**significant**
Semester		9	1.103	0.370	not significant
Being arch student		1	10.945	**0.001**	**significant**
From OZU/ITU		1	7.690	**0.007**	**significant**

Chart 3. Tukey test

(I) School &department		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Arch.students from OZU	Non.Arch from OZU	-.22393	.10168	.076	-.4664	.0185
	Arch from ITU	.13750	.10168	.370	-.1050	.3800
Non.arch from OZU	Arch.from OZU	.22393	.10168	.076	-.0185	.4664
	Arch from ITU	**.36143***	**.10168**	**.002**	**.1190**	**.6039**
Arch.students from ITU	Arch from OZU	-.13750	.10168	.370	-.3800	.1050
	Non.Arch from OZU	**-.36143***	**.10168**	**.002**	**-.6039**	**-.1190**

According to the Tukey test on Chart 3, there is a significant correlation (p=0,02<0,05) found between non-architecture students from OZU and architecture students of ITU, which means that there is a wide gap between the lower and upper bound (0.1190-0,6039=0,4849) in terms of *mean openness* value between the familiar group with building from other departments and unfamiliar group from architecture department of ITU. This result shows previous experiences of students in the building highly effects their perception of openness.

There is a significant relationship (p=0,001<0,05) between the independent variable of *being an architecture* *student* and *mean openness* value. This result may be indicating that architecture students are more familiar with the concepts of openness and permeability concepts of space than students who have a different educational background and therefore also have a differing jargon.

There is also a significant relationship ($p=0,002<0,05$) between the independent variable of *being a student from OZU or not* and *mean openness* value which once again indicates that familiarity with space is an important parameter since perceptual processes of individuals are highly affected due to previous cognitive accumulation of personal experiences.

The parameters of the semester that the students are in found not to be significant while assessing the spaciousness and openness. This indicated that familiarity with the environment is achieved within the first year, decreasing the value of experiences of the subsequent semesters. There is also the finding that the advantage of having the spatial familiarity is a question of yes or no situation rather than a continuity showing the period of experience. On the other hand, although having higher values compared to semester parameter, the gender issue also found not to be significant in the assessment of spaciousness or openness. This indicates that if verbal definitions are correctly set, then the visual perception of humans do not change according to psychological or physiological aspects of gender differences.

4. CONCLUSIONS

This research is based on visual evaluations of university students about the concepts of spaciousness and openness. The experiment is organized according to the selected 16 vantage points from two floor levels of an actual university building. Reflecting the visual potentials of these vantage points, which were converted to virtual scenes, the research intends to lead a way to evaluate the ambiguous form of visual polyhedrons created on these fixed vantage points. As visual perception has long been tackled by space syntax researchers, behavioural aspects of perception also have been studied by researchers from various disciplines. In this research we combined the psychological outcomes of visual perception through concepts of spaciousness and openness with three dimensional geometry of visibility. By the help of novel methods of calculating volume, natural light and infinity values, we managed to present a quantifiable data of comparison of semantic assessments with syntactic ones.

If we extend our research objectives from these fixed vantage points to a route or a direction, then we can talk about series of nodes as decision making points, which would be leading us to the investigation of sequential series of polyhedrons. Based on dynamic and drifting nodes including the agents within their body movements and gazing, would necessitate calculating a sequential series of polyhedrons, for example, on a building's evacuation route. The authors consider to extent this pilot study by extracting the significant spatial and syntactic values of   the research in order to frame the contours of an experimental model in the near future.

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