ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 1, No. 48 Apr. 2021, pp 213-229
Journal Homepage: http://erj.bu.edu.eg

Using Space Syntax as a Tool for Architecture Design: An Academic Library Space Design Case Study

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Abstract: Academic library spaces are the physical spatial installation of different design ideas. Despite there are a lot of studies that improving the design of library spaces, there are no rigor results that could be implemented to understand possible effects of their design proposals. Architectural design is a complex process, from abstract thinking to concrete design. In this process, the designed product is created and impacted by the unique experiences, observations, perceptions, and characteristics of the designer, while the design work of the architects develops through the use of varied design tools and the designer's own architectural knowledge, one that is fed from various disciplines and fields. It is this scientific knowledge that guides the designer's intuitions

This research focuses on contributing a link between scientific tool and academic library design process, trying to generate a kind of knowledge that can help architects find out how their design might work and explore the potentials and advantages by using space syntax. The aim of this work is purposed to serve as decoding of the invisible characteristics of physical space of academic libraries by focusing on the configurational theory of space also to investigate the research theme by focusing on Space syntax itself, its main idea and its role in architectural practice. To undertake this work, space syntax is used to examine the spatial morphology of the new central Cairo university library in Egypt.

Results showed that the space syntax succeeds in creating a link between science and design by producing graphical and numerical data that the designer can use in testing his/her design proposals.

Keywords: Academic libraries, design process, spatial configuration, space syntax.

1. INTRODUCTION

Library space is the process of transforming different design abstract concepts into physical space installations. Although the architect envisioned the space as a living thing in the design process, and used his own intuition, feeling and experience. Designers have no real way to test their human dimensions before the design is produced and used [1].

Design is a sophisticated cognitive activity. In architecture, this activity begins by generating an abstract idea and continues by transforming it to concrete spatial formations. Whether it is called as “image” [2], “primary generator” [3], or “concept” [4], all refers to the same: the idea that makes an architectural design unique or different from all others.

Hanson [5] emphasize that any architectural design work that is socially responsible must be supported by evidence-based research. Design that accords with scientific theories is stronger as it is supports by reliable sources.

In other words, even if a physical representative test can be performed and the psychological configuration is explained during the design process, the end result is a construct. That is built without human trial. It is at this confluence that the designer feels the need for methods and tools that will allow him or her to test the design suggestions. Design is about experimenting and probing, experiments lead architects to discover something, and then these help them to redefine their underlying concept [1].

According to Ziesel [6], design interconnects three components: imaging, display and testing. Evaluation, rebuttal, criticism, judgment,

comparison, thinking and comment are all types of tests. After presenting a design idea in whatever form, designer steps back with a critical eye and examines his/her product [7].

Ziesel [6] argues that designing works with two sorts of information: heuristic catalyst for imaging and a large amount of data for testing. This means that designers rely on information to tell them how things might be, but also that they use information to tell them how well things might work.

Space is the unit within which all human activities occur. It is necessary to understand the space from a functional point of view to understand how people work and use it [8].

Three kinds of geometric ideas can be used to describe space: linearly presented when people move in it, convex space (where each point can see each other) once they interact within it and finally isovist which from any point of space can be seen as a variably shaped [9]. There is an expected relation between space and its use lies within the relation between configuration of people and configuration of space.

Also, an indicator to measure the degree of function and social efficiency of space as the structure of spatial relation of in building depend on the way of handling the determinate of space like walls and floor [10].

Haghighi [11] describes space as one of the main elements in a library and it can play a critical role in success or failure of plans. There is a direct relation between spaces of a library and using its service and study and research in a comfortable, calm, pleasant, attractive and accessible place, which are necessities of such a cultural and spiritual place.

The focus of designing spaces for users is far more complex as it needs to take into account the variety of user's activity needs (physical and psychosocial) and behavior; libraries are able to accommodate students who want to work quality as well as those who prefer to work socially with others, so it is important to consider all the major factors that affect the use of the academic library space and classify space use.

There are many guides to library space planning, both conceptual and practical in the library literature listed below in **Table 1**.

TABLE 1. Spaces that constitute the academic library planning

Space		Description
Primary	**Collaboration**	**Highly active & engaging communal spaces**
		▪ Open Reading Hall ▪ Closed Reading Hall
	Individual	**Quietness spaces for thinking, for quiet reflection short stay individual information**
		▪ Studying Room - Research Room
Support	**Interactive**	**Provide facilities for student & technology to work**
		▪ Digital Resource Hall ▪ Multimedia Room ▪ Electronic Archive
	Community	**Social nature of students learning information spaces**
		▪ Reception Area ▪ Cafeteria
Circulation (Vertical – Horizontal)		**Spaces or elements to do with movement around the spaces**
		▪ Lifts and Stair cases ▪ Lobbies and Corridors
Service spaces		**Spaces containing activities which support an individuals**
		▪ Toilets

Source: Authors adapted from [12, 13, 14, and 15].

2. SPATIAL CONFIGURATION

Configuration as defined in Hillier's book "space is the machine" is a set of interdependent relations in which each is determined by its relation to all the others. This arrangement of spaces affects the use of space, which is consistent with how we relate these spaces to each other.

In general configuration is defined as, at least the relation between two spaces in layout taking into account the third, and at most, as the relation among spaces in the complex, taking into account all the other spaces in the complex [16,17].

Spatial configuration becomes critical because it identifies flexibility and limits of space for serving users' changing needs. On the other hand, Hillier also suggests that architectural program has more significant effects on spatial preferences than spatial configuration. Hillier defines architectural program as the arrangement of relationships of activities those planned to realize also defined architectural program as a kind of function map of space that prescribes each function/activity, which happens in a location of the related space and affected by the design concept [16].

Space Syntax describes the spatial configuration based on its functional implications, i.e. on how configuration affects social dynamics. Through their influence on movement and visible co-presence, it is possible to understand the relationship between the configuration pattern in the building and the social pattern it generates (Exploring pattern of space use). The spatial configuration is understood as a continuous system of spaces, ordered by adjacency relationships translated into physical and visual permeability gradients [18]. Academic libraries (ALs) configuration patterns were analyzed by means of accessibility and visibility.

a) Accessibility analysis is defined as the longest distance that can be reached before blocking by spatial elements. In this study, all spatial elements are taken as an obstacle that obstruct movement such as tables, bookshelves, galleries, staircases, columns, walls.

b) Visibility analysis is defined as the longest distance that can be seen before blocking by spatial elements. In this study, all spatial elements that block eyesight are taken as obstacles such as walls, bookshelves, columns, and staircases [19].

By means of graph theory, each field of view at each point in the analysis space can be calculated and the level of visibility can be determined. The results obtained are represented by a color scale ranging from red to blue and the red shade corresponds to the most visible area, while the blue corresponds to the restricted field of view. The analytical and graphical data analysis is relied on the software program (UCL Depthmap10) to calculate the values of the integration and connectivity for accessibility, visibility and only connectivity for axial map analysis.

a) Integration is a kind of configurational characteristics refers to the potential accessibility degree of an area in relation with the whole spatial system also related to numerousness of connections of a space with other spaces.

b) Connectivity indicates the amount of direct connections of a space with adjacent spaces. Also, it relates to directness of connection of a space to other spaces [18].

These characteristics are expected to give possibilities of social interactions of space as many researcher supports [16, 20].

3. SPACE SYNTAX THEORY AND TECHNIQUES

Space syntax, originated and developed in the 1970s at the Bartlett Unit for Architectural studies, University College, London, but it has the first considered contribution after the publication of "the social logic of space" by Hillier and Hanson in the 1984s, space syntax describes the spatial layout based on its functional implications .

The unique concept of space syntax theory obtained from the study of architecture as it used to describe and analyze patterns of architectural space both at the building and the relation between human and their inhabited systems as Hillier and Hanson prefer to discuss architecture regarding visual styles, its most far-reaching practical effect is not at the appearance level at all, but at the spatial level [18].

Space has two topological properties that provide a significant influence over architecture's capacity to function. The first refers to the way spaces are connected or configured. The second refers to the degree to which spaces can be distinguished from each other only according to their position in the system or space network. The topology of space is significant because it "can reflect and embody a social pattern" However, "space can also shape a social pattern" [21].

Space syntax theory and techniques focus on the topology of space to examine the relationship between configurationally patterns in architecture and their generative or reproductive social structures. Space syntax measure distance between spaces topologically, this topological distance is named depth.

Depthmap concept defined by Batty and Rana as a certain number of intermediate lines must cross to get from space to another space, the minimum number of step depth indicates integration, and the maximum number of step depth indicates segregation [22].

In brief, space syntax analyzed the structure of spaces and configuration, (i.e. the way spatial

elements were put together to form interconnected system of space) and understanding of how people make and use it.

Recently spatial syntax work attempts to simulate spatial design suggestions and provide a basis for predicting how it works.

The analytical techniques that draw a graph theory variable are relied on the software program (UCL Depthmap10) to calculate the value of the integration and connectivity.

a) Convex space (Convexity), like a convex polygon, is one where all the interior angles in the room's plan are less than 180. Hillier et al. define convex space as an area outlined by a border of straight lines, any two points in this convex space can be joined by a straight line which doesn't go outside the space. Convex map consists of the largest and fattest convex spaces that cover the area [23].

b) Linearity (Axiality), an axis is a straight path or vector that passes through the space, which represents the potential of movement and vision in the plan and objects in the space (furniture) will temporarily hinder movement or vision and prevent them from following a perfect linear paths. Hillier et al. defined as an axial line will extend as long as at least one point is visible and directly accessible. It could also can be described as the set of fewest and longest lines in an architectural plan, which give access to all spaces and allow a person to move everywhere and see everything in an environment [23].

c) Isovist is defined as the set of all points visible from a given vantage point in space, it is the field of view in which the whole space boundaries can be defined through the transportation of observer's eye around 360◦ without geometric obstacle [9].

4. METHODOLOGY

The proposed analytical model to analysis the spatial configuration of floor plans by using Space Syntax method, taking into account the architecture drawings, based on two main stages in space syntax analysis [19].

The first stage convex spaces are identified by abstracts or reduce various properties from architectural floor plans by defining the borders of plans and the walls inside it into a serious of differentiated components and connections between them which is called a map.

As outcome of the literature review, variables affecting the physical and visual relation between configuration patterns of space were analyzed by means of accessibility and visibility, the analysis relied on computer modeling software program (UCL Depthmap10).

So many variables were investigated like: integration, connectivity for both of the accessibility and the visibility value and axial map analysis. Other variables are excluded from this study.

The second stage analyzes the topological properties of the map using graph theory to analyze accessibility and visibility analysis.

The software program (UCL Depthmap 10) program working with a grid system, after determining a grid towards this influence area, was connected with identical field of view and the grid separations, calculating the physical and visual space relation within the boarders selected for analysis

Architectural floor plans will be analyzed by means of accessibility and visibility techniques relied on the software program using "depth map" to acquire numerical and graphical data analysis. The study focused on the spatial variables that strongly related to the space efficiency and how accessible and visible every space is to the users. So many variables were investigated like: integration, connectivity for both of the accessibility and the visibility value and axial map analysis. Other variables are excluded from this study.

5. CASE STUDY

This part aims to apply the proposed analytical model to Cairo university new central library as an existing designed case; and present the results of the assessment and demonstrate its capability of measuring the academic library spaces design function efficiency.

The building of the case study located in Giza, and consists of five floors, with approximately area 4000 m^2 for each floor. It is built in 2002 using reinforced concrete construction system. The building includes several core and function spaces such as reading hall, study halls, research rooms, conference hall, meeting room, multimedia room, archives etc. The research focused on assess the primary reading zones at the ground, second and fourth floors. These floors contain the following spaces: Open reading spaces, separated study space, private research rooms and horizontal circulation and support spaces as shown in **fig. 1**, other spaces on this floor but they are not included at this study.

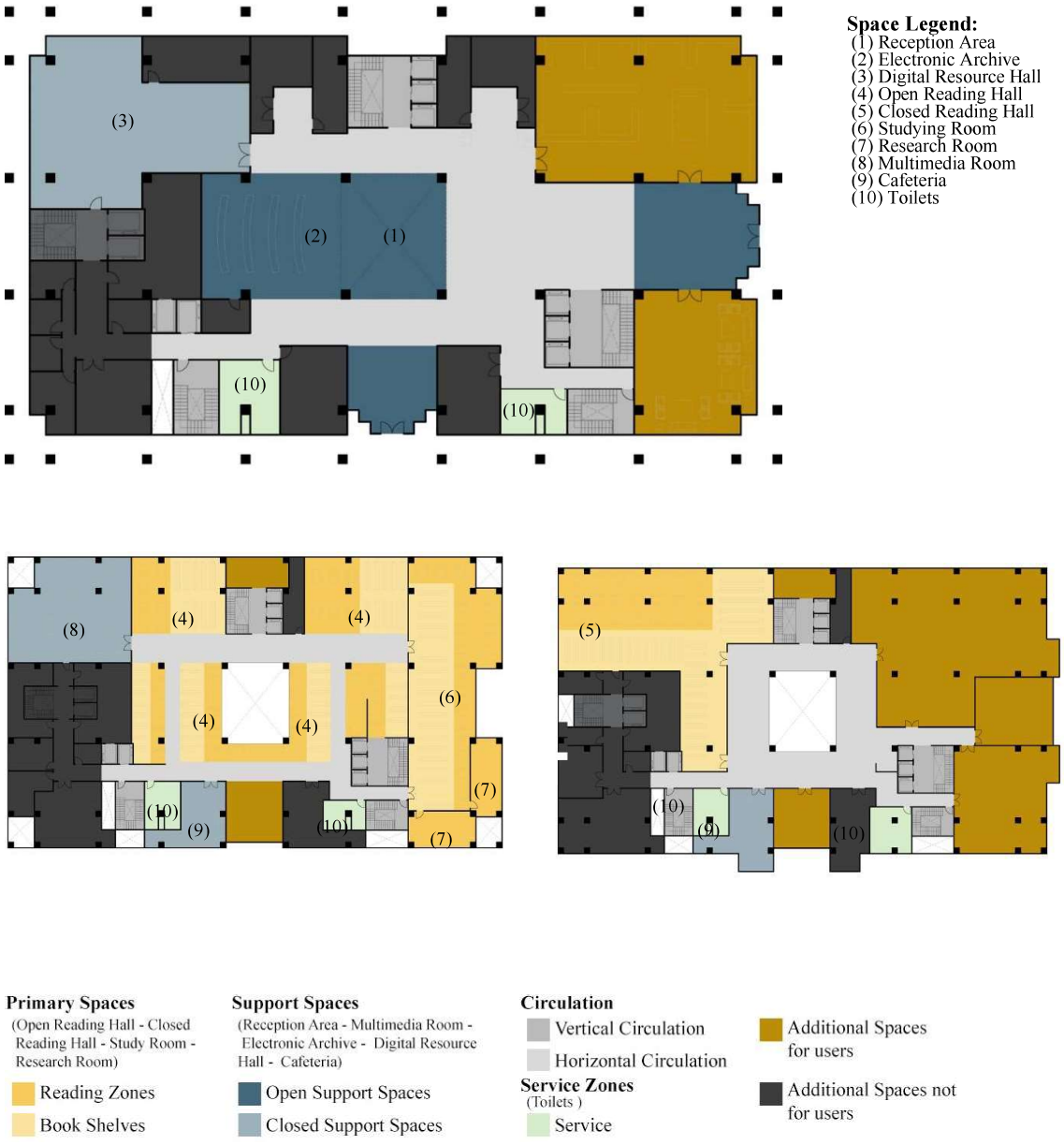


FIGURE 1. Simple architecture plan program of the floors based on the function of spaces. Top (Ground Floor), Bottom Left (Second Floor), Bottom Right (Fourth Floor).

Source: Authors

6. THE SPACE SYNTAX DATA RESULTS

There are two main stages in space syntax analysis. **The first stage** convex spaces are identified by abstracts or reduce various properties from architectural plans for the ground, second and fourth floor by defining the borders of plans and the walls inside it into a serious of differentiated components and connections between them, the set of connected components is a called a "map" here convex spaces are designated according to geometry and function of spaces in each floor as seen at **fig. 2.**

FIGURE 2. Convex spaces division of floor plans.

Source: Authors

The second stage shows example of spatial elements that can obstacle walkability and eyesight as seen at **fig. 3** and **fig. 4**

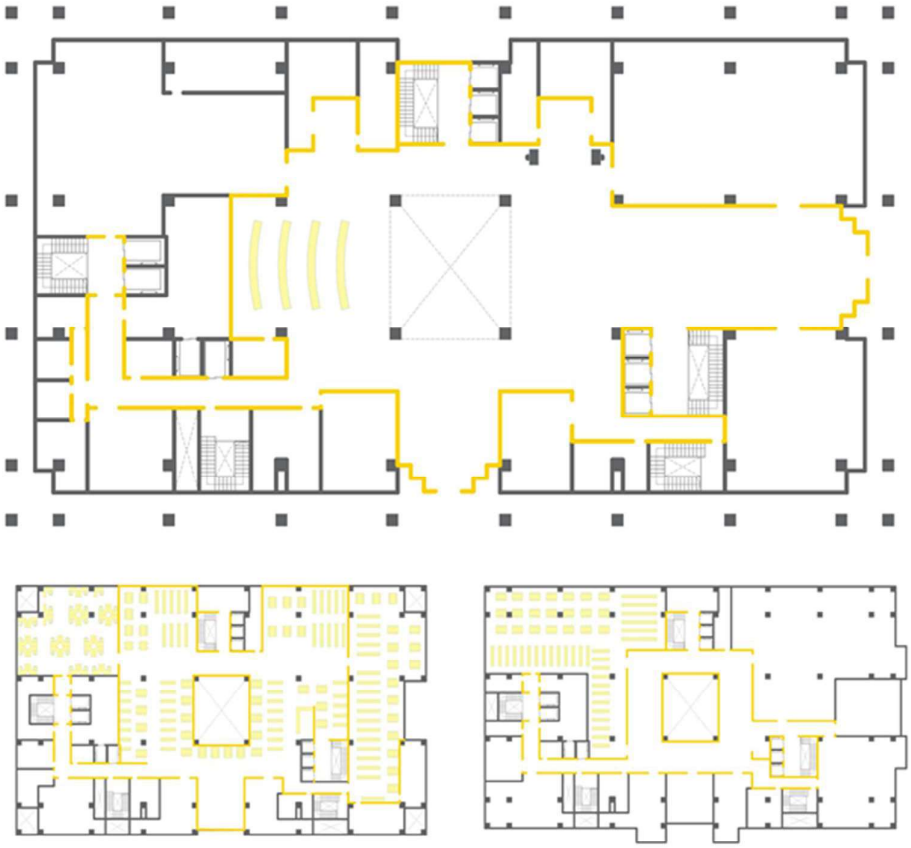


FIGURE 3. Accessibility analyses are made by considering all spatial element that block knee-access as shown. (Yellow: spatial elements that block accessibility).

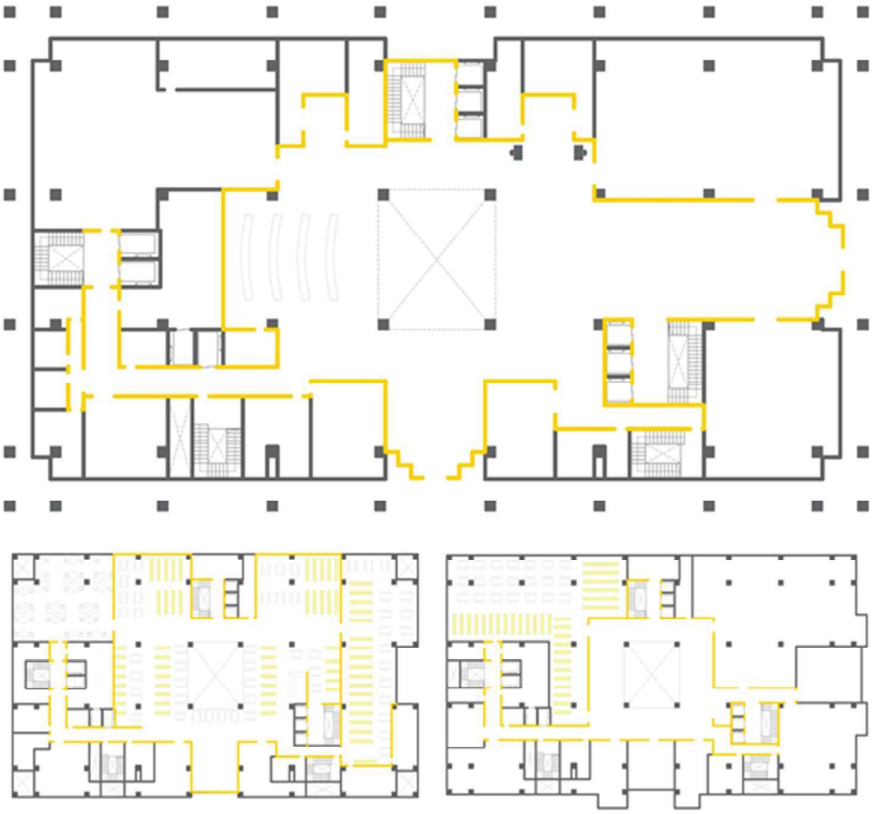


FIGURE 4. Visibility analyses are made by considering all spatial Elements that block eyesight as shown. (Yellow: spatial elements that block visibility).

Source: Authors

6.1. Space Accessibility Analysis

By means of graph theory, accessibility calculations were established for each floor plan, the results obtained are represented by a color scale ranging from red to blue, which helps to understand the calculations simply, the red shades in the graph represents area with highest value of connectivity and integration. While the connectivity and integration value decreases in the color code moving from red to blue represents the lowest value of connectivity and integration.

It's clear from the colored plans the gradual distribution of connectivity values as seen at **fig. 5,** that **on the ground floor** level, the reception area and main corridor paths and the electronic archive have the highest connectivity values, followed by digital resource hall while main stairs and lift, toilets and cafeteria are the spaces with the lowest connectivity values.

On the **second-floor** level, the main corridor and inner paths and central open reading hall has the highest integration values, then followed by stairs and lifts also multimedia room and studying hall

On the second-floor level, the main corridor paths to the stairs and lift also the secondary paths have the highest connectivity values, then followed by the central open reading hall, multimedia room, studying room also main stairs and lifts and cafeteria, while research room, toilets are the spaces with the lowest connectivity values.

On the fourth-floor level, the closed reading hall has the highest connectivity values, then followed by main corridors paths to the stairs and lifts, while stairs and lift also toilets and cafeteria are the spaces with lower connectivity values.

Regarding the gradual distribution of integration values as seen at **fig. 6,** it was found that on the **ground floor** level, the reception area, digital resource hall and the electronic archive also the main corridor paths to the stairs and lifts has the highest integration values, then followed by toilets, Other spaces not in the study scope.

followed by cafeteria, while research room and toilets have the lowest connectivity values.
On the **fourth-floor** level, the main corridor paths to the stairs and lifts and the closed reading hall have the highest integration values, and then followed by stairs and lifts also toilets and cafeteria while other spaces not in the study scope are the spaces with the lowest connectivity values.

As seen at the **Table 2**, it was found that, the average connectivity in the designed plans varies between **2.1** and **2.8** and average integration values vary between **1.000** and **1.172.**

TABLE 2. Space syntax accessibility values calculated **by** UCL Depthmap10 software.

Floor number	Accessibility connectivity				Accessibility integration			
	Min.	Max.	Mean.	Std. deviation	Min.	Max.	Mean.	Std. deviation
Ground	1	10	2.1	1.808	0.578	1.827	1.0	0.282
2nd	1	16	2.677	2.952	0.646	2.019	1.134	0.276
4th	1	24	2.804	3.443	0.635	2.045	1.172	0.274
Mean	1	16.66	2.527	2.734	0.619	1.963	1.102	0.277

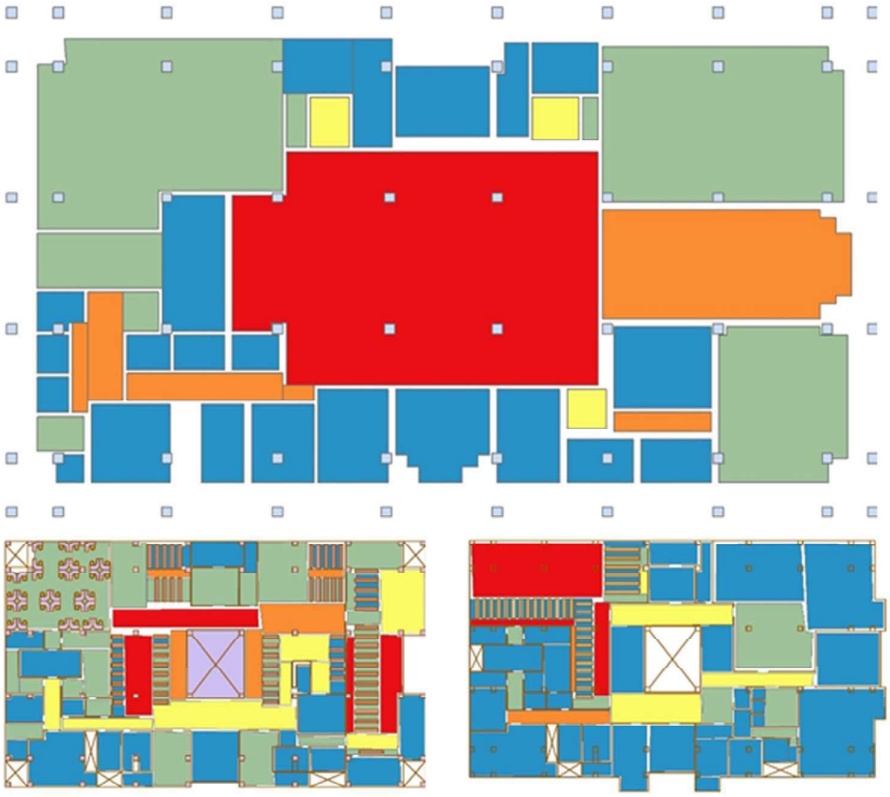
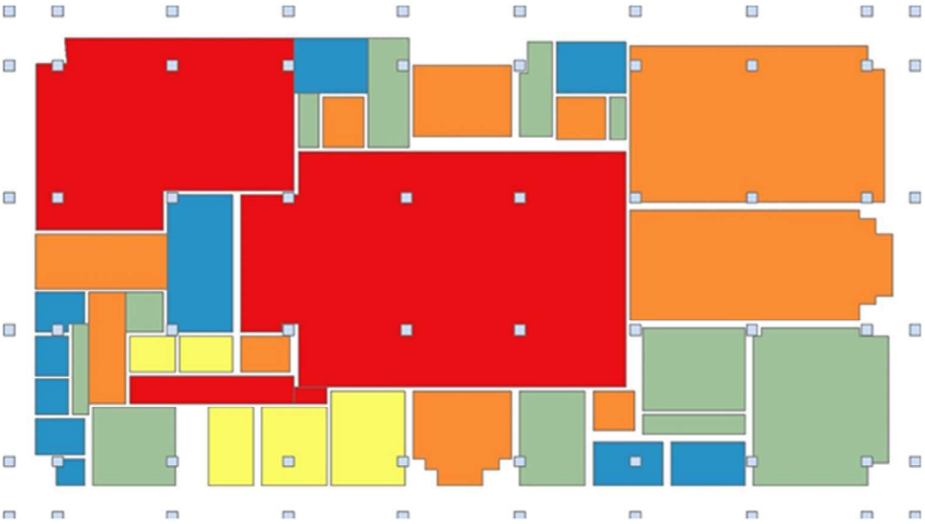


FIGURE 5. Space accessibility connectivity analysis calculated by UCL Depthmap10 software.



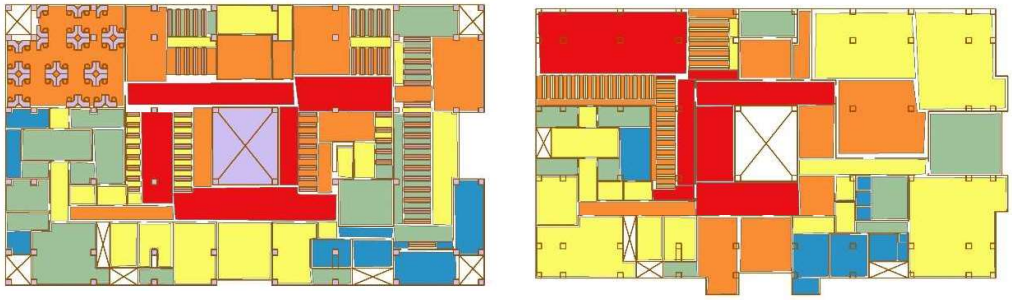


FIGURE 6. Space accessibility integrated analysis calculated by UCL Depthmap 10 software.

6.2. Space Visibility Analysis

Although Open reading spaces separated from each other by bookshelves, the height of bookshelves (220 cm) has led to a great similarity between the values of the accessibility and the visibility.

By means of the graph theory every visual field from each point of analyzed space is calculated and the level of visibility identified. The results obtained are presented by a color range from red to blue, which helps to understand the calculations simply, the red shades in the graph represents area with highest visibility, while blue presents areas with more restricted visual fields.

It is clear from the colored plans the gradual distribution of visibility connectivity values as seen at **fig.7**, that on the **ground floor** level, the specific spots in the main reception area and the electronic archive due to low partitions in the open archive space has the highest visibility connectivity values, followed by digital resource hall with medium visibility connectivity while lift and stairs are the spaces with the lowest connectivity values.

On the **second-floor** level, the main corridor paths to the stairs and lifts has the highest visibility connectivity values, then followed by lift and stairs followed by toilets and cafeteria

While the height of bookshelves led to low variety in the visibility connectivity values inside reading hall followed by research and studying room.

On the **fourth-floor** level, other spaces not in the study scope have the highest visibility connectivity values, then followed by the main and secondary corridor paths also the stairs and lifts, while the closed reading hall led to the lowest visibility connectivity values.

Regarding the gradual distribution of visibility integration values as seen at figure **fig.8,** that on the **ground floor** level, the specific spots in the main reception area and the electronic archive due to low partitions in the open archive space has the highest visibility integration values, followed by digital resource hall with medium visibility integration while lift and stairs are the spaces with the lowest integration values.

On the **second-floor** level, the main corridor paths to the stairs and lifts has the highest visibility connectivity values, then followed by lift and stairs, multimedia room, toilets and cafeteria.

The height of bookshelves led to medium variety in the visibility connectivity values inside reading hall followed by studying room. While the research room led to the lowest visibility integration values.

On the **fourth-floor** level, other spaces not in the study scope have the highest visibility connectivity values, then followed by the main and secondary corridor paths also the stairs and lifts, while the closed reading hall has the lowest visibility integration values.

As seen at the **Table 3**, it was found that, the average connectivity values vary between **9.14** and **2.8.** Also, the average integration values varies between **12.10** and **1.17.**

TABLE 3. Space syntax visibility values calculated by UCL Depthmap10 software.

oor number	Visibility connectivity				Visibility integration			
	Min.	Max.	Mean.	Std. deviation	Min.	Max.	Mean.	Std. deviation
Ground	1	21.97	9.14	6.79	-1	19.16	12.10	3.76
2nd	0	8.52	2.15	1.92	-1	23.50	4.55	1.51
4th	1	2.4	2.8	3.44	0.63	2.04	1.17	0.27
Mean	0.66	10.96	4.69	4.05	-0.45	14.90	5.94	1.85

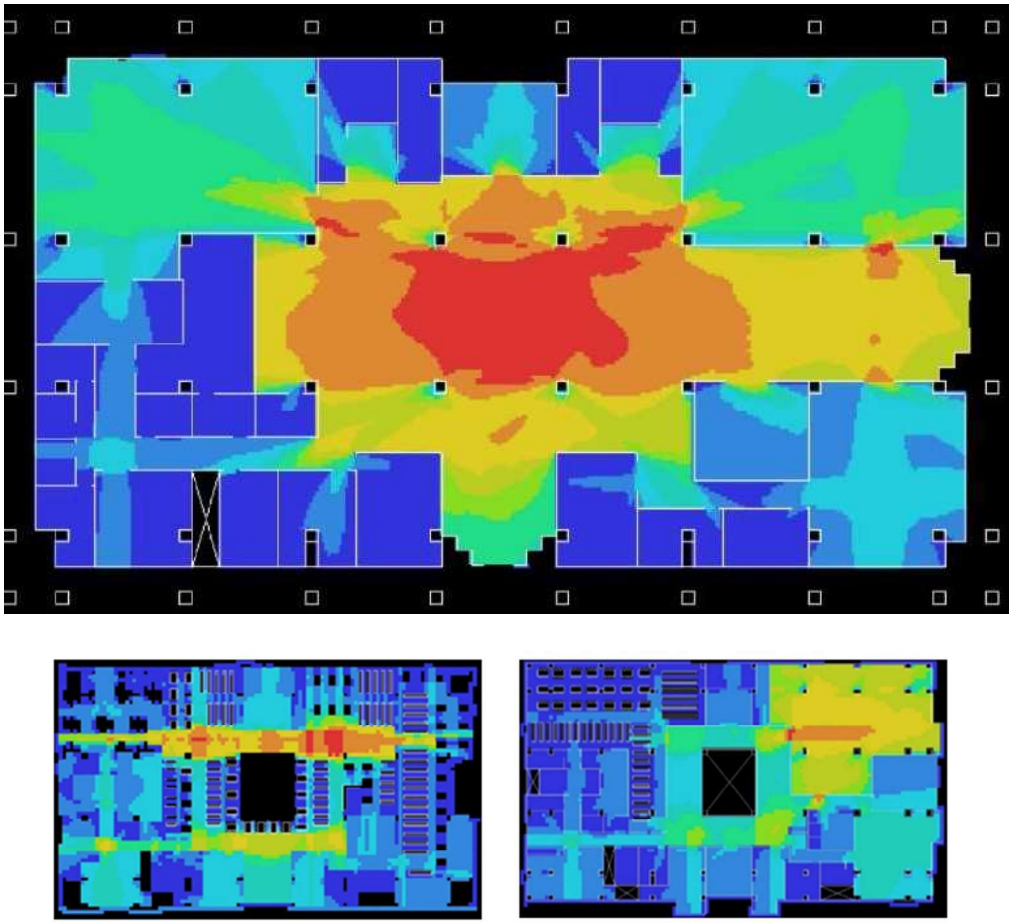


FIGURE 7. Space visibility connectivity analysis calculated by UCL Depth map 10 software.

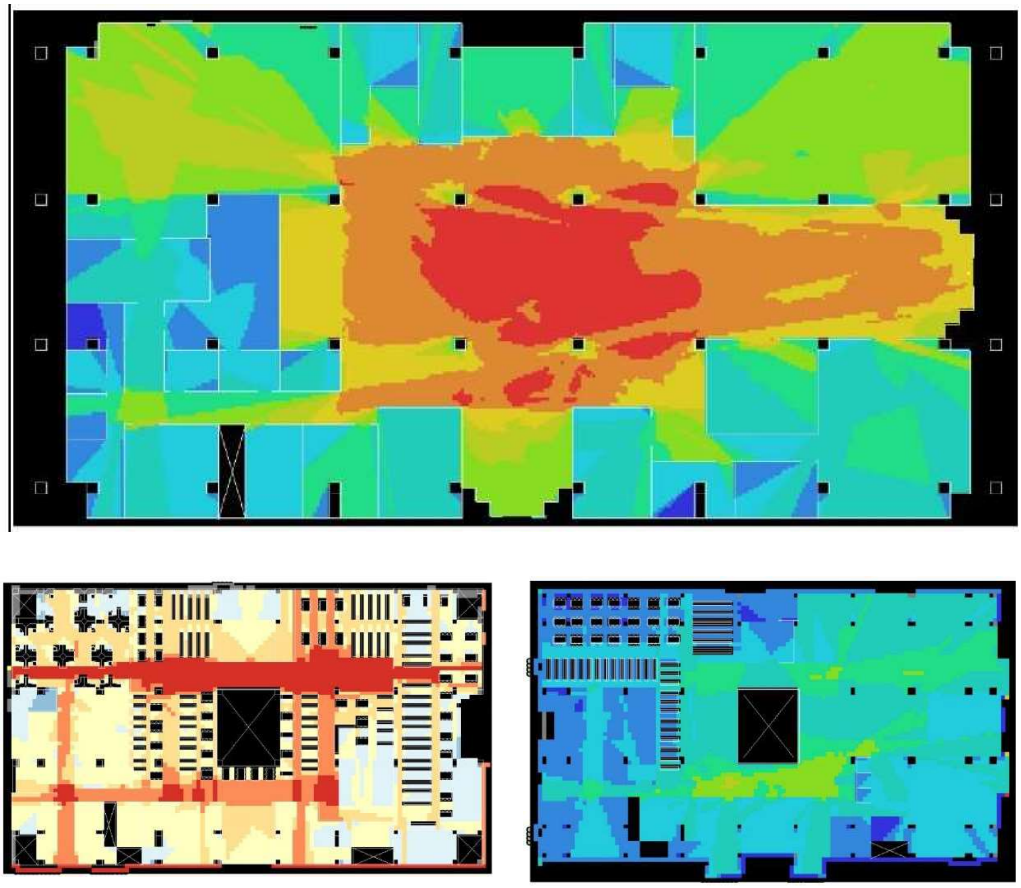


FIGURE 8. Space visibility integration analysis calculated by UCL Depthmap10 software.

6.3. Axial Map Analysis

Axial map describes the least number of axial lines covering all convex spaces of a layout and their connections. As seen at the **fig. 9.**

On the **ground floor** the main circulation corridor for reception area, the electronic archive and digital resource hall have the greater values of axial connectivity which are presented with red and orange colors.

On the **second floor** the main corridor path for lift and stairs also inner paths for multimedia room have the greater values of axial connectivity which are presented with red and orange colors, then followed by medium values at the secondary paths which are presented with yellow colors While the inner paths for the studying room and research room with lower axial connectivity values were presented in light blue and dark blue.

On the **fourth floor** the main corridor paths to the stairs and lifts also inner paths for closed reading hall has the greater values of axial connectivity which are presented with red and orange colors.

As seen at the **Table 4**, it was found that, the average connectivity values varies between **5.459** and **12.786.**

TABLE 4. Space syntax visibility values calculated by UCL Depthmap10 software.

Floor number	Axial map connectivity			
	Min.	Max.	Mean.	Std. deviation
Ground	3	6	5.459	1.155
2nd	2	84	14.669	14.233
4th	2	25	12.786	6.64
Mean	2.666	38.333	10.971	7.342

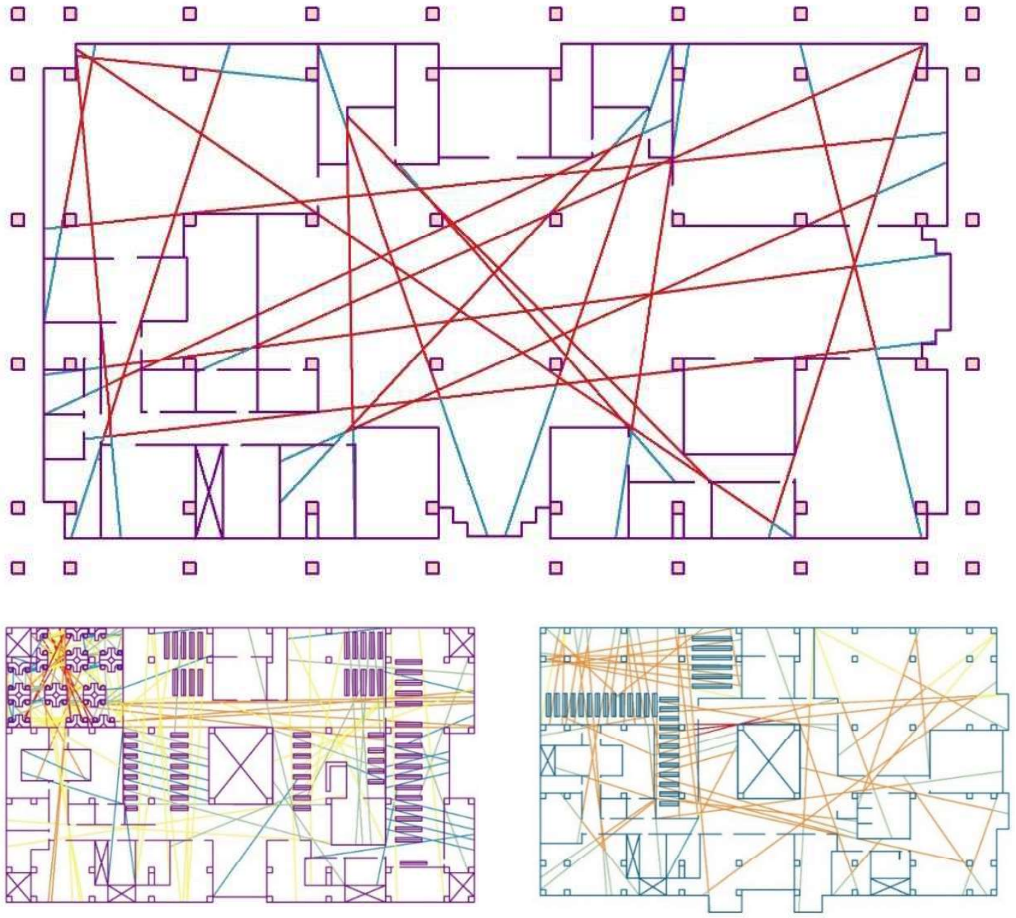
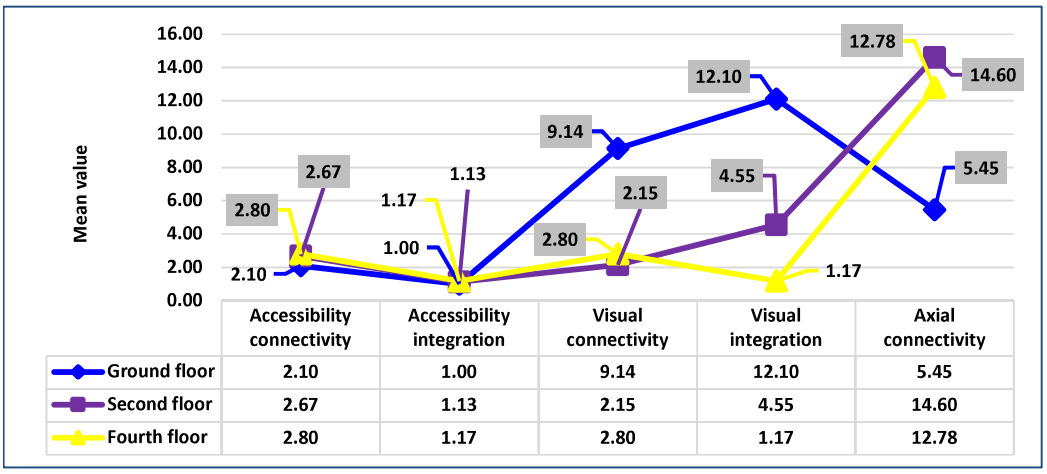


FIGURE 9. Space axial map connectivity analysis calculated by UCL Depth map 10 software.

7. DISCUSSIONS



	Accessibility connectivity	Accessibility integration	Visual connectivity	Visual integration	Axial connectivity
Ground floor	2.10	1.00	9.14	12.10	5.45
Second floor	2.67	1.13	2.15	4.55	14.60
Fourth floor	2.80	1.17	2.80	1.17	12.78

Regarding space syntax comparing three floors results as seen at the **fig.10**, in the **ground floor:** Regarding visual connectivity, it was found that the tangible aspects of spaces extent to which a space can be viewed from other spaces have the highest connectivity values.

Regarding visual integration, it was found the number of visual steps extent to the steps can be taken to get from a specific point to any other point have the highest integration values with the whole spatial system.

Its significantly provide strong visual intelligible and mental image about the way spaces related to each other in the spatial layout, also it is an indicator that obstacles elements not obstructed views horizontally and vertically.

In the **second floor**: Regarding axial connectivity, it was found the potential movement and vision for spaces extent to the straight and perfect linear paths have the highest axial connectivity values.

Its significantly provide direct access and movement and user can easy see every space in the spatial layout, also it is an indicator that obstacles elements not prevent users from direct circulation route.

In the **fourth floor:** Regarding accessibility connectivity, it was found that the physical connections inside spaces extent to the amount of direct connections of space with adjacent spaces have the highest directness connectivity values with each other.

Regarding accessibility integration, it was found the numerousness of connections of spaces to each other have the highest potential accessibility values with the whole spatial system.

Its significantly provide strong an easy reached for spaces, more used by users and high social interactions of spaces related to each other in the spatial layout, also it is an indicator that obstacles elements not obstructed movement horizontally and vertically.

8. FINDINGS

- **Significant factors of spatial configuration characteristics**

Space Syntax theory and its techniques can be used to analyze and diagnose the strength and weakness in the spatial configuration (organization structure) of academic library layouts functionally. Also a logical tool which able to combine both physical and social indicators in the spatial functional systems in order to identify their configuration in terms of differences and similarities.

This research has addressed the concept of syntactical structures segregation of spatial configuration characteristics which can achieve by spatial depth and physical obstacles elements. This is viewed by considering each space in itself is an independent structure carrying a specific effectiveness. Through that, it can be connected with different levels of other structures for the rest of the other spaces within the system. This independent structure carries certain characteristics in its internal entity that distinguish it from others. Furthermore, these characteristics provide the possibility of logical evaluation by linking indicators adopted by the research. These indicators include: accessibility connectivity, accessibility integration, visibility connectivity, visibility integration and axial connectivity.

- **Design implication findings**

The study found spatial configuration parameters are affected by the way designers allocate the spatial obstacles elements like: columns, partitions, temporary furniture , fixed furniture , atriums , stairs and elevators are taken as an obstacle that obstruct movement or block eyesight regarding space syntax analysis as high partition avoid obstruct movement and block eyesight, help in provide privacy, while furniture arrangement and low partition oriented the space away from pathways without block eyesight.

The study shows show that some obstacles block while other helped enhancing accessibility and visual inside the space, depending on space use.

While minimum step depth led to maximum integration, more accessibility, more visual range less control and less privacy.

9. CONCLUSION

- It is important for architect to build up his final decision supported by using space syntax as a design tool methodology in the first stage of the design process to understanding the space configuration as physical and visual relation between spaces, as the characteristics of the spatial configuration play a pivotal role in shaping and formulating these space in terms of functionality.
- The idea of space syntax and its technique success to detect the differences and similarities in the spatial configuration as a numerical and scientific data output, which support or reject out comes achieved from the other steps of the measurement tool that allow architects to test spatial constructs shaped ,showing as it might found some problems seems

10. RECOMMENDATIONS

- **Architect awareness**

Any architect specializing in the field of library design must set a special focus on the spatial configuration parameters to realize the important of these parameters and help them document the role of space in accommodating high level of efficiency respecting users, which in turn led to the implication of suitable conventional library space planning.

- **Space syntax tool**

Space syntax presents the only language for thinking about the space by focusing on the organization of space, movement, pattern and their social meaning as it is more scientific and more mathematical as it is a multilayered analysis technique; involves several types of analysis which can be integrated to reach accurate analysis results. Architects must be aware of different tools and knowledge to have a capability to use them, enabling them to comprehend the relationships between their designs and possible results through numerical and scientific data on designed spaces.

11. FURTHER RESEARCH WORK

Based on this study, there are a lot of aspects for improvement and further research in the study with regard to the academic library layout.

- The possibilities of technologies, the availability of resources online and new ways of learning changed the way people use the spaces and affecting greatly the physical design of library design. This fact transferred traditional design spaces into digital environments.

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