Isovist and Visibility Graph Analysis (VGA): Strategies to evaluate visibility along movement pattern for safe space

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Abstract. Quality of life is the main interest for people nowadays. Live in safe place with strong spatial economical will bring city liveable and among valuable assets in a city. Many innovations in town planning and design have been launched with great optimism over the years to addressing the people’s concern including crime reduction. High development in city nowadays will minimize the visual capability that can seriously cause fear of crime. Many studies proved that man-made and natural environment affect the visibility degree thus affect the crime. With the emphasizing of physical environmental such as contour, trees, and building height into the space visibility analysis could inherent the actual and real-time phenomenon. Isovist and Visibility Graph Analysis (VGA) could be methods to evaluate the visibility in environmental space. Thus, proposed approach which consider the evaluation of visibility in 2D and 3D with incorporate the movement pattern will allow the evaluation based on the human visual perspective.

1. Introduction

The sustainable of cities is the main interest for a planning process and designing the physical environment. Good environmental design and space will encourage high surveillance, social interaction as well as increase safety level. Human perception always be a major influence to be measured or quantified while visuality is often thought to be one of the significant human’s perceptions in environmental study. According to Jacob’s (1961) idea on “eye on the street”, explained the safest urban place is one that is continuously watched by human being. This idea then has been used as one of the principles in Crime Prevention Through Environmental Design (CPTED) called natural surveillance. Natural surveillance deals with location of physical features and people activity as well as to maximise the visibility naturally. Basically, resident will feel more secure in area consist of high surveillance for easier monitoring. [1] in the study on accessibility against crime believed the high integration of street will encourage number of user and create good visibility thus reduce crime.

Good visibility consists of better visual environment without any obstacle which inherent to unsafe activity. It is a crucial design process with rapid development nowadays especially in urban area where it can deteriorate the human visual. Physical feature and environment such as contour, vegetation, and building height and shape are among the contributor to affect. Study made by [2], recommended that contours of visual areas, useful and needed in the upcoming study of the relationship between humans and environments. [3] who conducted study on visibility and fear of crime using space syntax method urged to capture and consider the curvature of the surface. This recommendation supported by [4], who feel that environmental height or as the change in the topography of the surface, would allow researchers to more accurately in study of urban space in the future.
There is a long tradition of addressing crime in problem areas by removing vegetation to ensure the original line of sight designed do not get obscured over time. As a rule, the belief is that vegetation facilitates crime because it hides perpetrators and criminal activity from view. In visibility study, vegetation affects significantly in terms of height and density. Studied from [5] which focused on environment and crime towards the inner city of Chicago shows that the greener a building’s surrounding was, the fewer the crime reported. This finding supported by [6] where they admitted that tree canopy and crime index are correlated in waterloo, USA. According to [7] which conducted study to estimate the relationship between trees and crime in Portland, Oregon have found that several types, heights and sizes of tree can affected the human’s visual thus it can reduce or increase crime opportunity. Visibility should always be considered when designing or planning spaces. Some of man-made design would affect the sight line to be clear. For example, sudden changes of grade on walkways can also create the blind spot thus encourage the entrapment area. Other than that, street design and configuration also give an impact towards visibility [4],[8]-[11]. The street with high integration and connectivity can reduces the number of crimes. It shows that the higher integrated and connectivity of street will increase the number of street users, thus, increase the surveillance for that area and reduces the crime incident. Man-made and natural environment thought to give an impact to sight line. Thus, quantitative visual analysis should take part to give a good visual management and real-time process prior to real-life situation and environment. For this reason, this paper will explore on the use of visual analysis techniques of Isovist to promote safe space.

2. Isovist and Visibility Graph Analysis (VGA)

Isovist is an analysis to evaluate or measure the visual experience and analyse on physical body bound by closed polygon. It is an intuitively attractive way of thinking about a spatial environment, because they provide a description of the space ‘from inside’, from the point of view of individuals, as they perceive it, interact with it, and move through it [12]. This method is practically used for the analysis of architectural space and linked to pedestrian movement distribution. A set of visibility analysis can be constructed from a path to show experiences in human perspective as walking through the space from point of origin to a destination. Isovist could provide an alternative technique to evaluate space for representation of urban systems with GIS. In many studies, isovist analysis is limited to two dimensions in a horizontal plane [2],[13]. The integration of Isovist into GIS would stimulate study oriented towards visual analysis in different level. Spatial data analysis and 3D visualization capabilities in GIS will help to support urban studies thus provide different experimental analysis. Isovist is practically used for the analysis of architectural space and linked to pedestrian movement distribution for urban morphology research.

![Figure 1](image)

**Figure 1.** An example of visibility graph that showing the connection of nodes (Turner et al., 2001).

The integrating of analysis evaluation technique in space will provide important advantages from both systems and user point. Isovist which based on space syntax theory of spatial configuration will enhance
the functionality of GIS into urban morphology research. Rich of geo-referenced data and visualization analysis technique in GIS will promotes additional information in visibility analysis especially into human perspective. [14], then have constructed an undirected graph (figure 1) to connect all visible point in human scale grid called Visibility Graph Analysis (VGA). This graph is notated as a node and inter-visibility to linking all point together. The visual relationship can be calculated using different measure provided in the system.

The main topological measure for VGA that explain the inter-visibility of space based on urban morphology are clustering coefficient, global measure of integration and local measure of control. All the measure used depend on the neighbourhood size. Clustering coefficient is derived from the local configuration and calculate the degree of visible nodes from the observer. This measurement indicates the visual information, and any loses visual when moving. Next is integration which computes the mean shortest path from all nodes in the graph. The shortest path in graph is the number of linking nodes to be traversed to reach every node. The mean value shows the average value of all shortest path from the entire nodes. Lastly is a control that calculate the area of the neighbourhood with respect to the adjoining neighbourhood. This measure is suitable for large analysis of visual. Since, the VGA is suitable for evaluate visibility on path or movement, it can be used to promotes the safety since several literature emphasize that natural environment and man-made can affect the sight line.

Isovist and VGA is a suitable tool to evaluate the visibility on a movement pattern. Some of the researches have done the combination techniques to the indoor environment. [15] have done the experiment using that combination tool and compared to the behavioural data. From the result, it was found that several different descriptors can be used as measure describing the environmental complexity such as jaggedness, clustering coefficient, revelation and openness ratio. Thus, the combination of techniques was so benefit for the critical issues regarding behavioural. According to [16], using the combination of this techniques, the average number of turns and movement in space can allow to evaluate how the variation of volume influences the visibility. As the result from the study, it found that the movement and turn in space effect the visibility degree.

3. Visibility Analysis for Three Dimension Layout

Visibility analysis is a crucial process for designing better visual environment thus many techniques have come out. Study on visibility must consider on human perspective and real-time situation as to accurately measure. In the environmental crime studies, visibility analysis was used to identify the capability of human vision as a pedestrian, residents, driver, etc. to minimize the fear of crime as well as opportunity from being a victim. Study made by [17] which to identify the relationship between visibility and fear of crime has shown that low visibility degree reported higher levels of fear of crime. In addition, the visible distance was a significant element that affects fear of crime. However, the study was analysed with two visibility dimensions of visual connectivity of school layout. Fast development progress on digital software and technique can help to capture and analyse on height, density, and visibility degree including the features of building, terrain, trees and the social interaction.

Visibility analysis for human perspective should be made in 3D view. The visual significant of terrain is heavily influenced by the vertical dimension and distance. The capability of GIS to analyses line of sight in 3D such as viewsphere which proposed to measure the visible urban space quantitatively is a well-known enough even though the analysis has been conducted mainly in 2D before. A test case of Singapore’s urban space was conducted by evaluating the visibility of three alternative urban design scenarios and their potential impacts on the visual quality of open space [18]. As the result, the proposition that 3D visibility is more significant and effective as compared to 2D because the changes of height (z-dimension). This study has applied both directional and non-directional approaches to the mapping based on 2D and 3D indices.

According to [19], the easiest method to analyse the visibility in 3D by using the Line of Sight (LOS) technique in GIS. This tool can identify the volume of visible object from the observer to a target. With the integrate data of DEM, the evaluation of visibility could be more realistic base on the human perspective vision.
4. Elevation data for 3D mapping

By using appropriate data of Digital Elevation Model (DEM) such as Light Detection and Ranging (LiDAR), accurate model of layout can be created as well as analyst on visibility degree from a specific location. Many researches use the GIS and LIDAR technology for visibility analysis which based on the point clouds. According to [20], point cloud from LiDAR can improve the visualization in quantitative analysis on vegetation blockage. It has been proving that using the point cloud either by mobile or airborne LiDAR, the actual interpretation of vegetation physical can be drawn accurately for visibility analysis [21]-[23]. Thus, the analysis from a point cloud is the best way to find any obstacles between the driver, pedestrian, cyclist including physical environment of vegetation and man-made features.

5. Proposed approach

Based on the literature review before, about the visibility analysis technique and relation to the crime or safety purpose, a method on how to evaluate the visibility on the movement pattern for safety with relation to safety will be propose. Good visibility believes to reduce the fear of crime. To increase the visual capacity, the location or space need to analyse specifically to find out any feature that will minimize the vision capability. In an earlier theory of environmental planning, [24] noted human vision based on the following, (1) from 3 to 10 feet is in a "close relationship to us," (2) up to 40 feet "we can distinguish facial expression," (3) up to 80 feet "we can recognize a friend's face," (4) up to 450 feet "we can discern body gesture," and (5) 4,000 feet is the "maximum distance for seeing people." The idea of [25] “eye on the street” will be using to create the method on how to measure the visibility based on real-time and human-based vision.

To get the real-time situation for visibility analysis, 3D layout needs to develop so that all vertical height including man-made can be observed using the DEM and point cloud from LiDAR. Movement pattern also need to trace so that the visibility can be analyst on the path to as for real situation sight view. The visibility analysis using the GIS and Isovist with maximum vision boundary buffer of 450 feet (discern body gesture) have to analyst and integrated with an overlay 3D layout. Movement pattern will be used as the starting point of isovist to find out any features that affect to visual degree. From this analysis, the output of visibility degree needs to correlate with crime incident using statistical method.

5.1. Observation method for movement pattern

Visibility analysis for environmental crime must observed anything that related to a real-time situation. Thus, incorporate with movement pattern in this study is a good technique to know what is seeing by pedestrian. Based on Jacob’s idea “eye-on street”, where more people (eye) on street, the more surveillance will be in that location thus, will increase the safety level. The movement pattern should be observed on-site at every street and junction. Observations allow retrieving something that might be considered as an objective view of human behaviour in the built environment.

5.1.1 Gate Counts. This count usually helps to observe the pedestrian’s density and vehicle movement flow in urban layout. This technique allows researchers to collect data and represented in graphic or statistically. The method as show in figure 2, must be applied consistency at many locations that cover area under study.
5.1.2 Movement traces. This method is useful to tracking and mapping flow dynamics in specific area (figure 3). Green color in the map shows the movement pattern of pedestrian captured within several minutes while yellow point shows the location of people. Movement trace will help the researcher to understand the movement pattern from one location to another. The observer can collect and trace the pattern manually or using the other equipment (recorder) based on the area. Normally, observer will stand over in one location which maximize their vision and trace every 5 to 10 minutes (based on the people crowd) at several time interval. Observer also can capture the pattern by using drone to record the video on specific time and area based on needed. Every movement then will be mapping to see the pattern.

5.2. Measuring visibility for safe environment

GIS offer many analyses for visibility and most common tool is view dome tool. This tool which can found in CityEngine scene allow user to specified visible and non-visible feature in some extent. User can visualize visible and hidden area from an omnidirectional observer. Using the 3D layout, visibility for safety purpose can be analyse using this tool by set the limit of human vision to 450 feet in globe to identify how many percentages that observer can see from the starting point as shown in (figure 4). [28], have used dome visibility tools to identify 360 degree of the visibility from a single spot. Any obstacle within the globe that can blocking the view will be shown in red colour and anything that can be seen from the observer point will turn to green. The observation point can be move from one location to another and recommend testing on the traced movement path (pedestrian or vehicle). This technique must implement to see the relationship between visibility and crime in human perspective.

In environmental crime studies, identifying the ways for crime prevention always related to the spatial configuration. That is the reason of using the isovist-based visibility analysis to measure the visibility index. Isovist was use for visibility analysis in 2D and that is no doubt that, that is the limitation of the technology. However, with the needed of 3D to measure visibility for human-perception, the integrated analysis of visibility for Isovist into GIS is needed. Using the isovist, path and scan was the most suitable tools for studying the visibility and safety. Path analysis need to test on the movement pattern either pedestrian or vehicle. The values of visibility will dynamically be updating into the line-chart that was drawn across the viewport. However, scan analysis will allow to produce high resolution of isovist measure as shown in (figure 5). This tool will analyse the layout in 2D to identify in every angle which location is visible. [29] with the experimental test conducted to measure the visibility at Hans Hollein’s Monchengladbach museum. From the tested, several volumes of area are shown in several colour’s scheme. From red to blue, the map was notified the area with high accessible (red) to low accessible (blue). It has shown that the high accessible is much easier for the observer to see and visible.
6. Conclusion
Several strategies to analyse and evaluate the visibility on movement pattern are evaluated. Each method allows to extract the important spatial and topological information with 2D and 3D environment. The obstacle will promote some unsafe phenomenon thus increase fear of crime. That is why the evaluation of visibility is important to identify poor sight line. Studying the visible space for safety purpose must go wide with the interference of physical environment such as terrain, vegetation and buildings height. Building on related work of point cloud-based, show that it is still lack of integrate visibility analysis for urban spaces. The proposed approach which consider the evaluation of visibility in 2D and 3D with incorporate the movement pattern will allow the evaluation is based on the human visual perspective. Setting up the limit of human sight and height will make it the observation and measurement as real. Future work will investigate, the parameter of visibility that can influence the crime activity in urban area with the same visibility evaluation method and relate to the spatial location of crime based on the idea of [25], ‘eye on the street’.

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