Using Three Dimensional Isovist to Detect the Property of Surprise in Architectural Artifacts: Islamic Architecture as A Context

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Abstract: Isovist is the amount of optical field viewed from a given point of view thus it represents the environmental visual properties of space from that point. As a contribution to link the concept of *3D Isovist* with the behavioral studies and the affective evaluations of the spatial experiences, as highlighted through the previous literature, the current research aims to test the suitability of *3D Isovist* in the detection and prediction of the property of *Surprise* in architectural spaces. It intends to support the possibility of investing the 3D Isovist as a tool to detect the experience of *Surprise* in the previous Historical Architecture on the one hand and to evaluate it in the new designs on the other. To achieve this goal, the research adopted a method of generating a parametric environment that includes the measurement of *3D Isovist* and exporting the resulting data to statistical programs which are specially prepared to summarize them automatically, then measure the sense of Surprise, and finally, discuss and analyze the results of the application and draw conclusions about the suitability of the *3D Isovist* in the detection and prediction of the property of Surprise locations. The research concluded that *3D Isovist* is a suitable tool for detecting and predicting locations that have a surprise in existing environments on the one hand and in evaluating new designs on the other hand for surprise, thus enabling the necessary developmental measures to enhance the surprise and modify designs accordingly.

Keywords: 3D Isovist, Surprise, Heat Map, Principal Components Analysis, Islamic Architecture

1. Introduction

The current research deals with the concept of Three-Dimensional Isovist and its suitability as a tool for detecting the quality of Surprise in architectural products. It intends to present an alternative approach to the previous approaches as being more objective in terms of the capability of capturing the quality of Surprise directly from the representations of the built environment such as blueprints, for example, instead of capturing it through a survey of opinions and evaluations of a specific sample of recipients. It is also an easier tool in terms of shortening the methodological procedures required to capture the Surprise feature by adopting the questionnaire/ interview tool. The methodology adopted is based on developing the ideas presented in recent studies about the 3D Isovist as a tool, then analyzing the correlation of the results obtained with the results of the questionnaire methodology, which is the previous tool approved for measuring the characteristic, and then adopting the strength of the correlation to conclude the suitability of the 3D Isovist in detecting the quality of Surprise. In view of the distinctiveness of Islamic Architecture, in particular the Mamluk Architecture, with the feature of Surprise, it is adopted as a context for measurement and analysis to reach the relevant conclusions.

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2. The Concept of Isovist: Definition, Development & Application

2.1 The Isovist: Definition of the Concept

Benedikt was the first who introduced the term Isovist to architecture. He defined it as an area of all the visible points from a specific point of view within the space. The form and size of the Isovist can change according to the location of the view point. The Isovist is thought to capture spatial-visual properties of visible space in a way that provides an alternative new approach for the description of the physical environment as compared to the previous approaches. This is because each point in space has unique geometric relationships with its surroundings, thus defined as having individual and specific properties (Benedikt, 1979).

2.2 The Concept of Isovist: First Applications

Benedikt associated the concept of Isovist with behavioral and cognitive studies in architecture through linking it with the cognitive model of Gibsn. He considered the size and shape of the Isovist as measures for the potential visual sense of the observer from a certain view point. For him, the measure of the size of the Isovist approximates the available potential size of the information at the point within the space. Therefore, it is possible to measure several sensory and cognitive factors and to predict the spatial behavior by using certain numerical measures related to the Isovist shape and size. The Isovist was linked to a number of attributes of formal environment such as privacy, control, defense, complexity, spaciousness and surprise by describing the behaviors of people in the environments that show those attributes depending on the size and shape of the Isovist (Benedikt, 1979).

2.3 The Concept of Isovist: From 2D Isovist to 3D Isovist

After twenty years of Benedikt work, Batty was able to calculate and represent the two-dimensional Isovist Fields and to develop statistical measurements that could visualize the spatial attributes and reveal their ability to give an interpretation and meaning of architectural and urban morphological differences. For example, those measures were invested in the description and analysis of the visual experience of walking in a specific street. The cognitive changes were connected to the Isovist properties and the perimeter of the Isovist is a measure of the feeling of spaciousness, compactness and sense of closure (Batty, 2001). In 2001 Turner & Others introduced a new methodology that was an extension of the idea of Isovist and sought to link it with social and aesthetic issues. This was achieved by integrating the concept of Isovist with the description of the space structure, making it part of the theory of Space Syntax for the analysis of the vision schemes, and then proposing a more general technique of Visibility Graph Analysis for points seen from multiple locations within the environment (Turner, et al., 2001). In their search for a way to measure human sensory perception, Fisher & Others attempted to analyze the three-dimensional environment. They developed the Spatial Openness Index (SOI), which can be considered as a 3D Isovist that represents a quantitative measure to describe three-dimensional spatial visual information. It measures the size of the free space that is probably seen from a particular point of view (Fisher, et al., 2005). Fisher and her colleagues also started a second attempt based on the LOS (Line Of Sight) measurement in a developed model to enable accurate visual analysis of a complex 3D environment and approach the Gibsonian visual space in which the quantification of the three-dimensional vision results from the interaction between the urban environment and the lines of sight (Fisher, et al., 2014). Koltsova et al. (2013) presented a 3D analytical tool for the urban environment that provides the possibility of continuous analysis, directly and dynamically, during the design and continuous revised of the analyzed models, which is not available in other ways. This tool is based on the Ray Casting Method for analyzing the vision of the surfaces from the given view point and thus calculating the best vision of the buildings from the streets. This tool was also developed using the Rhinoceros Modeling program (Koltsova, et al., 2013).

2.4 Measurements of the Three-Dimensional Isovist: A Recent Application

In order to study the Phenomenon of Salience in the built environment, (Bhatia et al., 2012) presented another attempt A Three-Dimensional Isovist has been invested to simulate the sensory cognitive ability of people as much as possible. They intended to provide quantitative measurement of Observed or Salient Sites using a fixed and objective method. The method was based on measuring the amount of the Space Salience using three-dimensional Isovist by calculating the value of space distinction using statistical methods that provide the amount of variance in the acquired data according to the following steps (Bhatia, et al., 2012). The construction of the Isovist was based on the development, as a first step, of Two-Dimensional Ray Casting so that the Isovist Rays cover the horizontal direction at a 360-degree angle and the vertical direction from (0- 180). This was not as traditionally known from (0-90), to ensure that the whole space is included into the analysis from floor-to-ceiling. Three-Dimensional Isovists were calculated for different points and multiple heights (to ensure that the representation of optical space is closer to reality and covers different age groups from children to adults and from tall to short human beings). The second step is to transform the Three-Dimensional Isovist data into Heat Maps. The transformation has been achieving through the development of an algorithm capable of generating automatically, and storing the lengths of rays as a data set in both horizontal and vertical directions, which are in the form of a matrix (360*180). The obtained data were statistically treated to generate the Thermal Maps. Each Thermal Map provides a summary of all Isovist data at various levels and heights of single point. Then a Principal Components Analysis (PCA) had been carried on. The aim was to shorten the data set dimensions of the large number of interrelated variables and convert them into a new set of variables, that describe the original data, but with the greatest variance. The resulting set of components is known as (component subspaces) (Jolliffe, 2002). Then, Salience had been calculated using two indicators of Angle and Entropy between the sets of components in terms of (distance difference) which are between (0-1). The values nearest to (0) are with the least difference, and the values nearest to (1) are of the greatest difference.

Indicator no.1: The Angle between Subspaces

As the first method to compare the Component Subspaces is the Angle between each two of them. The magnitude of Angle can be obtained by the calculation of their similarity factor using the equation (1), presented by Krzanowski in 1979, to measure the similarity factor between two different matrices (Jolliffe, 2002).

$$S_{PCA}(A,B) = trace(LM^T ML^T) = \sum_{i=1}^{k}\sum_{j=1}^{k} \cos^2 \theta_{ij} \quad [1]$$

Where (L, M) are the resulting matrices that include the first component, (K, θij) is the angle between the two components. The value of (SPCA) is between (0 and k). However, Bhatia study introduced a modification of the above-mentioned equation in order to allow the comparison of subspaces with different components. The previous equation was presented as an inverse of the value of the cosine angle between the components of two subspaces, whereas the value of k is the sum of the components divided by two (Bhatia & Chalup, 2013), Equation (2)

$$S_{GH} = \frac{K}{trace(L^T M M^T L)} \quad [2]$$

Indicator no.2: Entropy of Subspaces

In 1948, Shannon introduced the concept of Entropy as a statistical measure of the existing information content in a data set as getting information depends on the differences between the entropy of the data (Shannon, 1948). This link between Entropy (information content) and surprise and uncertainty is based on probability theory, as it is when there is a probability that the event will occur, it means that there is uncertainty about it, or that there is a surprise when the event occurs (Singh, 2013). As in equation (3), where EG is the information content, pi distance between components, m total number of distances between components.

$$E_G = -\sum_{i=0}^{m} p_i . \log(p_i) \quad [3]$$

Finally, carrying on a comparison between those components on the global and local level, the study results highlighted the possibility of using this method to detect the variances in the spatial synthesis for each point and identify the most noticeable and distinct locations when compared with the entire spatial synthesis of the environment.

3. Surprise as a Phenomenon for Detection Using 3D Isovist:

Surprise represents an important phenomenon of the built environment, whether architecture, urban design, interior design. It is a characteristics designers resort to in order to create a deliberate effect on the recipient. In architecture, Surprise is an effect that designers aim to produce so as to make their products evoke exceptional feelings and experiences when they use forms and spaces that prompt the recipient to notice and stand in contemplation. Frank Lloyd Wright, for example, achieves Surprise in the Waterfall House by adopting a strategy to reach the house through winding paths that wind through a thicket of trees that barely penetrates the sun rays, and suddenly the white horizontal lines and planes of the house emerge within the natural context of the vertical trunks of green-leaved trees in spring yellow in autumn (Rasmussen, 1964). Surprise, also, takes an important role in the urban experience in addition to fun, mystery and irregularity (Stevens, 2006). As for the experience of designing Urban Scenes, a (Drama of the Unexpectedness) emerged when natural scenes suddenly unfold while walking around the buildings, stimulating the pleasure of the passersby through visual contrasts or/and changing levels in order to generate a shock or surprise (Gassner, 2013). In fact, what gives the experience of the unknown in the urban environment its attributes, is the element of surprise and pleasure, as well as the shocking diversity that depends on many factors (Lehtinen, 2015). Previous studies indicated that Surprise is one of the built environment affective qualities that resulted from linking the affective responses to the specified physical characteristics of the built environment which work as stimuli. Qualities such as spaciousness, pleasure, containment, closure, excitement are other examples of the affective qualities of the built environment. Experiencing the built environment affects the emotional state of the human being through the formation of the emotional evaluative response (Affective Response) that is directly related to the physical-space environment, as it results from the continuous interaction between his activities and his environment. In spite the fact that this experience involves many processes of sensory and cognitive perception and may differ between individuals according to personality, social and cultural experiences, associations and biological differences, yet there are common denominators in their emotional responses (Nasar, 1994). This means that the built environment can have specific emotional/ affective qualities that it acquires when its physical features become stimuli the experience of which will result in specific emotional or affective responses. On the other hand, previous studies have presented several theories to explain the phenomenon of Surprise, most notably the theory based on the amount of information contained in the built environment per unit time. The environment with the highest rate of information is the most influential in the emotional/ affective experience. Both (Russel and Mehrabian) determined the rate of information through novelty, surprise, and complexity, which are related to the amount of number and changes of the stimuli. While (Wohlwill), who depicted the environment as a main source of sensory information, identified basic factors capable of increasing information, which are Variety, Novelty, Complexity, Contrast and Surprisingness (Schweizer, et al., 2006).

4. Research Problem, Objective and Methodology

The critical review of the studies on Three-Dimensional Isovist highlighted that it can be used to describe the built environment attributes associated with people's behavior. Therefore, the following question emerges: As an alternative to the real experience of spaces and without using the conventional techniques, is it possible to use Three-Dimensional Isovist to detect and predict the phenomenon of Surprise in architectural artifacts. The main objective of this research is to test the relevance of the Three-Dimensional Isovist for the detection and prediction of the Surprise phenomenon in architectural spaces. It aims to present a way to describe the experience of Surprise in Architecture on the one hand and to evaluate it in new designs on the other. The research intends to provide detailed knowledge on this issue. To achieve its objective, the research adopted the following tripartite method; Part One includes the following stages: (1) Determination of the context for the 3D Isovist to apply, calculate and measure. (2) Generation of a parametric environment needed to carry on the measurement of 3D Isovist, Export the resulting data to statistical programs that are, specifically prepared, to summarize them automatically, Conversion of the 3D Isovist data into 2D Heat Maps, Carry on a Principal Components Analysis, Calculation of the Angle and Entropy between the principal components, and finally, calculation of the Surprise value. In order to validate the results achieved in Part One, part two includes the following stages: (1) Introduction of virtual reality as a technique proposed for the validation experiment. (2) Definition of the experiment participants. (3) Definition of the experiment procedures. Finally, Part Three includes the following: (1) Discussion and analysis of results. (2) The conclusions achieved on the relevance of 3D Isovist for the detection and prediction of Surprise phenomenon.

4.1 Surprise in Islamic Architecture: The Research Context

A review of previous relevant studies reveals that Surprise is not a new concept as there are many references to the association of Surprise with Architecture throughout its long history. For example, Urma pointed out that there is an element of surprise in the Greek civilization which was resulted from its principles relied on in their designs. The organization, movement, surprise, and the great expressive power of the components of the successive scenes, in Greek Cities were achieved during the movement of the receiver in the site. The element of Surprise appears on the site in various ways, including covering the theater by the temple, and while moving through the winding streets around the temple, the theater appears suddenly (Urma, 2008-2009). Castex described the feelings of entering the Pantheon as causing the old visitor a feeling of complete surprise because of the huge size and light that fills the dome (Castex, 2008). Levy talked about the aesthetic-formal standards of the Middle Ages and the Renaissance urban squares, one of them was the element of Surprise stimulated by narrow streets and crooked streets that provide moments of Surprise when the pedestrian reaches the end of the road (Lévy, 2008). In Japanese Architecture, the gardens have been designed in a way that surprises the visitor, as a path of stones is usually used at the edge of a lake, where the visitor focuses his eyes on the path he is walking in and suddenly arrives at a special view or a sudden element in the garden or to a narrow path between trees or using the technique of hiding and revealing scenes, as the path gives a hint about the scene, then hides it and then appears suddenly, while helping the plants to achieve Surprise due to their seasonal changes (Locher & Simmons, 2010). In addition to the above-mentioned contexts, Islamic Architecture has been described as containing the element of Surprise provided by the kinetic experience within its urban and architectural space, as one moves from the narrow and dark space to the sudden wide space (Foroozani, 1991). This can be seen in particular in the Ottoman Architecture at the level of urban and architectural spaces and details (Erzen, 1991). Mamluk Architecture was distinguished by the use of transitional spaces and broken entrances in public and private buildings, and its space was described as surprising, as it presents a space experience that reveals little about the interior and was isolated inside the building from the outside in an experience different from the buildings in previous periods (Al-Harithy, 2001). Whereas in the late Mamluk period, the sites of new construction were relatively small and irregular, which provided surprising scenes at the urban level (Jarrar, et al., 1994). Finally, a description of the city (Toledo) and its effects on the visitor through mechanisms that achieve Surprise, such as the sudden discovery of small triangular places around the corner in small streets, the sudden discovery of large closed places after passing through narrow streets, and the sudden appearance of nature in all its forms (Salat, 2010). The current research has chosen Islamic Architecture a context for testing the hypothesis that the 3D Isovist is a relevant tool for detecting the quality of Surprise within the architectural artifacts. A sample of nine schools of three groups representing three Islamic periods was selected as each group consisted of three schools, which in turn represented a specific Islamic period of architecture The sample covers each of the Seljuk period, including the Masoudiya school, Al-Burjia and the twin minarets, the Ayyubid schools, including Al-Firdaws, Al-Zahiriyah and Al-Kamiliya schools, and the Mamluk period schools, including the Sultan Hassan School, Al-Zahir Barquq and Al-Ghuri.

4.2 3D Isovist Calculations of the Research Cases

In order to invest the 3D Isovist as a tool to detect the Property of Surprise in the sample cases, the current research carried on a methodology with the following steps:

Step One/ Building the Three-Dimensional Model for the Schools under Study. This step included the following procedures:

1. Drawing AutoCAD Two-dimensional plans for the nine cases/schools.
2. Drawing AutoCAD Three-Dimensional models for the nine cases/schools.

Step Two/ Determining the main points for which 3D Isovists are required in each case under study.

As the application of 3D Isovist is intended to imitate, as closely as possible, the human perception capacity, the positions of those vantage points are proposed or expected, by this research, to be located on what may be called the Most Probable Path that is the path most likely to be taken by the user in the building / school. To define this path, the notion of sequential vision was adopted to determine the most probable path on which potential visitors' move. This stage included the following procedures:

1. Compositional Analysis which includes:
   - Determining the basic functional components of the school.
   - Determining the principal spaces and neglecting the service and residential parts thereof.
   - Locate the main school entrance.
   - Determining the shapes of basic components and their location in relation to the entrance to the school.
   - Determining how to enter the building and the transitional relationship of the entrance to the school spaces.
   - Laying out the plan in a way that ensures that the entry threshold is perpendicular to the direction of movement (angle 90).
   - Point (0, 0) is the starting point of the path.
2. Syntactical Analysis which includes:
   - Conducting visual analysis and finding the values of spaces integration to determine destinations and arrange spaces according to their value. The highest integration value represents the most likely destination for visitors.
   - Performing the visual analysis and finding the visual steps (to determine the places where the visual step change occurs) for determining the thresholds and fixing them on the path.
   - Conducting axial analysis to obtain axial integration, which indicates the potential visitor movement.
3. Defining of the Most Likely Path that the visitor will walk, which include:
   - The possible movement path was recorded from the entry point (0, 0) using the (Walkthrough) tool in SketchUp program. This enables the user to move within the drawn model in a way that simulates the real human movement at a height equal to (1.68 m), which is an average height of the human eye, by (Plugin (Su Animate)).
   - This path was recorded at specific points and stored in an (Excel) file in the form of (x, y, z) coordinates for the most likely path steps.
   - The path is plotted as a continuous line based on the coordinates obtained from the relevant analysis.
   - The resulting path was divided according to the following procedures:
     - Determining the reversal points in the visual-motor step (thresholds) to ensure that they are included in the analysis. This divides the path into several straight lines.
     - Dividing the resulting path segments into points using the command (Divide Distance) within the Grasshopper algorithm and determining the maximum distance between two points (1.5 m) that corresponds to two steps for a normal person.

The following section shows the analysis carried on (Al-Ghuri School) as an example for the whole nine schools under study.[1] Figures (1) & (2) show the ground floor plan of Al-Ghuri School, while Figures (3), (4) and (5) shows different images of Al-Ghuri School.

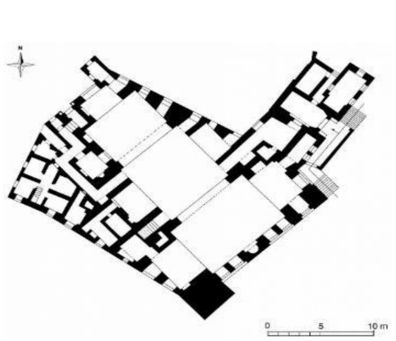


Figure 1: Al-Ghuri School Main Floor Plan

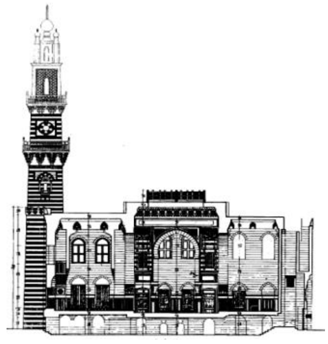


Figure 2: Al-Ghuri School Section

Figure 3: Al-Ghuri School Prayer Ewan

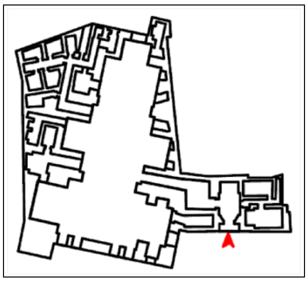
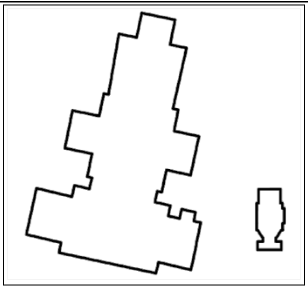
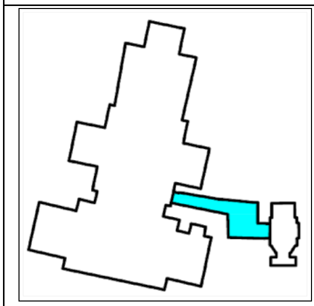
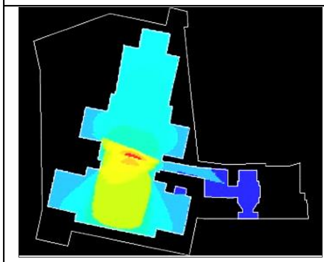
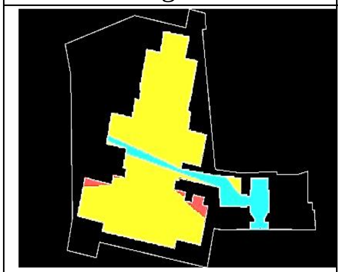
Figure 4 &5: Images from Al-Ghuri School

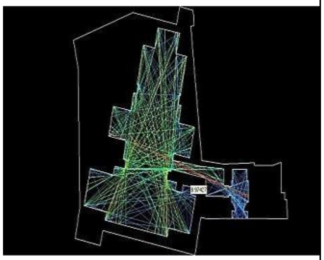
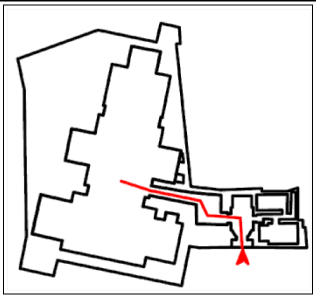
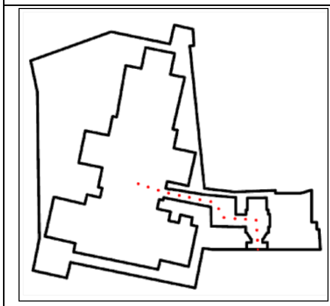
Also, the detailed analysis of Al-Ghuri School according to the steps (One & Two) mentioned above are shown in Table (1)

Table 1: Analysis Procedures of Steps (One & Two) for Al-Ghuri School

Analysis Procedures			Analysis Levels		
	Courtyard	Entrance	Principal Spaces	Components Analysis	
	Ewan	Vistible			
		Dargaa			

[1] See (Al-Moula, 2017) Study, to review the analyses of the whole cases of research sample

	Defining the Principal Entrace Placing the plan so that the access threshold is perpendicular on the direction of movement path Fixing the Point (0,0) at the Threshold of Entrance as the Path Start Point	Defining the Entrance and the Path Start Point		
	The Plan is Cruciform with Principal Courtyard and Four Ewans The entrance space is far away from the school spaces	Spatial Components		
	The School is isolated and hidden from the outside space There is a transitional space linking the entrance with the school spaces The transitional space controls the access to the school and the movement of visitors	Transition between the outside and the inside		
 Visual Integration Diagram	The Courtyard is the main destination as it is the most spatially integrated space	Destination Definition		
 Visual Steps Diagram	No. of Thresholds= 4	Thresholds	Syntactic Analysis	2

 Axial Integration Diagram	Patterns of the likely movement paths for the users	The Likely Movement Paths		
	The path is represented as a series of coordinates (x, y, z) Using the too(walkthrough & SU animate) within Sketchup The most likely path as drawn in AutoCad	The Movement Path Drawing	Defining the Path with Segments	3
	Using an algorithm written specifically for this task, the path as divided into 16 segments/ points, with a distance of 1.5 m between each two points	The Path as Segments		

Step Three / Measuring the 3D Isovists for each of the nine schools according to the following procedures:

1. Calculating the 3D Isovists:
   In order to calculate the 3D Isovists for the research cases, the current research introduced a methodology for generating the 3D Isovist using a (Grasshopper) algorithm within the parametric environment. The algorithm written by the researchers is based on the idea of (Bhatia, 2012), in addition to the capabilities provided by (Grasshopper). The 3D modeling program has been prepared using components available within the algorithm (Component Built-in Grasshopper), as well as components developed by researchers available on the Food 4 Rhino (1), a site that provides applications that can be added to (Rhino) and (Grasshopper)[2] (Figure 6). The 3D Isovist generation was based on the traditional Ray-Casting technique to represent the scene visible by a person standing at a certain point and at a certain height (H). It was represented in the form of rays emanating from a specific point and at a specific height to cover the scene as in the horizontal direction and at an angle of (360°) in full, in addition to the scene in the vertical direction and at an angle of (0°-180°). The basic idea of generating the 3D Isovist is based on generating a ball that simulates the visible visual field of the human being,

[2] For more details, refer to (Al-Moula, 2017) Study

and then using the Ray-Casting technology to calculate the lengths of the rays after hitting the obstacles. Therefore, the ray ball was generated in two steps; the first is to generate a semicircle of rays in the vertical direction with a number (180 rays) to ensure that the angle between each ray and its neighbor is (1°), and the second step is to copy the semicircle in a circular way starting from the point in the horizontal direction with a number (360 rays) to ensure that the angle between each semicircle of rays and its neighbors is (1°). Thus a full sphere of rays emanating from one point is formed with a number of rays of (180 * 360 = 640000 rays) (Al-Moula, 2017). It is worth noting that for the Ray-Casting technique, the ray stops when it hits an obstacle, and is linked with the ball of rays that has been generated, so that each ray in it becomes an “Isovist Ray”. Therefore, specifying obstacles is to be considered, and determining the maximum distance required for the calculation. The first is to the borders of the building when dealing with windows overlooking the outside, thus using the (BLIs) method. (Figure 7). The second includes the transgression of the rays to the boundaries of the building (the ray reaches its maximum specified length) when dealing with internal openings and the courtyard), thus the use of the (FLIs) method. (Figure 8)[3].

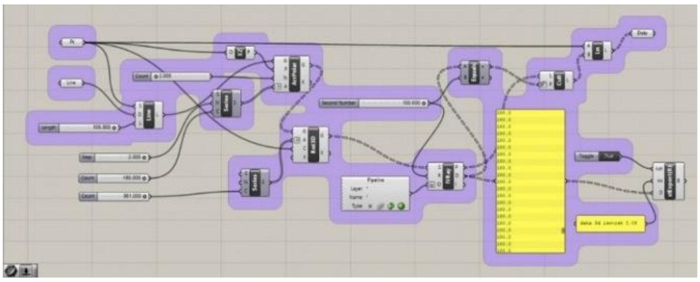


Figure 6: The Algorithm written by the Researchers for Calculating 3D Isovist Generation

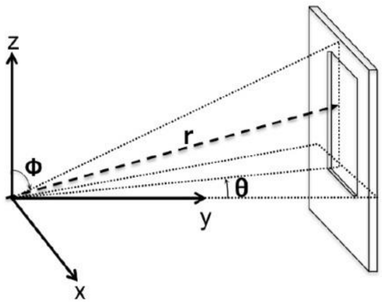


Figure 8: FLIs Method (Bhatia et al., 2012)

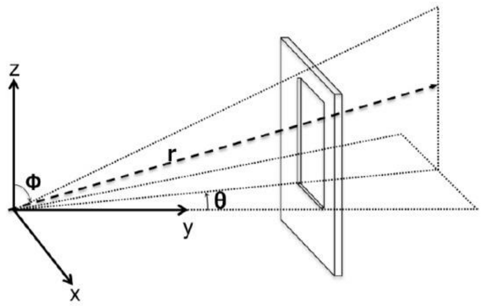
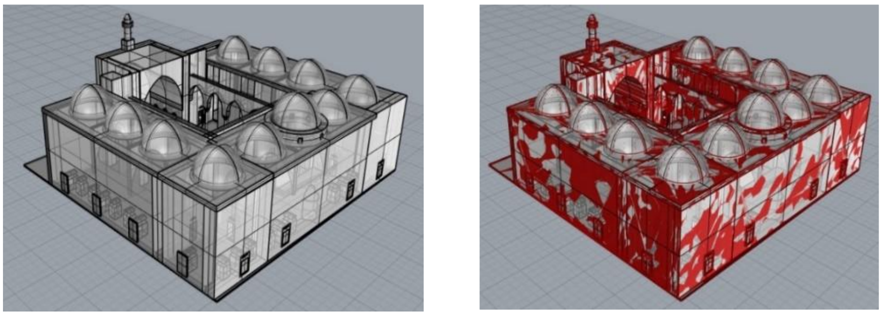


Figure 7: BLIs Method (Bhatia et al., 2012)

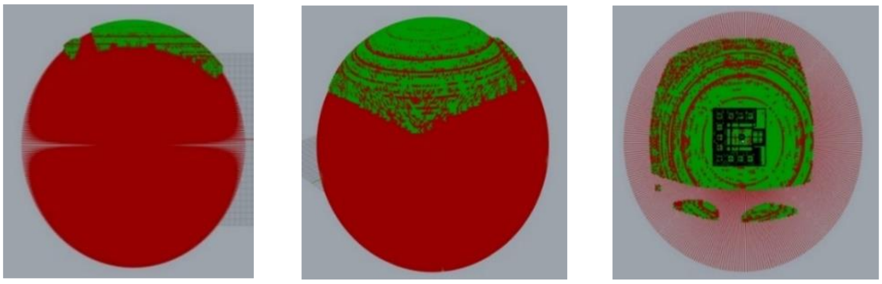
The algorithm applied for all points representing the heights to be calculated, so that the values of the three-dimensional (3D Isovist) of a certain coordinate with multiple heights are obtained: (1.28 m, 1.48 m, 1.68 m, 1.88 m, 2.08 m). Consequently, the 3D Isovist data for the specified path points were obtained by applying a written algorithm to calculate the 3D Isovist automatically for the coordinates of (specific location) at five heights (the operation took for one point twenty minutes, and the entire process of Al-Ghuri School took five hours and twenty minutes), the process was repeated for all the points of the path, the data were stored and statistically summarized (Figure 9).

[3] For more details, refer to (Bhatia et al., 2012) Study



Import the 3D model within the software before applying the algorithm

Applied the algorithm, all the model surfaces are identified as occluding surfaces for Isovist rays



The resulting ball rays from the application of the algorithm (the green-colored section represents the rays that did not meet any obstacle and completed its full path and recorded a length of rays representing the length of the full ray was entered), while rays which did not appear in green, has encountered an obstacle and recorded a length of rays representing the length of the ray from the point of view to the obstacle surface that intercepting its path.

Figure 9: Application of the algorithm to get the data used for 3D Isovists calculations of Al-Ghuri School

2. Preparing the Two-Dimensional Heat Maps:
   The 3D Isovists data has been dealt with statistically to summarize the resulting matrix (180*360). This was achieved by first: calculating the variance of the values and making statistical summaries of the single coordinate. The result is a matrix of (1) row and (360) columns. By the compilation of the statistical summaries of the five heights of the specified single coordinate, the result is a matrix of (5) rows and (360) columns. This resultant matrix represents a Heat Map. Using Matlab, the preparation of the 2D Heat Map of each coordinate provides a specific visualization of the data as the rows represent the values of different heights and the columns represent the 3D Isovist values summarized over angle (360°). The gray gradient was selected to express matrix values, as the white represents the highest value (the maximum ray length) and black represents the lowest value (the shortest ray length)

3. Carrying on a Principal Components Analysis (PCA):
   For each Heat Map a Principal Components Analysis was carried on, using Matlab, to define the number of components (subspaces) that account for 95% of the variance in the data.

4. Calculating the Angle and Entropy between the Principal Components:
   Using Matlab, a specific statistical program was written to carry on the Analysis of Emanation by calculating the Angle and Entropy between the Principal Components Subspaces. It is

worth noting that the calculation of Emanation corresponds to the calculation of the property of Surprise.

5. Calculating the Surprise Value:
   To calculate the Surprise value associated with the Angle and Entropy for each point, a comparison carried on to count the total difference between angle and entropy values and their combination for each point with each other and their relationship with all the points of the most likely path points, to get the local and global Surprise. The value (1) represents exact difference and (0) represents the exact similarity.

4.3 Results Validation

In order to provide an objective validation for the obtained results on the possibility to invest the 3D Isovist for detecting the property of Surprise in the architectural artifacts, the research adopts a methodology based on arranging a spatial experience to which a group of respondents were subjected. In this experiment, a sample of people moved in the spaces of the study cases/schools, specifically, on the most likely or probable path that was identified in the first part of the research. Then they were interviewed about their responses regarding the feature of Surprise in the cases under study.

4.3.1 Virtual Reality: The Experiment Technique

Because of the difficulty of achieving this in real buildings for practical reasons, virtual reality technology has been invested to make possible for a sample of (34) people to roam in the spaces of the chosen sample on a path (the most likely path) that was specified (in the first stage), in a way that simulates reality, in order to get data on the participants' sense of Surprise. This step was accomplished according to the following procedures: After completing all the details of the three-dimensional model and drawing the path deduced from the first stage of the movement within the spaces it passes through. The path was made so as to be surrounded by two vertical planes at a distance of (0.5 m) from both sides in order to restrict the movement of the participants and to ensure the similarity of their experiences as a result of passing through the same scenes and in the same sequence to ensure the validity of the data obtained. In order to prepare the model for the purpose of using it in virtual reality, it was imported into the Unity 5.5.0f3 Program to build the model of the environment to be experienced. The two vertical planes surrounding the path were made to ensure that the participant does not feel restricted in his/her movement by using transparent materials within the program. The virtual reality camera has been placed at the start point of the movement path (0,0) at a height equal to the average height of the human eye 1.68 m and setting the viewing angle at [180 (-90, 90)]. Special care paid to the smoothness of the participant's movement when moving his head in during the experiment and activating the sound of the movement of the feet. The ready model (Prefabs) of the type (First Person Controller (fps)) was chosen to achieve these settings and activate virtual reality by checking the option (Virtual Reality Supported). SDKs Oculus is the virtual reality device chosen for the test. The final task included building the virtual environment model and storing it in the form of a game on the computer in the form of (exe) file to run it easily by simply connecting the virtual reality device with the computer connected to the internet and pressing the (play) button to perform the experiment easily.

4.3.2 Experiment Participants

The participants in the experiment were randomly selected from the students and faculty members of the Department of Architecture at the College of Engineering at the University of Mosul Their number was (34) of both sexes. The experiment was arranged as open; their participation was according to their desire. Figure (10)

Figure 10: Some of the Students who participated in the Experiment

4.3.3 Experiment Procedures

The experiment was explained to the participants as a measurement of human feelings during their experience of the architectural space in general without any mention of the subject of Surprise to ensure that the participant's feeling is not biased towards Surprise. The experiment was conducted according to the following:

1. The subject of the experiment was deliberately hidden. The goal of the experience was explained to the participants as measuring feelings related to the space experience in general.
2. A brief definition of the study case was given, including: the name of the building, the founder, the location, to which historical period it belongs.
3. The participants started to experience the building spaces using virtual reality, informing him of the freedom to experience the time and place.
4. The participants' words and behavioral changes, if occurred, were recorded using a camera that captured the entire experiment. The camera was placed in a hidden place to achieve spontaneity and unbiased answers. At the end, the participants were informed of the matter to obtain their consent.
5. The questionnaire form was presented to the participants. They were asked to answer the questions and they were given the freedom to answer and assess their feelings while experiencing their movement on the specified path passing through the selected study case spaces.
6. A direct interview conducted by the researcher and the participants, in which a tape of pictures of the scenes, they passed through during their experience was shown. Participants were asked to answer the questions of the questionnaire. They were requested to access the sites that carry the feature of *Surprise* and their evaluations. The surprise positions were obtained for the study sample as the participants' feeling of surprise was measured using the Likert scale.
7. These procedures were repeated for all study cases.[4]

[4] To find out more details on the other cases under study, The Study of (Al-Moula, 2017) may be reviewed.

4.4 Results Analysis & Discussion

1. Reading the Table (2), Table (3) and Table (4) together, the results of the *Angle* of the *3D Isovist*, showed a difference in value between the *Surprise* moments as compared to previous location in all cases investigated. The highest value was found in the Vestibule of Sultan Hassan School, while the lowest value was at the threshold of the Mausoleum of Çifte Minareli School. The results of the *3D Isovist Entropy*, show a difference in value between the locations of the *Surprise* moment as compared to previous location in all cases investigated. The highest value was at the threshold of the Entrance of Mesudiye School and the lowest value was at the threshold of the Mausoleum of Al-Firdaws School. The results of the *Angle* and *Entropy* of the *3D Isovist* (combined), show that there is a difference in value between the location of Surprise moment as compared to the previous location in all cases investigated, the highest value in the threshold of the Courtyard of the school of Al-Ghuri, the lowest value was at the threshold of the Courtyard of Al-Kamiliyya School.

Table 2: Surprise in Al-Ghuri School as Calculated by the 3D Isovist Indicators (Angle, Entropy & Combined)

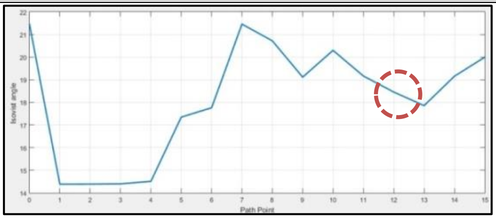
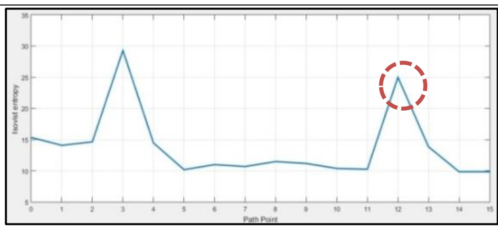
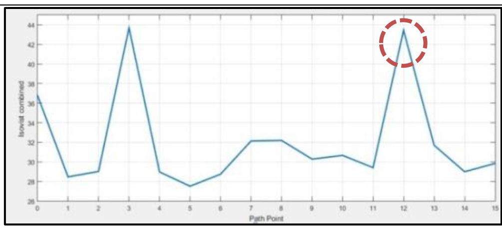
	Indicators	Surprise Values Recorded for the Most Likely Path Points
1	3D Isovist Angle	
2	3D Isovist Entropy	
3	3D Isovist Combined Angle & Entropy	

Table 3: Heat Maps of the Al-Ghuri School Surprise Points and the Corresponding views seen by Participants[5]

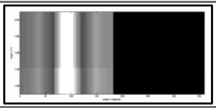
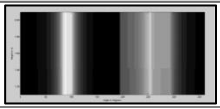
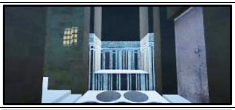
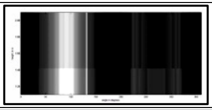
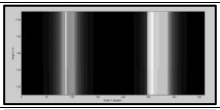
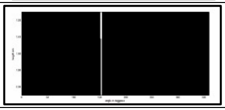
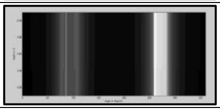
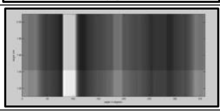
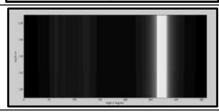
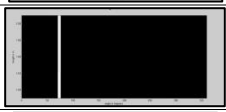
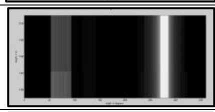
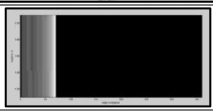
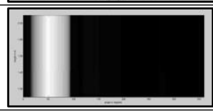
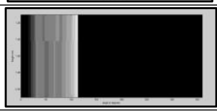
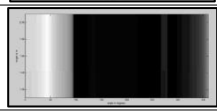
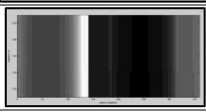
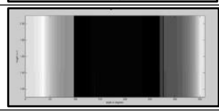
	View	Heat Map for 3D Isovist		View	Heat Map for 3D Isovist
0			8		
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		

Table 4: The Property of Surprise of Al-Ghuri School as Measured by the Participants and the Corresponding Related 3D Isovist Indicators

	Era	School	No. of Surprise Points	Surprise Value	Entropy	Angle	Combined
1	Seljuk	Mesudiye	3	4.88	0.6021	0.3421	0.2155
		Buruciye	21	4.88	0.3776	0.5580	0.0317
		Çifte Minareli	43	2.82	0.0672	0.0160	0.0500
2	Ayyubid	Al-Firdaws	8	4.35	0.0720	0.0507	0.0320
			11	4.59	0.0431	0.3275	0.1766
			41	4.47	0.0297	0.3741	0.1412
		Al-Zahiriyya	32	4.85	0.3595	0.3967	0.1056
		Al- Kamiliyya	9	4.94	0.2731	0.3880	0.3093
			14	4.06	0.2218	0.2781	0.0109
			24	4.62	0.1084	0.6066	0.2992
3	Mamluk	Sultan Hassan	17	4.94	0.1570	0.7077	0.1328
			25	4.94	0.2932	0.1884	0.1166
			37	4.82	0.3602	0.2983	0.0791

[5] To see the Heat Maps of the other cases of the research sample, the Study of (Al-Moula, 2017) to be referred to.

			83	3.91	0.2225	0.2864	0.0146
		Barquq	9	5	0.4450	0.3367	0.1764
			19	4.94	0.2678	0.3279	0.0554
			34	3.97	0.3556	0.1979	0.2706
			43	4.21	0.2705	0.1558	0.0636
		Al-Ghuri	12	3.76	0.5902	0.0384	0.3231

2. The study variables were analyzed according to the simple linear regression to calculate the correlation between the independent and dependent study variables where the analysis showed that there is a strong positive relationship between the Angle of 3D Isovist and Surprise as the correlation was (0.793**) at a level of significance less than (0.05). There is a strong positive relationship between the Entropy of 3D Isovist and Surprise as the correlation was (0.586) at a level of significance less than (0.05). There is a medium positive correlation between the Angle & Entropy of 3D Isovist (Combined) and Surprise as the correlation was (0.468) at a level of significance less than (0.05).

4.5 Conclusions

The discussion and analysis of the results showed that the indicators of the 3D Isovist were the most closely related to the features of Surprise, and Angle of the 3D Isovist was the most effective indicator on Surprise locations. This conclusion represents an experimental support of (Bhatia et al., 2012) study on the capability of the 3D Isovist Angle in capturing the Salience locations in the built environment. Also, this conclusion represents a new contribution in this field, as the above-mentioned study did not calculated sites Salience by empirical measurement. The 3D Isovist Entropy is the second factor in Surprise production. This conclusion represents an experimental support of (Bhatia et al., 2012) study on the capability of 3D Isovist Entropy in capturing the most Salience locations in the built environment, this conclusion also represents an addition of current research in this field, since the above study did not approach the study of Salient sites with empirical measurement.

Also, the analysis of the results supported the statement that 3D Isovist measurements provide a more accurate representation of the environment than 2D isovist as the associated Heat Maps provided a sufficient visual representation of the 3D Isovist which enables visual comparisons between different locations.

The results of the research supported the effectiveness of the algorithm for the generation of the 3D Isovist that was written which provides an objective and stable methodology to generate it automatically and at a relatively reasonable time (5 minutes per analysis). It can also be developed using colors that represent the longest ray of the Isovist which enables users to visually judge their results, as this algorithm can be developed and stored in a component that can be embedded within the Grasshopper associated with the 3D modeling program (Rhinocerose). This provides a ready-made parametric measurement of 3D Isovist for users during the design process, enabling them to know the characteristics of their visual designs and thus the possibility of modification before implementation.

Based on the above-mentioned conclusions, it can be finally concluded that 3D Isovist is an appropriate tool for detecting and predicting locations that involve a Surprise in existing environments on the one hand and evaluating the new designs, on the other hand, for the property of

Surprise, enabling the necessary developmental measures to enhance Surprise and modify the designs of the new built environments accordingly.

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