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THE STATICS OF SPACE SYNTAX: ANALYSIS FOR STATIONARY OBSERVERS

DOI: <http://dx.doi.org/10.26687/archnet-ijar.v12i1.1282>

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Keywords

mosque layout; space syntax; architectural design; religious spaces.

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Abstract

Space Syntax is a set of techniques for the analysis of spatial configurations of all kinds including architectural designs. Traditional Space Syntax has been devoted to analysing dynamic views of an observer moving through space, which is the case in most building spaces. However, some architectural spaces are usually experienced from static viewpoints. Consequentially, the way this space is viewed has a significant impact on the spatial cognition and experience of the occupants. Examples of such buildings where the occupant may observe spaces from mostly static points of view are religious spaces such as mosque or churches' prayer halls. This paper presents an analysis of a typical "static space" in terms of its spatial logic. A typical configuration for a prayer hall consisting of a bilateral symmetry space with four columns is considered. This configuration is manifested in many religious buildings and is assessed using visibility graphs, axial lines as well as various isovist field properties and measures. This paper shows how the most basic alterations to the configuration of the plan can affect the spatial experience and cognition of the place. In addition, special Space Syntax measures that are relevant to the design of the static spaces are extracted and discussed as well as the consequences of an omni-visual observer of typical Space Syntax in comparison to the directional observer in a static space. The analysis presented in the paper has implications for both architectural designs of spaces with similar configurations as well as for research on Space Syntax focusing on stationary observers.

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INTRODUCTION

Space Syntax is an area of research that deals with investigating spatial configurations in an attempt to identify their logic and structure (Hillier 1984, 1996). Space Syntax is useful in describing and analysing patterns of architectural space at both the building and the urban level and it seeks to answer a number of questions including: (1) how can the configuration properties of spatial systems be measured? And (2) what is the nature of the relationship between the spatial cognition and configuration?

Given the advances in the theory and tools of Space Syntax, the spatial configuration of architectural and urban spaces can now be studied to sharpen the spatial cognitive experience. Moreover, it is evident that in recent years the development of reliable methods in studying spatial patterns has led researchers attempting to use Space Syntax as a tool to examine the cogency of design proposals in terms of functionality, which according to Hillier (2007) can be reflected in the flexibility, accessibility, safety and suitability of a structure to hold a varied range of activities and not just remain limited to one. The question remains however as to what particular aspects of architectural space affect the human behavior (Rana & Batty, 2004). It has been argued that spatial organization and hierarchy can reflect and mirror the unique characteristics of various societies (Mustafa & Hassan, 2013).

Traditionally, classic Space Syntax theory deals with the dynamics of people's movements through and with spaces. It further highlights the spatial traits with which designers are able to have a comprehensive and perceptual outlook at the narrative of a formation. Space Syntax can be also elaborated on as a tool for quantifying spatial patterns thus allowing for comparisons on mathematical and perceptual levels (Malhis, 2016). It captures user experiences and reflect on the visual, axial and compositional attributes within a complex of spaces. For simplicity, one of the main premises presented in this paper entails limiting the discussion to static observers that mainly experience the space from stationary points of views. The study presented here offers clues to visualization and interpretation of architectural spaces through a study of a typical prayer space, in which the observers are mainly stationary. How the most basic of design decisions can affect the experience of space is explained in terms of sacred spaces such as mosques, churches, and synagogues, where the psycho-religious experience that one encounters while engaged in religious activity is significantly impacted by the surrounding space.

The analysis in this paper is presented with the aim of helping architects to understand the implications of the spatial configurations of "static" spaces on the spatial cognition and experience of the occupants. Space Syntax is the calculative method of establishing an understanding of spatial configurations of any building through the lens of society and social interactions amongst users (Dawes & Ostwald, 1926). The study of Space Syntax focuses mainly on the relationship between configurations of spaces and users' behavior within these spaces (Mazouz & Benhsain, 2009). However, very few research studies focus on the influence of the space's geometry on users' behavior and experience. Many articles would only brush on the topic without reaching any level of depth on the interrelationship of the internal elements of the mosque and their relationship to the overall praying experience, as it likely would not be the focal point of the studies of the literature in this area. These studies, nonetheless, provide stepping-stones to the research at hand. There are many approaches used within the field of Space Syntax research. However, what these approaches lack is definition and accuracy when it comes to a specific point within a space. Hence, an alternative approach is suggested, intersection points. This method can be extremely beneficial when it comes to small scale, concentrated Space Syntax studies providing exact values of specific locations within a well-defined, compact architectural space. Ratti communicates some discrepancies within the field of Space Syntax for being that calculative

method (Ratti, 2004). It's a renowned technique used to analyze relationships between the built environment (physical) and social environment (meta-physical). Multiple attempts were made to quantify such relationships and only the field of Space Syntax was able to deliver such quantifiable measures.

Space Syntax is based on the use of computer techniques to analyse, but is not limited to urban configuration (Ratti, 2004). There are limitations of the axial map as the only input data to deduce a quantifiable measure for Space Syntax "is not to say that a more refined form of analysis... would yield even better results" (Ratti, 2004). This method may be reduced when speaking on an urban scale; however, speaking on a singular space scale would not be as questionable. There's always room for improvements to gain a deeper insight on the matter of the "social logic of space" with new technologies and more recent, reliable material sources (Ratti, 2004). In Hillier's response to Ratti's questionability of the simplistic nature of axial maps, which Ratti believes reduces its significance and accuracy, Hillier believed that axial maps are able to "work because they capture key properties of urban complexity in a simple way" (Hillier & Penn, 2004). While a number of issues brought up by Ratti indeed challenge the Space Syntax theory, it is evident from Hillier's work and other literature citing the impacts of the mosque geometry on behavior that the use of depthmap as the main tool is currently the main methodology for data collection and space analysis to further advance the contemporary mosque design. In the next section, we will discuss the prototypical space used for the analysis in this paper.

TRADITIONAL VS. MODERN "CONTEMPORARY" MOSQUE DESIGN

It is important to link Space Syntax to a historical context when speaking of religious buildings such as mosques. Mazouz and Benhsain discuss how historical constraints affect a common mosque's geometry. The study aims to articulate the similarities between the genetic and syntactic approaches to the architectural form and design of buildings with socio-culture significant and relevance (Mazouz & Benhsain, 2009). It capitalizes on the idea of an evolutionary model, one where the building shapes the users and vice versa. It is a model suggesting a relationship between behavioral and architectural systems. However, research mainly refers to architectural spaces rather than the influence of the behavior of users on these spaces as well as the influence of the geometry of these spaces on such users. This is also true of Chebaiki-Adli and Chabbi-Chemrouk's analysis of the Great Mosque of Algiers. The geometry and form of the mosque is discussed stating its simple, unchanged square form and the evolution of the space by "integrated spatial divisions" as well as spatial elements (Adli & Chemrouk, 2015). The conversation mainly is in spatial terms not space syntactic ones. Okuyucu evaluated 10 separate mosques in two separate categories studying the relationship between traditional and contemporary "i.e. Traditional and Modern". Historical mosques were defined within the scope of "Traditional Approach", whereas the structures which had been constructed by the attempt of being different by using modern material and technique within its own style and aesthetic, out of traditional concept, were defined within the scope of "Modern Approach"(Okuyucu, 2016). Little is mentioned on the impact of geometry on the internal functions, however, the focus was on the relationships carried on from the traditional to the modern in terms of new materials and innovative building forms.

A mosque by Sinan and a church by Palladio were compared in their research to one another on multiple levels, include syntactic and geometrical ones (Eilouti, 2017). Surprisingly, there were numerous similarities between the two building typologies. Geometrically, both shared similar proportions amongst other morphological arrangements (Eilouti, 2017). However, it lacks a connection between the morphology and geometry, and

human behavior and experience. The comparison may be “rigid” still focusing on architectural syntax rather than Space Syntax with relevance to user behavior. Therefore, there is a need to analyze the contemporary mosque internal geometry as related to human behavior as well. A very relevant study by Kershen and Vaughan discusses the physical context of social space, which is mainly geometrical configurations, however, on the scale of the ‘community’ rather than a ‘single user’. Othman and Mohamed conducted one of very few researches that communicate on the scale of that ‘single user’. It studies the influence of a mosque’s geometry and proportion on an aspect named speech intelligibility, defined as “where all speech sounds should be comprehensible irrespective of the position of the listener.” (Othman & Mohamed, 2012). The study goes in depth in the effects of the space’s geometrical configuration on only one of the aspects affecting user’s experience, which is sound, neglecting many other aspects that this research aims to analyze and discuss.

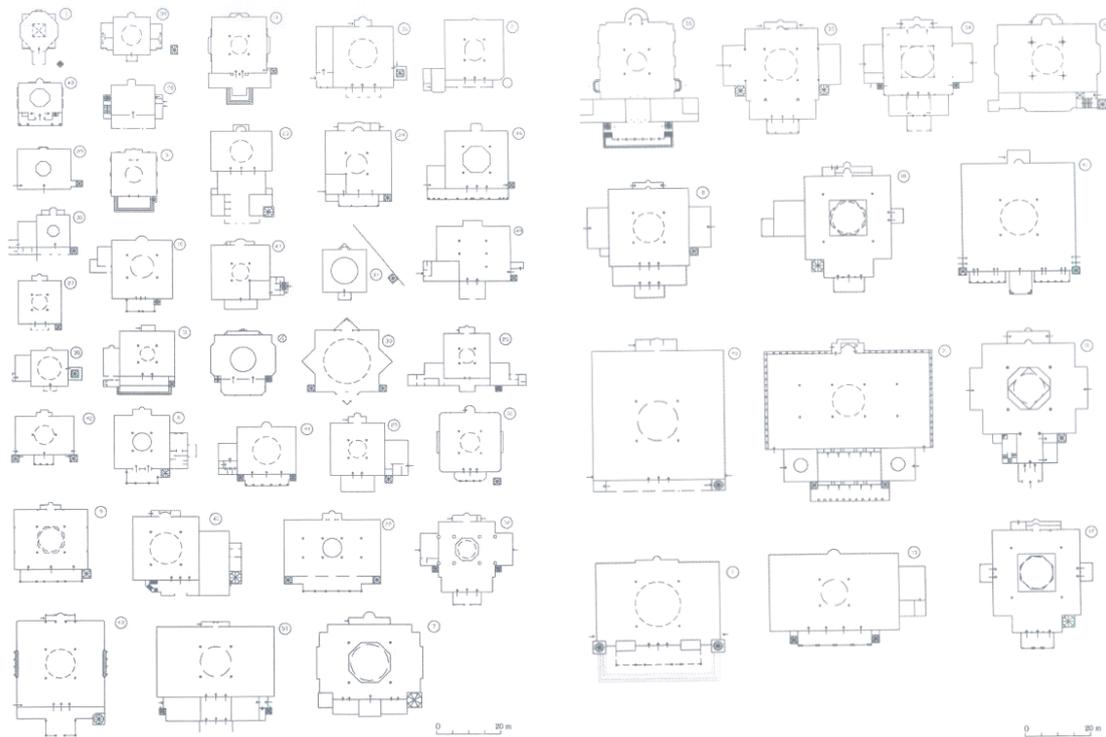
A PROTOTYPICAL SPACE

There are many configurations for religious buildings and it is a difficult task to concatenate all of their spatial designs into one prototypical space. Throughout history, the mosque has taken various forms from the hypostyle to the dome mosque. It is essential to break the mosque into spatial categories before attempting to analyze it (Aazam, 2007). The most important space in the mosque is obviously the prayer hall, which usually takes the form of a square and/or a rectangle so worshippers can line up in equally spaced rows during prayers. Accordingly, other forms of the prayer hall such as a circle or a hexagon are uncommon, as they will result in lines of unequal lengths. Non-rectilinear prayer halls do exist sparingly and may have taken these forms for other reasons; the circular Hagia Sofia in Turkey being the most notable since it was originally built as a church. However, in today’s mosques, there seems to be one particular configuration that is recurring; that is the bilateral symmetry space with four columns often carrying a significant feature such as a dome. Figure 1a shows shapes of several mosques built in the Gulf region within the last 30 years, while figure 1b shows the plans of a number of Greek cross churches, which also shows a bilateral symmetry space. In our discussion, we will focus on the mosque space with the essential configuration shown in figure 1c.

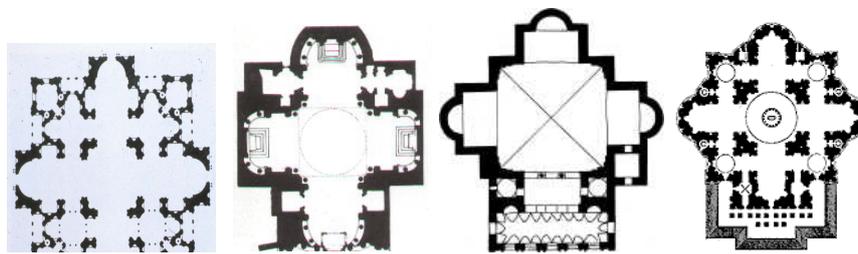
In addition to its religious role, mosques often play an important educational and social role affecting the overall design of the spaces throughout the years. . Both the ritual’s temporal and spatial activities including the five prayers helps in defining the spatial within a mosque (Aazam, 2007). Although the designs of these religious buildings have evolved throughout the years in terms of the morphology, size and program, the basic configuration of the prayer halls in mosques for example has evolved slightly over the years. Consider for example the typical mosque plan shown in figure 1c.

Configurationaly, the plan of the mosque is a simple modification to a basic square shape, where primarily wings have been added, followed by a set of four columns placed in the center. It is important to realize that there is always continuity in space when considering any modifications to the basic square primitive i.e. any three subjects are directly visible and accessible from each other in any point of the open square. This is what Hillier refers to as “we are together in the space”(Hillier, 1996). However, after the simple modification, belonging to the same space is not guaranteed. The degree to which this has changed can be measured, but the effect of various configurations alternately changes (such as the location of the columns and the size of the wings); in this sense, togetherness can also be assessed using Space Syntax as will be discussed.

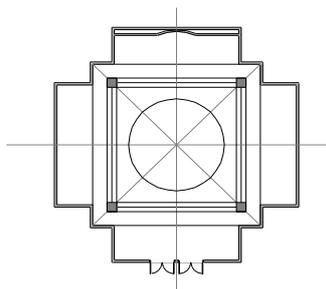




a.



b.



c.

Figure 1: Typical Plans of Modern Mosques (Source: A History of Architecture, SB Fletcher 1987).

An example of current literature examining the morphology, geometry, and syntax of two religious historic structures is a paper by Eilouti (2017) where a comparative analysis of Palladio's Il Redentore Church and Sinan's Süleymaniye Mosque designs in terms of morphometric and "morphosyntactic" were presented. In this paper, we see how these two

simple modifications to the basic square primitive can completely alter the perception of the space and we will study the effect that this configuration has on the awareness of the space. We will focus the attention on mosque designs, although the same treatment can apply to similar spaces such as that in the Greek Cross Church.

Notice that the plan has a center square, which is marked by four columns. Typically, these columns carry some sort of a structure to let in light in the form of a raised dome of clear storey windows. The columns not only serve a structural purpose but they also serve as “islands of refuge” or virtual sanctuaries in the open space of the mosque hall, where several functions are carried out such as Koran recitation or religious studying. In historical mosques, the columns would even serve as places of lectures, where a Sheikh or an Imam would provide his lectures to students as in the case of the Azhar mosque. Only prominent Sheikhs would be given the privilege of a column space and hence came the terminology of the “column sheikh” (a sort of a chair position in modern day academia).

The columns therefore serve more than just structural purposes and have a number of spiritual, functional and physiological purposes. Nevertheless, the existence of the columns in the middle of the prayer hall space provides some occlusion of the qibla and the Imam during public sermons where the entire congregation is required to listen and see the Imam. Qibla is the direction of Mecca where Muslims must face during prayer. Therefore, it becomes imperative to locate the columns in prayer hall to minimize occlusion and yet maintain the full utility of the column.

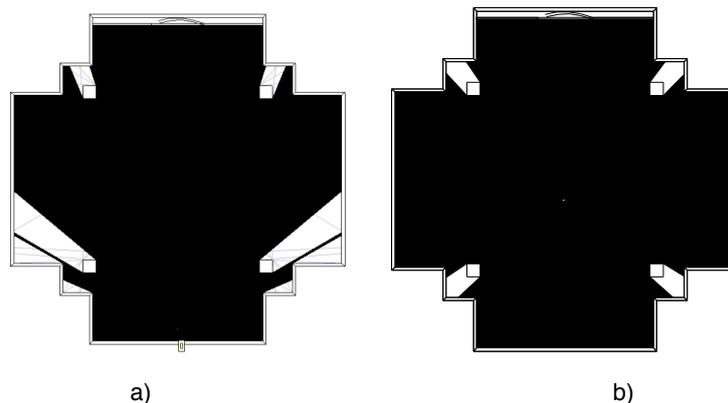


Figure 2: Isovists at Two Different Locations in the Prayer Hall a) At the Entrance, b) Close to the Center of the Prayer Hall (Source: Authors).

Furthermore, the mosque’s prayer hall is a unique space. It is for the most part a static space where movement is not significant but is mainly directional, i.e. the orientation of the worshippers towards the qibla is an essential part of the mosque cognitive experience. From that perspective, it is similar to auditoriums and theatres. However, the mosque commands more than just a public performance experience. While there are often lectures and sermons, there is also an equally important private spiritual dynamic, in that often worshippers are engaged in private religious worship such as reciting the Koran or religious reading. This requires a sort of secluded privacy within the vast openness of the prayer hall. Often there are also group activities such as “halqas” or religious groups. Seating is not pre-assigned or fixed. Time of sermons and activities is also ubiquitous and there are no predefined patterns of use other than the daily five prayers and the weekly Friday prayer. Otherwise, mosques are usually always open. These unique features of the mosque make it very interesting for Space Syntax analysis.



THE SPACE WITHIN THE SPACE

Spaces can be divided into two basic scales, large and small-scale spaces, as defined by researchers of cognitive perception (Egenhofer & Mark, 1995; Montello, 1993). Large-scale space is one that cannot be perceived from a single vantage point, while small-scale can. This leads to the idea of an isovist (or viewshed); the area visible from a location in a plan. Unlike the visibility structure, where the entirety of a configuration is visible, an isovist can be described as “as single –point visual field” (Malhis, 2016). We regularly recognize a large-scale space throughout our experiences in small-scale spaces. Figure 2 shows two isovists from two locations in the prayer hall of the mosque. In both cases, the isovist covers almost the entire area of the mosque, which may indicate that one can still perceive the room’s structure without any difficulty. The isovists, like small-scale spaces are continuous and interconnected, meaning that the space cognition is a gradual process. The speed and ease of space cognition is obviously dependent on the configuration of the larger space and may be studied through Space Syntax, as we will see here. The isovist of the Imam is of crucial importance. Optimally, the Imam should be able to see most of the worshippers during ceremonies and therefore the area of the isovist from the imam should be maximized.

Therefore, an important aspect of the configurations shown in Figure 1 is the directionality. One of the walls in a mosque has a special importance and this is the qibla wall (the wall facing Mecca). Similarly, the altar in Greek cross churches is usually facing Jerusalem. The directionality of the mosque as well as the fact that the space is observed statically most of the time makes the assumption of an omni-visual viewer, common in traditional Space Syntax analysis (Figure 3), incorrect. Alternatively, as shown in Figure 3 Space Syntax analysis in such space should be carried out on “half-isovists” or a fraction of them.

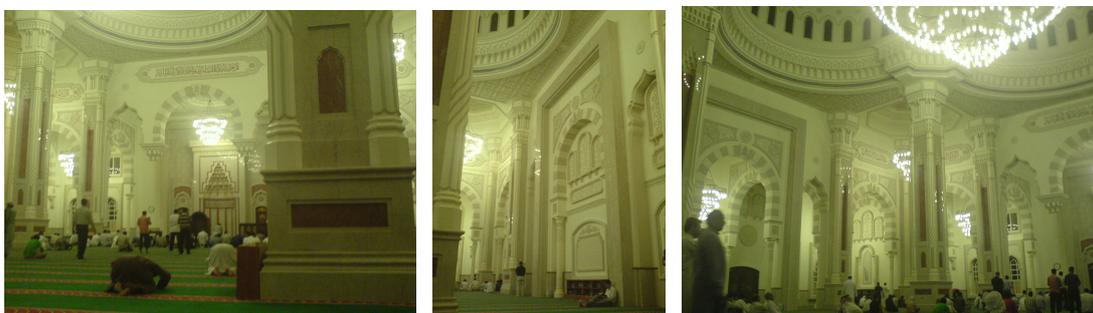
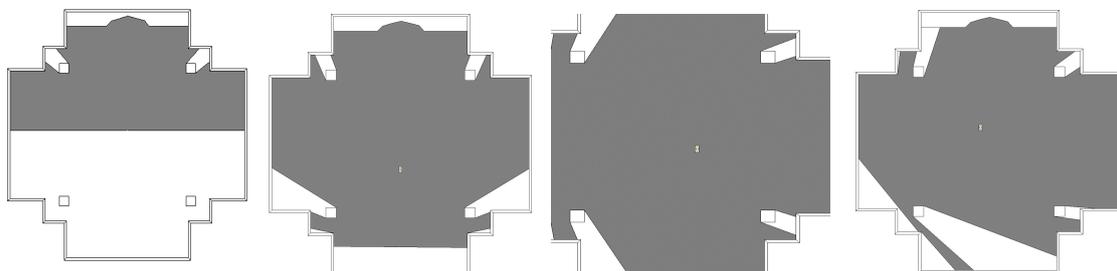


Figure 3: “Half-Isovists” and the Related Views from a Prayer Hall (Source: Authors).

Small-scale space awareness is essential for reasoning about large-scale spaces. Researchers have shown that the cognition of small-scale spaces must inevitably precede the cognition of large-scale spaces (Jiang & Claramunt, 2000). This active cognitive embodies a navigation learning process of the large-scale space. Unlike the case of historical mosques, the designs of modern mosques rely on basic shape primitives and

therefore, the navigation awareness is less of an issue in these modern mosques. Nevertheless, a significant portion of Space Syntax research deals with trying to define a set of finite individual small-scale spaces that fully represent the large space. Here the problem of partitioning a space into a number of convex polygons is essential. It is also believed that equilateral convex polygons can be used to portray a pattern within a plan (Eilouti, 2017).

A space is said to be convex if no line drawn between any two points in that space goes outside the space and that all pair of points within the a convex map is intervisible (Karimi, 2012; Malhis, 2016), i.e. a small-scale space. These convex spaces correspond to our intuition of two-dimensional spatial units (Hillier & Hanson, 1984) and directly affect our experience in the space. Here Hillier suggests that that any space should be divided into the “the least set of the fattest spaces that covers the system” (here fatness means area/perimeter ratio). This problem is similar to what is known as the art gallery problem (where for a hall with n vertices $\lceil n/3 \rceil$ guards have been shown to suffice). The question as what is minimum number of partition and even if such a partition can be uniquely specified has been studied extensively by researchers. (Peponis & Bellal, 2010) developed a way that gives a minimum partition but the question as to if that partition is uniquely specified in all cases is still open. One such partition for the mosque is shown in Figure 4 where seven lines are now needed (this is in contrast to zero for the basic square shape).

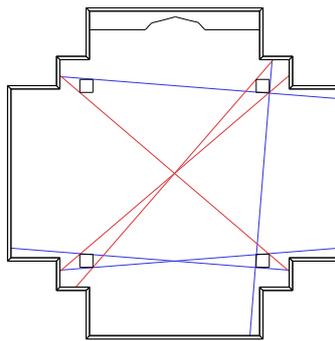


Figure 4: A Minimal Convex Partition of the Mosque Prayer Hall
 (Source: Authors).

The number of convex spaces is also affected by the configuration of the mosque. Figures 5 and 6 show the effect of moving the columns to the center of the prayer hall. As the columns are moved towards the center, the number of convex polygons needed is reduced. In contrast, as the size of the wings is reduced the number of polygons needed is increased. The latter point seems to be counter intuitive since we would expect that as the shape of the prayer hall moves back closer to the square the number of such convex polygons would decrease. However, due to the fact the small variations in the outline perimeter of the prayer hall this does not happen. This emphasizes that the number of the minimal convex polygons does not tell the whole story about the space.

Another kind of partition that would be of interest is what is known as E-partitions of the plan. These partitions divide the space into convex polygons, where if we remain inside the same vertices would be visible. These polygons are dubbed e-spaces and by definition are stable with respect to visual information concerning the vertices of a plan. This means that surfaces or parts of surfaces will not appear or disappear while one remains within these e-spaces. In other words wall end points or corners will remain visible when one stays within an e-space



(Peponis & Bellal, 2010). Similarly, every time we cross from over one of the dividing lines discontinuities will appear in our visual field.

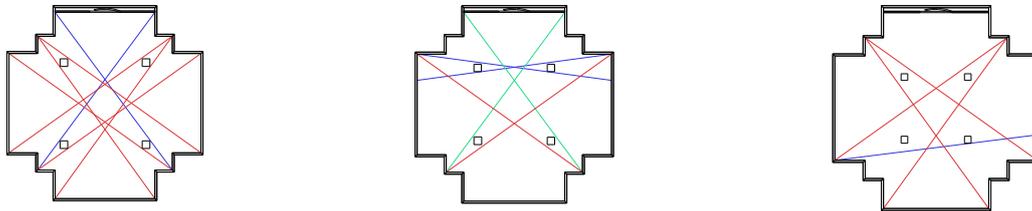


Figure 5: The Effect of Moving the Columns to the Center (Source: Authors).

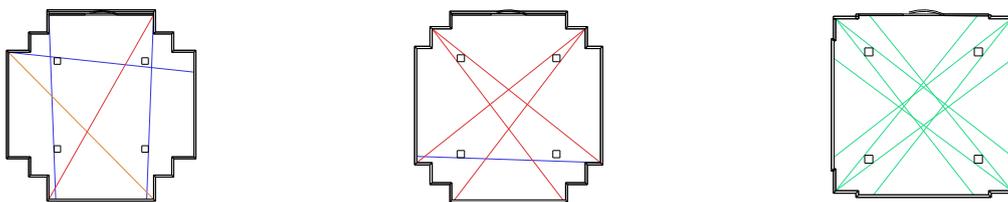


Figure 6: The Effect of Reducing the Size of the Wing (Source: Authors).

Figure 7 shows the e-partitions of the mosque prayer hall. It is clear that the sides of the mosque seem to be more visually stable than other areas of the plan. The areas around the columns are the least stable, while the center of the mosque lies in between these two extremes. Areas of the plan that have the largest e-partitions and the least number of them will seem to be steadier and provide a uniform constant view. Such areas may be of importance to activities within the mosque where distractions are not wanted such as halqas or religious study groups.

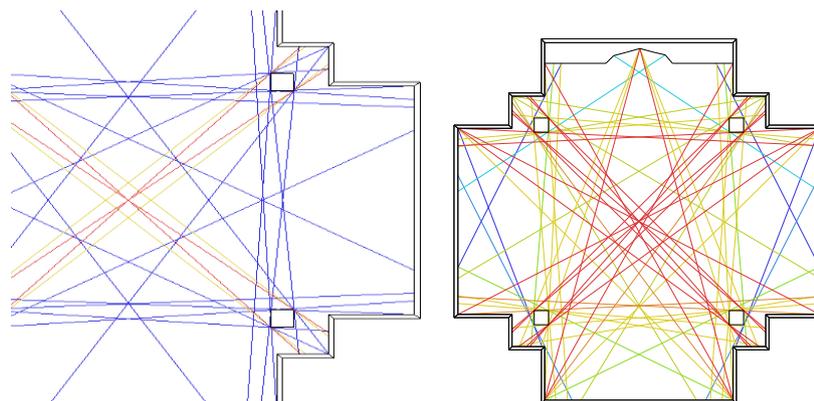


Figure 7: E-partitions of the Prayer Hall Space (Source: Authors).

The lines that partition the space in the figures above are referred to as axial lines and are central in the study of Space Syntax. In fact, the lines above are called 'Fewest-Line Map (Minimal)' and are only a subset of multiple axial lines. These lines are chosen to get the fewest lines that both complete all islands and see all of the space. These lines that "see everything" are basically dominant lines of visibility and are considered to act as subtle

indicators of direction (Hillier & Hanson, 1984). Generating these axial lines involves breaking down the space into non-overlapping convex subspaces and drawing the minimum number of lines that could connect the subspaces. The minimum number of these convex spaces is a very basic representation of the spatial structure of the mosque. This subdivision embodies the relations of co-presence and occlusion in the prayer hall.

The entire set of axial lines for the mosque is shown in Figure 6. Axial lines have shown to correspond well to our sense of intelligibility of spatial patterns and our sense of orientation within them. As such, it is clear that from the figures that the plan of the modern mosques retains a sense of centrality. This is not true however when we consider the qibla. A small modification to the plan by adding a round mihrāb changes the configuration of the axial lines and our sense of orientation. One of the main spiritual experiences in the mosque is the orientation towards the qibla or Mecca. The centrality of the prayer hall space can nevertheless be adapted to induce this sense of orientation through the simple introduction of the round mihrāb. We will see that this round qibla has another primal utility in the Space Syntax.

STRONG VISIBILITY POLYGON OF THE QIBLA WALL

One of the most important aspects to consider about the configuration of the mosque plan is the difference between the strong and weak visibility polygons of the qibla wall. “Strong visibility polygon” is defined as that polygon associated with a wall surface, and which includes all points visible from each of the points on the surface in question (Peponis & Bellal, 2010). This is in contrast to a “weak visibility polygon” which would include all points visible from at least one point of the wall surface. Figure 8 shows the strong and weak visibility polygons of the qibla wall of the example mosque. As one can see, this polygon is not necessary a convex one but is the union of multiple convex polygons. This is important because a designer would usually try to maximize such a polygon in a mosque setting. As expected, an empirical observation of any mosque before Friday prayers reveals that the shape of the earliest arriving worshippers seem to form a shape that strongly resembles the visibility polygon of the qibla wall. The rectangular part is filled first and then the back triangle follows. This is due to the belief that there is greater reward in Islam for those in the front rows in the mosque.

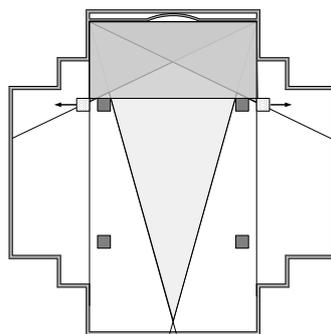


Figure 8: The Strong Visibility Polygon of the Qibla Wall (Source: Authors).

Peponis & Bellal (2010) show that strong visibility polygon, discussed earlier; of a wall surface can be treated as the union of some number of “e-spaces”. Figure 8 shows the strong visibility polygon of the qibla wall as a union of e-partitions. The strong visibility polygon of the qibla wall is obviously very sensitive to the location of the central columns.



Consequently, the strong visibility polygon is greatest if the columns located parallel to the sidewall of the qibla wing. In any case, these axial lines intersect convex spaces and match strongly to our instinct of space and the movement within that space. This is because movement in spaces usually involves potential final and intermediate destinations represented by these axial lines. Although a large portion of Space Syntax involves studying axial lines as movement indicators, the mosque is essentially a static space and movement in the mosque space is not significant. If we were to consider movement, for example, we would be interested in finding lines “that get anywhere” as well as lines that get everywhere; in addition to being able to recognize plan topology. This would be similar to the “mobile guards” problem, which tries to determine the route and number of guards that can see a “gallery” of polygonal shape (O’rourke, 1987). It is interesting to note here that the intersections of the axial lines give emergence to a traditional motif used in mosques and in Islamic architecture in general. However, this is not the entire picture, because the sizes as well as the number of these convex polygons are obviously also important. Therefore, once the space is portioned the second step becomes creating a graph from the various nodes in the space where the visibility can be studied. This visibility graph can be used in linking these individual small-scale spaces as will be discussed below.

VISIBILITY GRAPH ANALYSIS OF THE PRAYER HALL

A set of isovists can be used to generate a graph of mutual visibility between locations. Having derived a visibility graph for a spatial environment, we can study it by making use of some of the many measures available from analysing the resulting graph. For example, by adding up the number of nodes visible from a specific location one can determine how visible that particular location is. Again, we will see that even with such a simple floor plan, the most basic configuration changes will affect the interpretation of space.

The isovists described in the previous section offer a way of studying the relationship between the worshippers in the mosque and their immediate spatial environment. One may consider for example the geometric properties of isovists, such as area and perimeter and therefore we can start to quantify space and its perception in terms of isovist fields. Isovist fields record a single isovist property for all locations in a plan. If contours of the field are plotted, then the way that the isovist property varies through the space can be studied. The contours of the isovist field shows the rate at which the property is changing. Consider for example Figure 9, which shows the isovist area, i.e. the area of the isovist at each point in the prayer hall. The area of the isovist correlates to the amount of visible space from each point. For a square, this would be a uniform field but with the configuration of the modern mosque, it is clear that the isovist area follows a flower-like shape. As the columns are moved closer, the area of the uniform isovist area gets smaller and is more central. The differentiation of area within the space of the prayer hall becomes more pronounced, as those worshippers in the center of the prayer hall tend to see more of the space than those in the peripheries. In addition, areas of equal isovist areas start to appear in the wings of the mosque, where the strong visibility polygon of the qibla wall starts to intersect with the columns. This observation is in line with what Hillier called the squaring law.

As the columns are moved from the center to the corners of the prayer hall, total inter-visibility in the prayer hall increases. Also, as the columns are moved from the center to the corners, visual and metric integration increases. Visual integration is defined as how few visual steps we need to link all points to all others, while metric integration is the sum of shortest paths between all pairs of points in the prayer hall space, which decreases as we move the obstacle from center to corner. In other words, wall end points or corners will remain visible when one stays within an e-space (Peponis & Bellal, 2010). It is also clear that

the manner in which different spaces are linked to one another could even on a visual level affect the integration within a structure making some areas more accessible than others (Mustafa & Hassan, 2013). Expectedly, as the sizes of the wings are reduced the isovist area starts to become more uniform, i.e. closer to that of a square. This has implications to the worshippers, since now the areas where one would sit for private spiritual mediation (i.e. reading Koran, etc...) become scarcer.

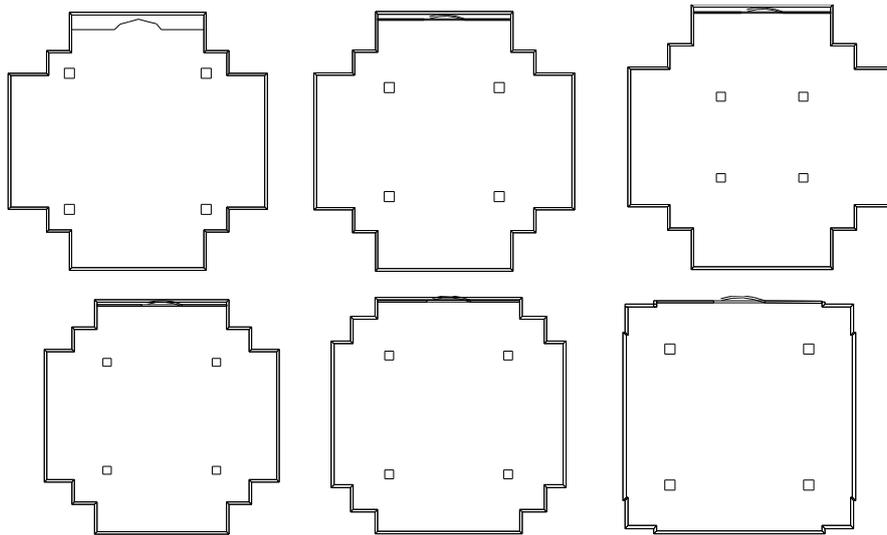


Figure 9: Isovist Field for the Area Property (Source: Authors).

The connectivity values of each node in the space (how many locations each node can see) take an identical contour shape as the area isovist field. Notice that the shape of the isovist connectivity is continued at the mihrāb in what seems like a completion of the parabola formed by the contours. Although the purpose of the round shape of the mihrāb was for acoustical reasons so that the entire congregation would hear the sermons, it also seems to have a beneficial visual effect. The round shape of the mihrāb slightly increases the connectivity, visual integration and thus the intervisibility in the mosque prayer hall.

The isovist field for the control and controllability property also takes the same shape as the area isovist field. Control is a measure that picks out visually dominant areas, whereas controllability delineates areas that may be easily seen. The prayer hall has very similar control and controllability fields, which also closely resemble the area field. This means that if a location in the prayer has a large isovist area and if many other locations can see it, the control value will be low. This means that controlling locations see a large fraction of the space, and at the same time the areas of the space they see, have somewhat of a low visual access to the entire space. This is the case for the center areas of the mosque, where one has visual access to most of the prayer hall, while the small areas between the columns and the corners cannot see the entire central area. That may further explain why the center area is usually the most densely occupied area during the weekly Friday prayer sermon. On the other hand, there are areas with low control. This is the case of the corner of the prayer hall and is especially true for the areas between the columns and the corners of the space. Typically, if one were to be engaged in personal spiritual worship, one would look for areas with low controllability as well as low control. These are areas where one would go to if he does not want to be seen but still wants to see the rest of the mosque.



Controllability on the other hand differentiates areas that may be easily visually dominated within the space. Some spaces such as the mosque prayer hall are both controllable and controlling. This is similar to the simple square hall. In that sense, the addition of the columns and wings do not affect the control and controllability of the mosque. In any case, the ratio of the total prayer hall area to the area with a low control value may be an important parameter in mosque space since it indicates the amount of private “uncontrolled” space. The shape of the isovist field for the minimum radial length (MRL) and maximum diametric length (MDL) is shown in Figure 10.

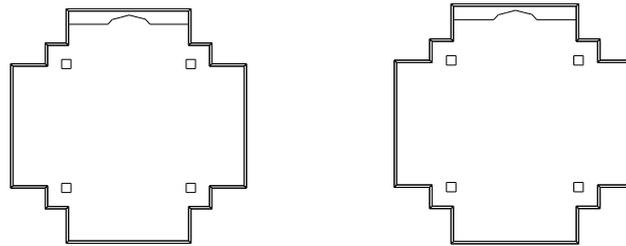


Figure 10: Minimum Radial Length (MRL) and Maximum Diametric Length (MDL) (Source: Authors).

The minimum radial length of an isovist is the shortest distance to the boundary and the maximum diametric length is the longest distance in an isovist. These measures can offer a sense of the directionality of the space. One can see the effect of adding the circular mihrāb to the basic square shape of the prayer hall, in that the MDL field seemed to have been elongated in that direction. Another measure of interest is the isovist perimeter field, which measure the amount of surfaces and walls seen from each location in the space. Figure 11 shows that perimeter isovist field has a distinct shape where “islands” of equal perimeter are seen between the columns. Although, these areas are not visually stable like the e-partitions discussed above, they offer a similar kind of visual experience in that the amount of surfaces seen from these areas is constant.

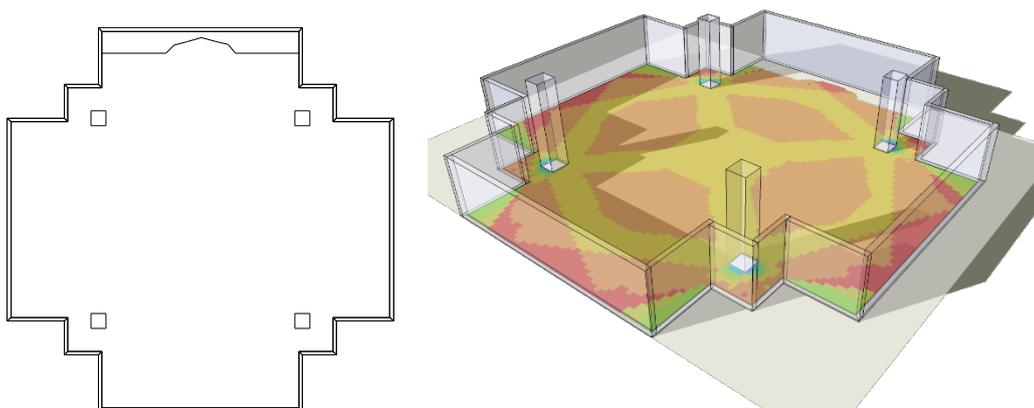


Figure 11: Isovist Field Perimeter, i.e. the Amount of Walls that are Visible from a Particular Location (Source: Authors).

The compactness measure is also shown in Figure 12. Compactness value for a point in the space is defined by a circle whose radius is equivalent to the isovist's mean radial length from that location. Compactness gives a sense of how much the isovist's shape resembles a

circle. The shape of the compactness contours for the prayer hall resembles rotated squares. This can be explained by the fact that presence of the wings in the shape of the floor plan that alter the compactness isovist field in that way. Other measures that could be investigated include variance and skewness (variance these describe the degree of dispersion of the perimeter relative, while skewness describes the degree of dispersion relative to the asymmetry).

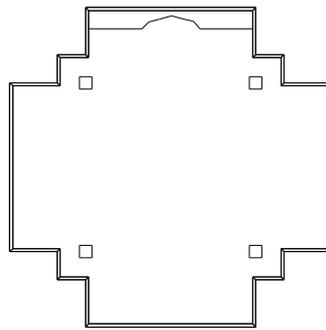


Figure 12: Compactness (Source: Authors).

The Occlusivity is shown in Figure 13. This measure points out where isovists have long lengths of occluding radials. An occluding radial is one that marks a boundary between visible and occluded walls and surfaces. In other words, it is the length of the invisible radial components separating the visible space from the space that cannot be seen from the point at hand. Occlusivity provides a measure of the degree of 'spikiness' of the isovist. Occlusivity is more important if one is interested in the navigation and exploration of the space. The occluding radials themselves demarcate areas of unexplored space that will be entered if a walker continues in the same direction of the occluding radial. Areas of high occlusivity in the plan are those between the columns and the corners.

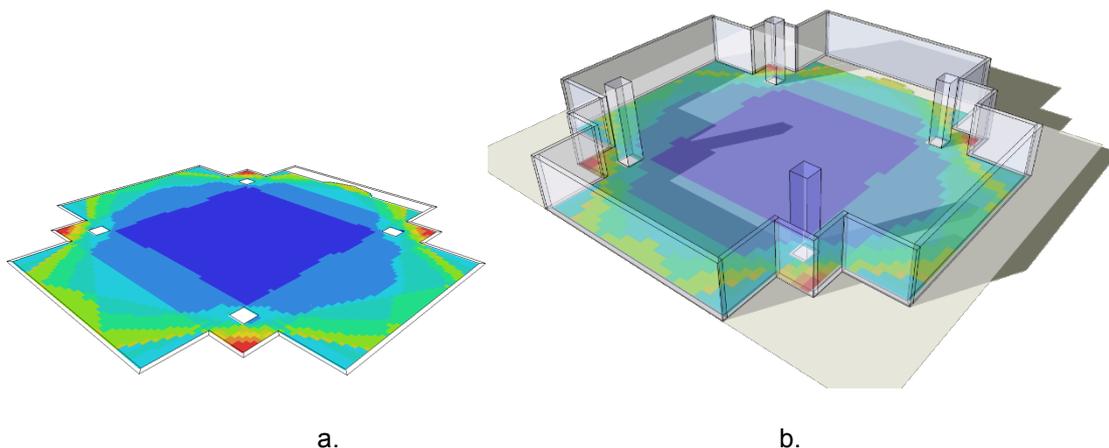


Figure 13: Occlusivity (Source: Authors).

The moment of inertia of the isovist is similar to that calculated in structural applications and is dependent on the shape of the isovist. The more the area is spread away from the centroid, the more the moment of inertia. Although the architectural implications of this measure have not been fully explored, an intuitive interpretation would be the less uniform the shape of the isovist, the higher the moment of inertia. This may correlate to how speckled



and diverse the view is from the point in consideration. We see that again in figure 14a that the small wings and the columns in the mosque hall significantly increase the moment of inertia compared to a basic square. Another related measure is the clustering coefficient, which is a measure that assesses whether or not a graph is a small world or not (Watts & Strogatz, 1998). It is defined as the number of edges between all the vertices of the isovist from a specific point in space. As such it is correlated to the convexity (the higher the convexity the less the 'spikiness') of the isovist at a specific point and measures how the visual information will change. The clustering coefficient of the prayer hall is given in Figure 13b.

Here one can see that the clustering coefficient is fairly well related to the shape of the space. The wings and the center have a higher clustering coefficient than the areas between the columns. This supports the fact that areas between the columns are somehow visually stable as evident from the isovist perimeter field. Isovists drawn from these areas tend to be almost convex polygons, and all the point locations within these neighbourhoods will be able to see each other (clustering coefficient is close to one). On the other hand, the isovist from the corners are very 'spiky' and hence many points within the isovist are not visible from each other (coefficient is close to zero). The clustering coefficient quantifies the proportion of inter-visible space from a specific point and therefore signifies the proportion of the visual field of an observer that will be retained or lost as that observer moves away from that point being considered. (Turner, 2001) found that this measure may dictate the way a journey is perceived and where the decision points come within it.

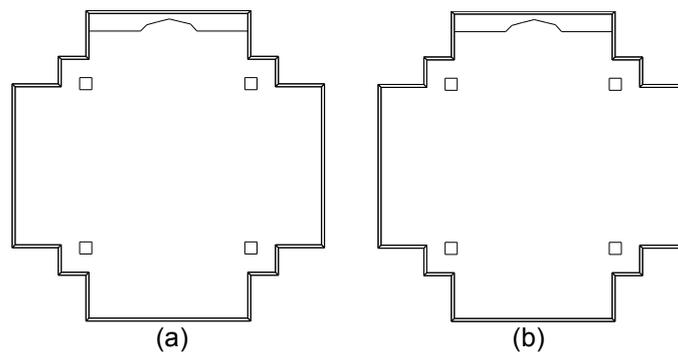


Figure 14: The Moment of Inertia and the Clustering Coefficient (Source: Authors).

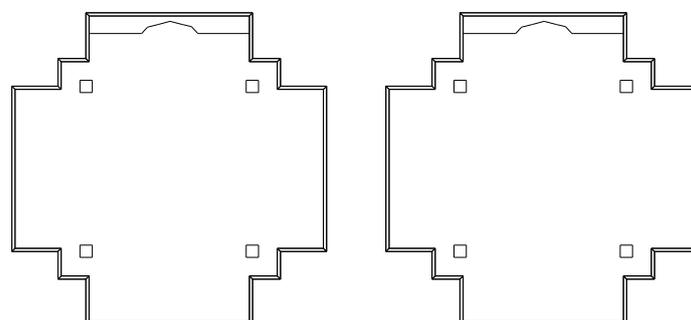


Figure 15: Entropy and Relativized Entropy (Source: Authors).

Some measures are based on the frequency distribution of the depths. One such measure is the point depth 'entropy' of a location, which gives an insight into how ordered the visual field is from a location. The relativized entropy begins to show more detail in the center of the



mosque, while the entropy shows a high relative difference between the center of the mosque and the areas between the columns and the corner walls. Note however how the entropy, moment of inertia and the clustering coefficient are all interrelated. Figure 16 shows the entropy and relativized entropy of the prayer hall. Now let us consider changing the shape of the columns in the middle. We have already mentioned that changing the shape of an object from square to rectangular decreases inter-visibility. This is evident from the connectivity plots. In addition, the orientation of the columns has an effect on the connectivity, such that vertical oriented columns increase inter-visibility in the direction of the qibla wall and therefore will be more suitable. Conversely, horizontally place rectangular columns increase the entropy and thus the “surprise” in the space.

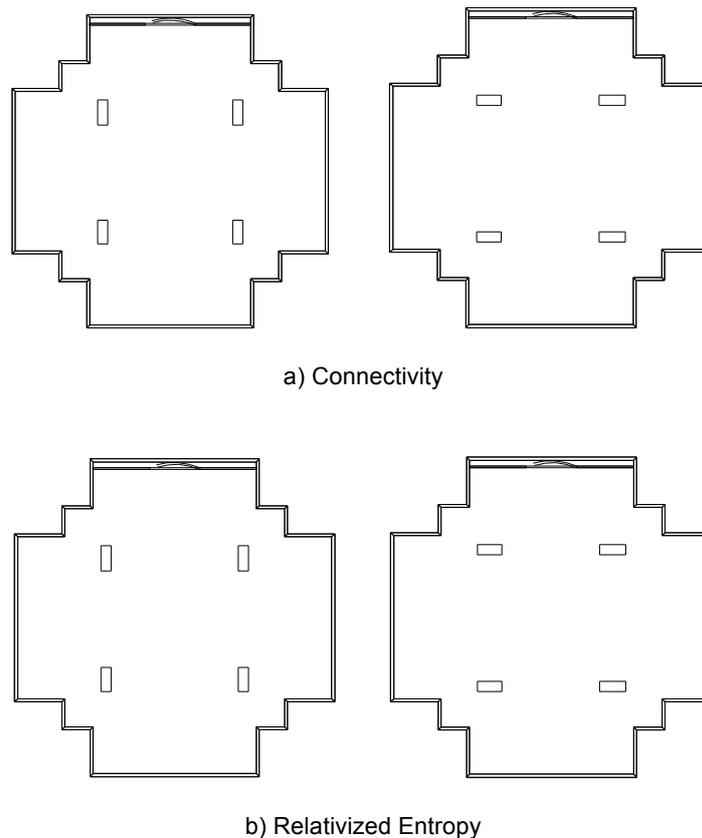


Figure 16: Connectivity and Relativized Entropy (Source: Authors).

Another way to present the analyses discussed so far is to plot two of the measure against each other and observe the distribution of the resulting points. Figure 17 shows the occlusivity versus the clustering coefficient for the prayer hall. It can be seen that there is no defined relationship between the two measures; instead, we can observe that most the points in the space have a high clustering coefficient with varying occlusivity. This means that most of the isovists of the space have a high degree of convexity with varying length of occluding radials. In spatial terms, this means that although the sense of the basic square is still maintained (as indicated by the high convexity), an occupant would still have lines of sight that mark unexplored areas. On the other hand, Figure 18 shows the control versus the moment of inertia. Here there seems to be a more defined relationship, whereas the moment of inertia of the points in the space increase so do their control. Furthermore, most of the points in the space seem to have high control and high moment of inertia. In spatial terms,



this indicates that most of the prayer hall has strong visual control and that this control is generally characterized by long and narrow visual fields.

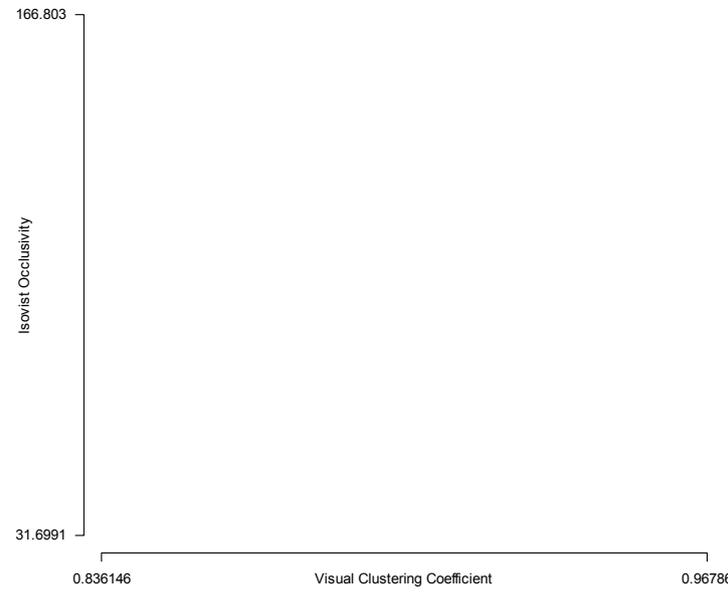


Figure 17: Occlusivity versus Clustering Coefficient (Source: Authors).

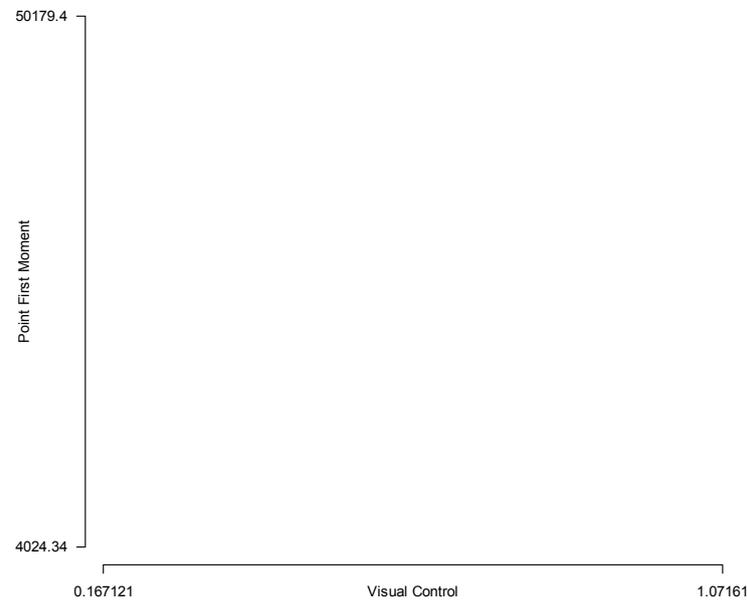


Figure 18: Control versus Moment of Inertia (Source: Authors).

Studying the measures in that way allows one to observe how configuration changes affect two measures at the same time. Figure 19 shows plots of the connectivity versus entropy for three cases; the base case with square columns; the prayer hall with the elongated columns in the vertical direction; and the elongated columns in the horizontal direction. It can be seen that the shape of the relationship in the first and third case is very similar, while when the



columns are elongated in the vertical direction the entropy values increase as well as become more spread out in relation to the connectivity values. In other words, this means that when the square columns are replaced with rectangular columns in the horizontal direction there is no change in terms of the connectivity or entropy of the prayer hall space. However, when the rectangular columns are placed vertically the inter-visibility in the mosque prayer hall increases.

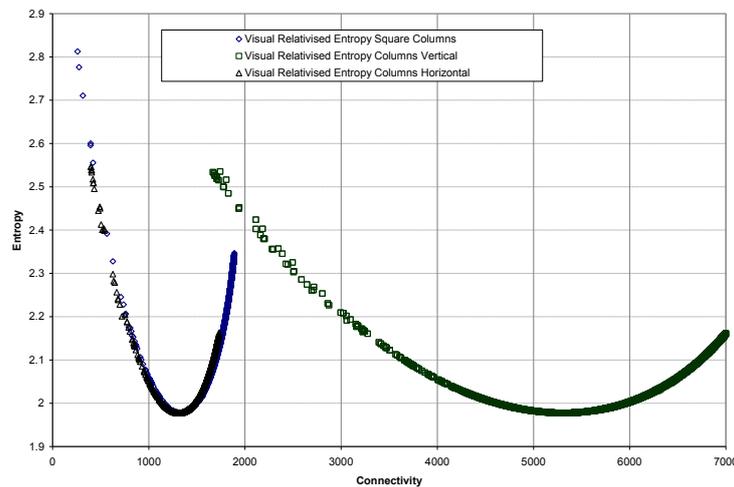


Figure 19: Change in Entropy Distribution with Column Orientation (Source: Authors).

Behavioral Study

A behavioral study during an actual Friday ‘Jumma’ prayer was conducted. The purpose of the observation (Table 1a, 1b and 1c) was to determine the behavior of worshippers as they approach the prayer area. The occupancy rate of the mosque was recorded on one-minute increments at the start of the prayer until mosque filled up. The sequence of pictures below show a preference of the worshippers for the selection of a location in the mosque. The observations recorded time, the total number of worshippers, the number of worshippers preferring to use a chair, resting on a column, resting on a wall, and those who prefer to have a clear line of sight to the Qibla wall and front lines. Our observations conclude strong preference of a number of the early comers to rest on the wall in lieu of sitting in the middle of the mosque. As the wall perimeter area is consumed, the rest of worshippers choose to sit in locations that can satisfy proximity and visibility. As the best locations decrease, worshippers began to locate to the best locations with clear visible access to the Imam. As concluded by the prayer observation part of the behavioral study, the data collection was based on the study of three main criteria within the mosque: Visibility (Visual Integration), Proximity, and Comfort.

- **Comfort:** A preference by worshippers for selecting the optimum position that would provide the best comfort for their listening to a speech in advance of a prayer. The comfort measure is calculated by the total available wall perimeter for resting and the available area surrounding the columns of the mosque.
- **Proximity:** A preference by worshippers for selecting the optimum location in proximity to fill in the front lines and near front lines of the mosque. This measure is calculated using the defmap tool utilizing the resulting values of each pixel.
- **Visibility:** A preference by the worshippers to select the optimum location to maintain a visual communication or clear line of sight with the Imam who leads the prayers and

stands by the Mihrāb in front of the congregation. This measure is calculated using the defmap tool utilizing the resulting values of each pixel.

				
Time	11:48am	11:53am	11:55am	11:59am
No. of worshippers	2	4	5	8
Chair	1	1	2	2
Wall	0	0	0	0
Column	0	1	1	1

Table 1a: Behavioral study during a typical Friday prayer (Source: Authors).

				
Time	12:00 noon	12:01pm	12:02pm	12:04pm
Number of worshippers	11	13	13	16
Chair	1	1	1	5
Wall	1	2	2	3
Column	1	2	2	2

Table 1b: Behavioral study during a typical Friday prayer (Source: Authors).

				
Time	12:06pm	12:09pm	12:19pm	12:19pm
Number of worshippers	21	29	41	50+
Chair	6	7	9	9
Wall	6	8	11	12
Column	2	2	2	2

Table 1c: Behavioral study during a typical Friday prayer (Source: Authors).

Comparative Study of Form Typologies

A comparative study is provided and tests two conventional mosque configurations; a square and a rectangle configuration. For each of the two configurations an in depth analysis of different mosque sizes was done. Data collection was based on the study of three main categories for Space Syntax within the mosque: Visibility (Visual Integration), Proximity, and Comfort. Two forms of mosque layouts are investigated with further classification within each form. Differences between layouts within each configuration are due to changes in: 1. spans between columns in all directions (x and y); 2. the number of columns constructed; and therefore, 3. dimensions for columns (z). Selected area assumptions were tested for each building form. For the square configuration, a 400, 600 and 800m² mosque total area was investigated. For the rectangular configuration; a 400, 900 and 1200m² was investigated and the collective observations were noted in a new section in the revised version of this paper. Areas for all layouts is merely length by width (L x W).

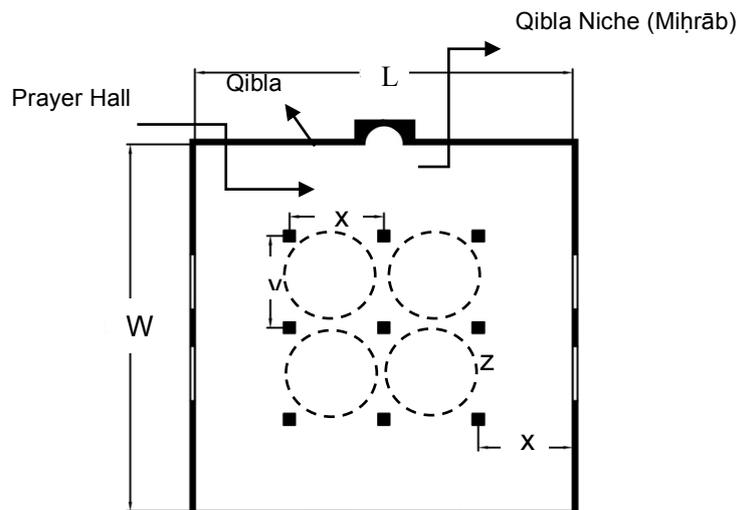


Figure 20: A general configuration for a mosque including space functions (Source: Authors).

The number of analyses conducted on both the square and rectangular forms are outlined in the following table (Table 2).

Table 2: Number of analyses conducted for each plan type (Source: Authors).

	Square		Rectangular	
	Area in Square meter	Number of Analysis	Area in Square meter	Number of Analysis
<i>Comfort</i>	400	9	400	9
<i>Proximity</i>	400	9	400	9
<i>Visibility</i>	400	9	400	9
<i>Comfort</i>	600	9	900	9
<i>Proximity</i>	600	9	900	9
<i>Visibility</i>	600	9	900	9
<i>Comfort</i>	800	9	1200	9
<i>Proximity</i>	800	9	1200	9
<i>Visibility</i>	800	9	1200	9
Total		81		81

For each of the square and the rectangular types, the analyses were conducted for nine different configurations of each plan area identified in our research.

Typical Analysis for One Type:

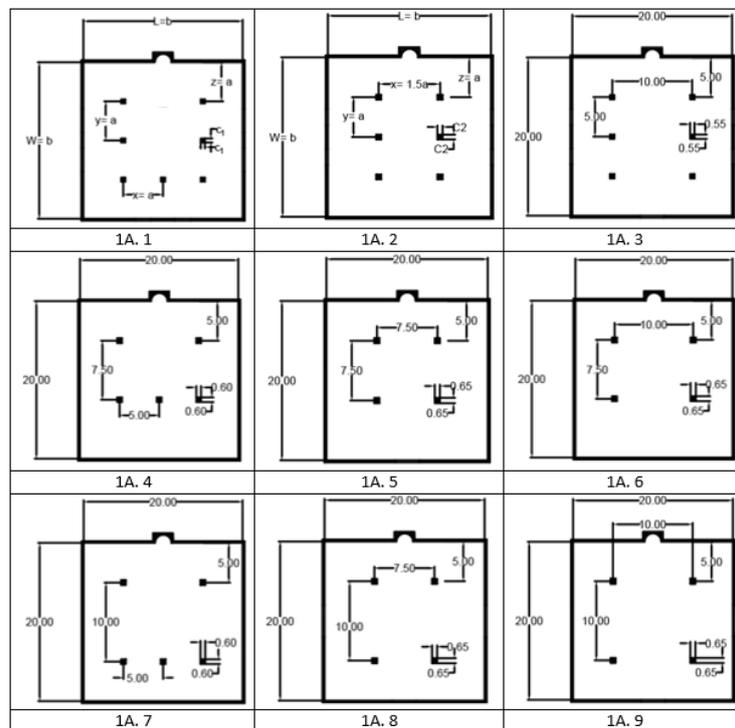


Figure 21: Square Floor Plan Layouts (400 m²) with different column configurations (Source: Authors).

Comfort Analysis

The availability of resting spaces for worshippers is among one of the top attributes that people compete for while visiting a mosque. The perimeter for the prayer hall along with the columns are the first spots to be occupied by mosque visitors. To determine the comfort level, the length of available spaces that mosque visitors or worshippers can lean or rest on is measured (Figure 22).

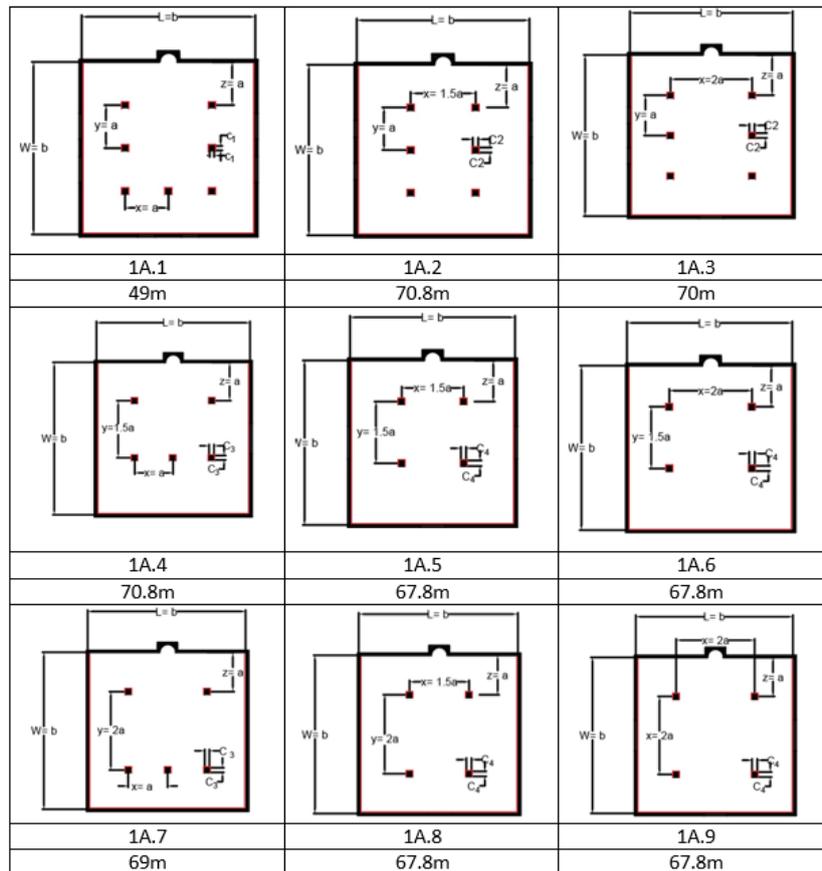


Figure 22: Comfort analysis for the Square Floor Plan with area 400m² (Source: Authors).

It is reasonable to presume that as the area for the layout and the number of columns increases, the perimeter used as resting spaces increases. However, decreasing the number of columns within the space requires an increase in the column dimensions. Therefore, the decrease in the perimeter used for resting spaces is not drastic. If visibility (Visual Integration Values) is taken into account along with this study, it is preferable still to use larger spans between columns and fewer numbers of columns, without jeopardizing the available resting spaces. The total linear meters of resting space are indicated in Figure 22 under each configuration.

Proximity Analysis

Behavioral mapping has revealed the third and final attribute largely impactful on the users' experience within the mosque. It is the linear distance or proximity to the Qibla wall, and as close as possible to the front lines. Dark blue indicate the shortest distance while red indicate the longest distance from the Qibla wall. The numbers under each analysis indicate the number of nodes within close proximity (distance ranging from 0-3) to the mihrāb (Figure 23).

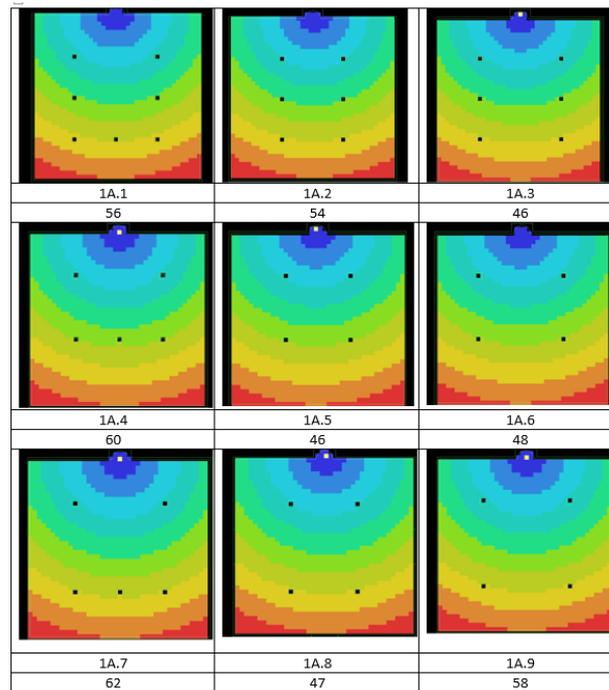


Figure 23: Proximity analysis for the Square Floor Plan with area 400m² (Source: Authors).

Visibility Analysis (visual integration)

The visibility of the Mihrāb where the Imam gives his Friday speech or leads the prayers is considered a vital part in the worshippers or visitors' experience in a mosque. The following table presents a visibility graph analysis testing the effect that different spatial configurations could have on the users' experience within the prayer hall of a mosque (Figure 24).

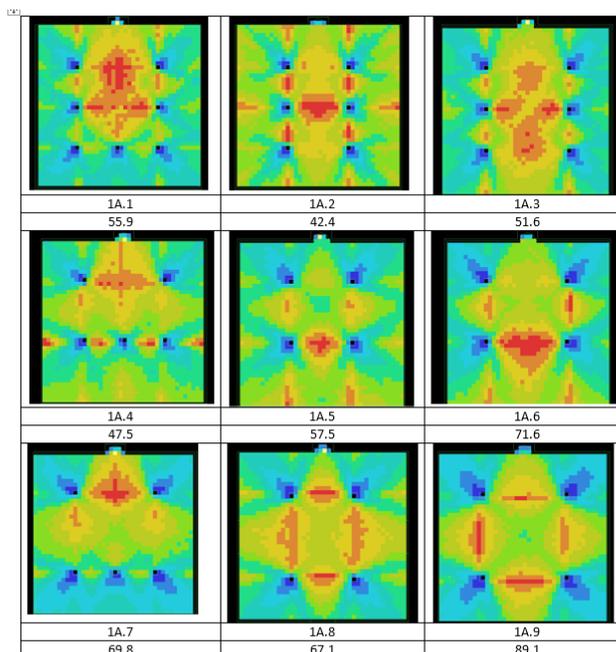


Figure 24: Visibility analysis for the Square Floor Plan with area 400m² (Source: Authors).

RESULTS

The following tables: Table 3 and Table 4 show the results of the analysis for the remainder of floor plan types. It is evident there is clearly a variability in all three criteria evaluated from one plan to the other due to the difference in column locations. The results noted below are classified in colour by high, medium and low for each analysis line. This classification shows for each analysis the best column configurations indicated in green, the best shown in dark green, average indicated in white and worst indicated in gradients of red, the dark being the worst.

Table 3: Analysis results for the square plan (Source: Authors).

	Area in Square meter	Number of Analysis	1A.1	1A.2	1A.3	1A.4	1A.5	1A.6	1A.7	1A.8	1A.9
<i>Comfort</i>	400	9	49.00	70.80	70.00	70.80	67.80	67.80	69.00	67.80	67.80
<i>Proximity</i>	400	9	56.00	54.00	46.00	60.00	46.00	48.00	62.00	47.00	58.00
<i>Visibility</i>	400	9	55.90	42.40	51.60	47.50	57.50	71.60	69.80	67.10	89.10
			1B.1	1B.2	1B.3	1B.4	1B.5	1B.6	1B.7	1B.8	1B.9
<i>Comfort</i>	600	9	105.70	106.20	106.20	103.50	101.70	101.70	103.50	101.70	101.70
<i>Proximity</i>	600	9	44.00	60.00	64.00	60.00	56.00	52.00	50.00	42.00	57.00
<i>Visibility</i>	600	9	52.60	44.90	58.07	50.04	58.29	67.28	66.33	61.71	74.29
			1C.1	1C.2	1C.3	1C.4	1C.5	1C.6	1C.7	1C.8	1C.9
<i>Comfort</i>	800	9	141.00	141.60	139.80	138.00	135.60	135.60	138.00	135.60	135.60
<i>Proximity</i>	800	9	56.00	70.00	75.00	68.00	62.00	48.00	60.00	42.00	54.00
<i>Visibility</i>	800	9	61.46	48.44	65.95	60.01	64.10	84.99	87.41	74.09	91.77

Table 4: Analysis results for the rectangular plan (Source: Authors).

	Area in Square meter	Number of Analysis	2A.1	2A.2	2A.3	2A.4	2A.5	2A.6	2A.7	2A.8	2A.9
<i>Comfort</i>	400	9	70.10	67.10	67.10	70.10	65.60	67.10	68.60	66.40	67.10
<i>Proximity</i>	400	9	56.00	54.00	46.00	60.00	46.00	48.00	62.00	47.00	58.00
<i>Visibility</i>	400	9	44.00	47.16	86.57	46.95	68.69	97.64	67.77	111.61	122.30
			2B.1	2B.2	2B.3	2B.4	2B.5	2B.6	2B.7	2B.8	2B.9
<i>Comfort</i>	900	9	105.20	100.70	100.70	105.20	98.50	100.70	103.70	100.70	100.70
<i>Proximity</i>	900	9	58.00	41.00	55.00	75.00	68.00	50.00	40.00	54.00	57.00
<i>Visibility</i>	900	9	51.09	61.13	88.39	60.82	82.14	97.07	93.59	94.07	185.28
			2C.1	2C.2	2C.3	2C.4	2C.5	2C.6	2C.7	2C.8	2C.9
<i>Comfort</i>	1200	9	110.30	104.30	104.30	110.30	101.30	104.30	110.30	104.30	104.30
<i>Proximity</i>	1200	9	56.00	64.00	61.00	58.00	60.00	58.00	61.00	46.00	38.00
<i>Visibility</i>	1200	9	56.09	62.13	94.07	63.93	85.14	98.47	111.95	122.45	179.41

CONCLUSION, LIMITATIONS AND FUTURE RESEARCH

Space Syntax issues have gone almost completely unnoticed in mosques except for a few recent studies. This paper presented an analysis of a typical mosque prayer halls using Space Syntax analysis tool “depthmapX”. The configuration of the mosque is assessed using visibility graphs, axial lines and various isovist field properties and measures. It was shown how the most basic of alterations to the spatial configuration of the plan of the mosque could affect the spatial experience and cognition of the mosque prayer hall. In addition, special Space Syntax measures that are relevant to the design of the mosque are extracted and discussed, including: the ratio of the area of the strong visibility polygon for the qibla wall to total area; the visibility of the pulpit in terms of the isovist area; the number of axial lines enforcing the orientation of the qibla; and the ratio of total area to controlling space. The impact and importance of these measures is presented and argued. Some of the findings include:

- Space Syntax analysis for mosques should be done using half or fraction-isovists
- Locate the columns in prayer hall to minimize occlusion and yet maintain the full utility of the column as a functional element of the space.
- Maximize the strong visibility polygon of the pulpit and the weak visibility polygon of the qibla wall
- Design for a Fewest-Line Map (Minimal) to coincide with the intended directionality
- Widen “Wings” to reduce axial lines and emphasize prayer hall direction
- According to the “squaring law”, as the columns are moved from the center to the corners of the prayer hall, total inter-visibility in the prayer hall increases. This needs to be balanced by the designer to meet the design problem at hand
- As the columns are moved from the center to the corners, visual and metric integration increases.
- Maximize controllable spaces in the prayer hall and minimize controllability of the pulpit
- Vertical rectangular columns increase the inter-visibility in the mosque prayer hall compared to square ones
- When the square columns are replaced with rectangular columns in the horizontal direction, there is no change in terms of the connectivity or entropy of the prayer hall space

A behavioral study was conducted for a typical Friday prayer and the behavior of the worshippers was documented. Three key aspects of behavioral patterns were observed - preference of comfort, proximity and visibility. Two mosque configurations; square and rectangular were studied to analyze the impact of changing column locations in the prayer halls. The three criteria were later analyzed and applied for each of the square and rectangular configurations. A number of 162 analysis types were conducted and the results are noted. It is evident that with greater variability in column location, there is an experiential impact for the worshippers in the prayer hall. In addition, it may be important to consider cost considerations resulting from larger spans required to increase visibility. Although the mosque is mostly considered a patriarchal building, females are also frequent occupants of the mosque. A special section of the prayer hall is often set aside for female worshippers. This section is created by subdividing the typical prayer hall using space dividers and partitioning the space. About a quarter of the prayer hall may be used for this purpose. This is ground for potential future research to study how to optimally partition the space to maintain and enhance the spatial cognition of the prayer hall. Another area of potential research is how to optimally design the prayer hall to maximize the Space Syntax measures that are of specific importance to the mosque prayer hall as well as to study and contrast

modern and historical mosques. This research method can be applied to other building typologies where visibility and obstruction are critical.

ACKNOWLEDGMENTS

The authors wish to acknowledge the work done by Mariam Amer and Arij Nabil, Graduate Research Assistants at the American University in Cairo in the development work of this paper.

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