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Promoting spatial cognition in hospital buildings using space syntax analyses

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Abstract

Spatial cognition is a pivotal consideration in hospital buildings. Potential circulation configuration alternatives in hospitals have been filtered to 59 significant alternatives, to be simulated using space syntax analyses for measuring connectivity, visual integration, and visual step depth. Best alternatives have been determined via comparison and correlation analysis. A survey has been conducted, comparing the preferences of professional architects with simulation outcomes. Results show that best and worst alternatives exist in triangular and circular buildings, respectively. Also, cul-de-sac corridors are argued to promote spatial cognition better than looped corridors. Notably, cognition is inversely proportional to the curvature of the circulation spaces, number of nodes, and the number of branches. The survey showed a weak perception of the best alternatives, while respondents have a better perception of highly visible locations in these alternatives.

Keywords: Spatial cognition, Circulation configuration, Building layout shapes, Hospitals, Space syntax

Introduction

Spatial cognition (SC)

Spatial cognition (SC) can be defined as “the way human beings deal with issues concerning relations in space, navigation and wayfinding” [1]. SC can be also defined as “a branch of cognitive psychology that studies how people acquire and use knowledge about their environment to determine where they are, how to obtain resources, and how to find their way home” [2]. Hence, SC refers to the ability to understand your position in a building, accordingly, navigate to desired destinations [3]. This implies the recognition of the location, size, distance, direction, connection, shape, pattern, and others [1].

SC is a partial concept in the wayfinding behavior, which represents a more dynamic process to emphasize the circulation through the three-dimensional world. Wayfinding is the process of moving from a location to a desired destination in a timely manner [4]; it implies the aggregate task and not merely a part of it [1]. It requires users’ “different levels of knowing” and “different needs” [5]. Thus, it can be supported by proper SC, a signage system, modern technologies [6], spatial orientation, navigation, intelligence, awareness, and others [3].

Hence, the promotion of SC in hospitals is highly appreciated. In addition to linking functional and service zones, circulation spaces are argued to play an important role in promoting SC. The promotion of SC implies a complex set of processes due to the great number of factors involved, including (a) human factors such as cognitive mapping abilities, capacity of perception, interpretation, memorization, user experience, current psychological emotions, culture, and gender and (b) environmental factors such as understanding the built environment, the proper use of maps, signage, and navigation-support devices. Human factors are supporting the decision-making process based on the information gathered from the environment [7, 8].

Space syntax analyses: overview

Space Syntax[1] is a method used to analyze the spatial structure of built environments examining the interactions of people within. By applying mathematics, calculations of spatial inter-relationships are performed based on the strong correlation between movement and spatial layout. In contrast to other methods, Space syntax combines both tangible factors (such as movement, space configuration, etc.) and intangible factors (such as SC). Further, it provides various techniques to correlate/interpret results of spatial analyses [10]. In other words, space syntax establishes a connection between conceptual arguments and real-world confirmation; this can be translated into measurable applications using the measures provided. These quantitative measures produce graphical presentations that help realize spatial and environmental patterns and linkages [11].

Space syntax provides the ability to illustrate the intervisibility of spaces through the visibility graph analysis[2]. In this study, the main measures that enhance SC have been selected as follows:

a) Connectivity: it explains the number of connections that each space has to its direct neighboring spaces; therefore, it indicates the ability of the space to be seen from adjacent ones (local integration) [10]. Hedhoud et al. [13] selected connectivity to measure human's ability to navigate. Haq and Zimring [6] tested the mental recognition of people visiting the place, using connectivity rather than integration for the new users of a building.
b) Visual integration (VI): it is defined as the degree of accessibility that a space has to all other spaces in the system; this reflects the knowledge of the entire spatial system (global integration) [10]. Hillier et al. [14] found VI to be of greater significance, as it refers to the level of comprehension of the whole system. In tracking people in museum buildings, as an example, Choi [15] found VI to be an accurate measure of wayfinding, while connectivity is argued as more accurate when visits are repeated.
c) Intelligibility: it is simply the correlation between local integration (connectivity) and global integration (VI); it indicates how comprehensible the spatial system is. Intelligibility can be defined as "the degree to which what can be seen and experienced locally in the system allows the large scale system to be learnt without conscious

[1] The space syntax theory first appeared in 1984 as a method of space reading in "The Social Logic of Space" published by B. Hillier and J. Hanson [9].

[2] Visibility graph analysis is "a space syntax method for quantifying some socio-spatial properties of the built environment by mapping the floor plan into a grid" [12].

efforts" [10]. However, space syntax experts refer to the strong correlation between connectivity and VI in space syntax [6]. Hence, testing connectivity and VI already include testing intelligibility.

d) Visual Step Depth (VSD): it refers to the shortest path from a selected line or segment to all other lines or segments in the system, and the total depth of a system is the sum of all possible steps [16]. Hölscher and Brösamle [17] found strong correlation between VSD and factors affecting SC, accordingly wayfinding, such as time, number of stops, number of getting lost times, distance traveled, and distance/shortest route. Correlation values range from 0.65 to 0.83.

Previous work

Within the scope of hospital circulation analysis, Afsary and Gharipour [18] analyzed visibility and circulation in the community health clinic using space syntax analyses; the visual attributes included connectivity, VI, and VSD; applied on the organization of key spaces such as waiting areas, nurse stations, and doctor's office. IHFG [19] used SC and wayfinding to conduct international health facility guidelines for architectural and interior design. Jiang and Verderber [20] reviewed the planning and design of hospital circulation spaces, while Nazarian et al. [21] reviewed different approaches of people circulation in healthcare facilities. Many architectural visions recommended corridor widths to be minimized [22], while Carthey [23] discussed the advantages and disadvantages of minimizing hospitals' corridors to promote functional efficiency. Hölscher and Dalton [24] performed an experiment to judge the design complexity of corridor systems in buildings, using two modes of stimuli: the layout of corridors (plan view) and movies for simulated walkthroughs.

Several studies investigated certain architectural design principles related to the configuration and articulation of circulation spaces in hospitals. Lee et al. [25] developed an approach to measure the effect of distances traveled by nurses to patient rooms via a simulated model. Aksoy et al. [26] evaluated the relationship between hospital plans and navigation decisions of first-time users via a real experiment, investigating the connectivity, number of nodes, use of colors, and others. The behavioral analysis included time, number of stops, number of getting lost times, distance traveled, shortest route, speed, and stopping times. Padgaonkar [27] studied the impacts of minimizing the travel distances of patients using simulation, considering travel frequency, number of trips, trip difficulty rating, and others.

Adopting the approach of real case studies, Zabihi [28] investigated the capabilities of planting design in Kerman hospitals to promote users' wayfinding using space syntax. Also, Khan [29] studied the effect of VSD and other measures on the efficiency of spatial organization in a general hospital. In another sense, Khan [30] analyzed the visual integration in six hospitals of two form types (courtyard and linked compact building blocks). Munzer and Stahl [31] tested a complex building to identify the factors that would affect SC. Haq et al. [32] conducted a correlation analysis between configuration, wayfinding, and SC in a real-life hospital using a VIEUCoM model.

Space syntax has been widely used in various scopes, e.g., enhancing outdoor campus design [33], investigating SC approaches in urban spatial environments (Esposito et al

[34], analyzing museum and tomb buildings [35], studying permeability of different site cluster types [36], testing pedestrian flow in streets [37], and assessing integration, connectivity, and visibility in elementary schools [38]. In another sense, Yamu et al. [10] gave a holistic overview of various space syntax concepts.

In hospital buildings, Haq and Luo [39] reviewed the use of space syntax in healthcare research to suggest some future applications. Other tools are still useful such as Grasshopper scripting which has been used by Jalalianhosseini [40] to conduct visual analysis. Jeong and Ban [41] used a J-Studio for Architectural Planning (J-SAP) program to validate the integration value of proposed design alternatives.

The literature reviewed reveals that most related studies have been conducted on real cases. Thus, findings might be useful for developing these cases, while results and recommendations cannot be generalized. This makes this study significantly different in nature and scope. No clear generic design guidelines to promote SC were found to be applied directly to typical hospital cases. This outlines the paper's aim, scope, and accordingly the methodology proposed.

Methods

Aim of the study

The aim of the study is to promote SC in hospitals through the configuration of circulation spaces, using three space syntax analyses/measures. Impacts of building layout shapes (BLSs), configuration of corridors, number of branches, nodes, segments, and others are to be investigated. This helps architects select the best circulation configuration alternative (CCAs) and avoid the worst, for the sake of promoting SC in hospitals.

Limitations and characteristics

For the aim to be attained, limitations have been outlined as follows:

- Space syntax measures selected are connectivity, VI, and VSD. Intelligibility is used for statistical purposes. Other measures that might promote SC in hospital building design, e.g., user's experience, signage, colors, and materials, are considered out of the study scope.
- Basic and symmetric shapes (either BLSs or CCAs) have been prompted. Complex and asymmetric shapes provide an intensive number of alternatives that is hard to be covered within the study. In general, hospitals require simple circulations tree except in specific cases that are considered out of scope.
- All the alternatives proposed and further analyzed have the same floor area, size of entrance lobby, and corridor width for analysis and comparison purposes.

Methodology and structure

For the aim to be attained, the study has been structured as follows. First, a wide spectrum of CCAs applicable to hospital buildings has been developed. To do that, an extensive review on hospital buildings has been conducted to identify the architectural design parameters that would affect the development of CCAs, e.g., building layout, floor area, average size of entrance lobby, average width of corridors, percentage of the circulation space, and common spatial configurations. Space syntax analyses, using the selected three measures, have been applied, results have been analyzed, and statistical correlation between variables has been calculated. A questionnaire has been designed and applied to compare academic and professional architects' feedback with the numerical outputs of the analyses. At last, attainments, features, and significance of variables have been investigated.

Development of CCA in hospital buildings

Architectural standards of hospital buildings

In view of hospital standards, different CCAs can be classified to be linear or nonlinear, dead-end corridor (cul-de-sac), or racetrack (loop) [42]. Other research added duplex, cluster, radial, and other configurations [22]. In this study, corridor types have been classified into cul-de-sac or looped corridors, and each can be further classified into branched or not. Also, CCAs can be designed in a compact circle, triangle, square, or others [42]; however, different possible layout shapes such as square, rectangle, and L shape have been included in this study. However, size of hospital buildings varies from 50 beds to >600 beds, while preferred architectural design module dimensions are 12m, 6m, and 3m, with minimum of 1.5m and 2.25m for ordinary and trolleys access corridors, respectively [43]. The minimum width of ordinary and treatment rooms is 3m and 3.6m, respectively, while the area of these rooms varies from 20 to 30m^2 [44]. Based on that, the basic architectural design module is proposed to be 4m, i.e., corridor widths equal 4m and room dimensions are proposed to be 4m × 8m, expandable to suit different functions as shown in Fig. 1.

Development of proposed CCAs

In view of the limitations set, the hospital building floor area has been limited to 400 m^2 in all CCAs. 10% of the building floor area (640 m^2) has been set to the main entrance lobby, while the area of corridors is proposed to be 10% of the total floor area (640 m^2).

As shown in Fig. 2, eight basic shapes have been proposed for the hospital layout: square (S), rectangle with an entrance on the longer side (R), rectangle with an entrance on the shorter side (R′), L shape (L), U shape (U), triangle (T), circle (C), and finger plan (F), along with four corridor types. Some corridor types cannot match/be applied to specific layout shapes such as looped corridors in L, U, and finger plan layouts, while some CCAs are much similar to others with no sensitive/significant difference so they have been excluded. Summing up, worked-out CCAs have been filtered to 59 alternatives.

Simulation

Results

As shown in Fig. 3, CCAs have been simulated via DepthmapX[3], classified, and ranked based on the measures identified before; a lot of findings have been outlined as shown below while more details are presented in Additional file 1: Appendix A:

[3] DepthmapX is an open-source and available multi-platform software to be used in conducting spatial analyses in different scales (buildings, small urban areas to whole cities or states). The software was originally developed by Alasdair Turner from the Space Syntax group. Specifically, it produces a map of spatial elements, connects them via relationships, then performs a graph analysis as an output. Outputs include visibility graph, and visual, axial and segment analyses. Moreover, DepthmapX may also be embedded in applications using other programming languages for allowing various types of analyses in solving more complex problems [45].

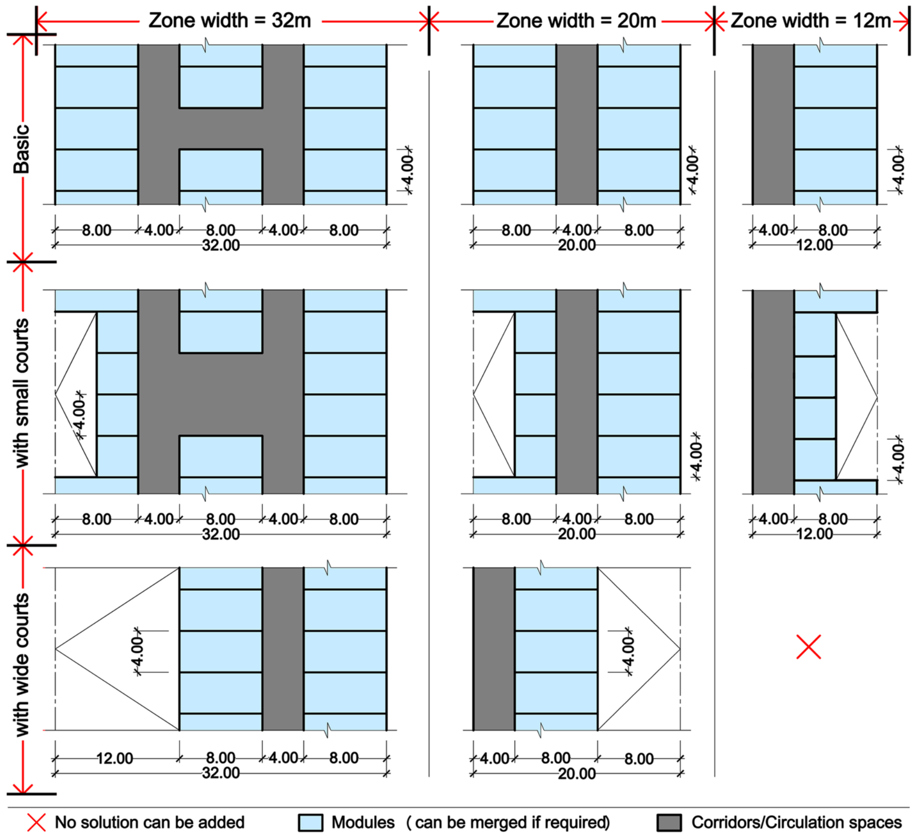


Fig. 1 Proposed dimensions to be considered in the design of CCAs

(1) Alts 58, 34, and 38 are the best CCAs in connectivity, VI, and VSD, respectively.
(2) Overall, no CCA achieves top 10 values in all the studied measures, while 9 CCAs achieved top 10 values in both connectivity and VI; these CCAs are Alts 2, 22, 34, 38, 40–43, and 55.
(3) CCAs articulated in the finger plan, and triangle then L shape represent best ones among others as shown in Fig. 3a, while circular BLS represent lower values in general.
(4) Triangle and circular BLSs represent the best and worst connectivity values, respectively; these ones include 5 of the best alternatives and the worst 10 CCAs, respectively.
(5) Regarding VI, CCAs in L-shaped CCAs represent the best cases, while circular BLSs achieve the worst values significantly; all the 6 circular BLSs are from the worst 10 cases among the entire alternatives studied.
(6) VSD results show that square then rectangle layout shapes provide best values, while circular BLSs presented better values than those achieved in connectivity and VI measures. However, U shape and finger plan CCAs are the worst alternatives. No significant differences between the best and worst CCA have been found.

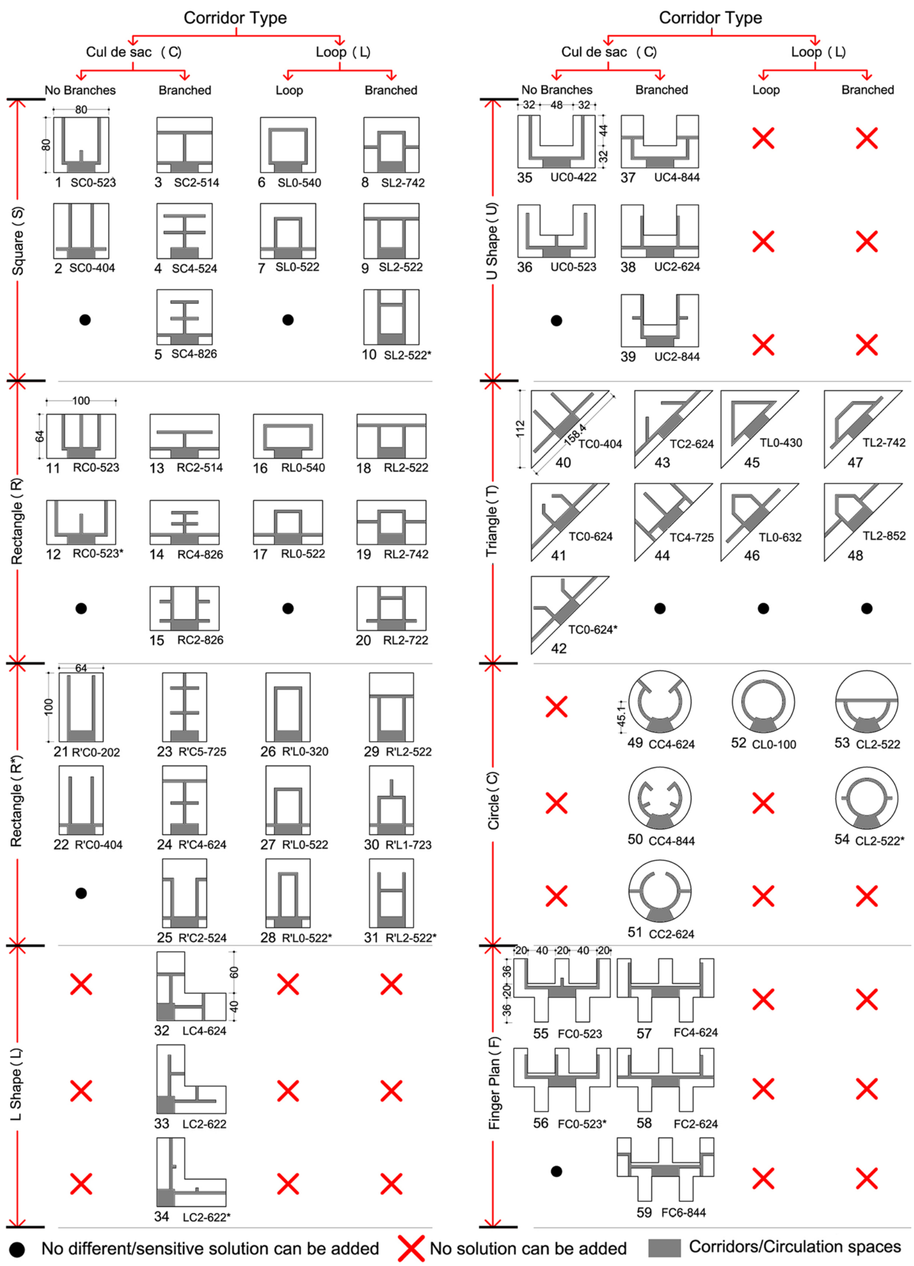


Fig. 2 Proposed CCAs to be studied. Notes: (1) All dimensions presented are in meters. (2) For all CCAs, proposed building layouts' area is 6400m^2, the area of the entrance lobby is 640 m^2, the total area of the circulation spaces is 640 m^2, and the corridor width is 4m. (3) All CCAs have been numbered serially from 1 to 59 (as presented below each CCA) and structured to have a code; this code contains 7 digits structured as (Xxa-bcd*); where (*X*) is a letter that denotes to the used BLS among the 8 proposed ones; (*X*) can be (S, R, R′, L, U, T, C or F) which denotes square, rectangle with an entrance on the longer side, rectangle with an entrance on the shorter side, L shape, U shape, triangle, and circle or finger plan, respectively; (*x*) is a letter that refers to one of two considered corridor types, either cul-de-sac (C) or looped (L). (a), (b), (c), and (d) are separated 1-digit numbers of branches, segments, nodes, and dead ends/exits, respectively. (*) is added only to differentiate the code if all previous features are the same. For example, Alt (TC0-624) refers to the CCA designed in a T-shaped building layout and with cul-de-sac corridors, no branches from the main corridor, 6 segments, 2, nodes and 4 dead ends/exits. Alt (TC0-624*) is another CCA with the same features

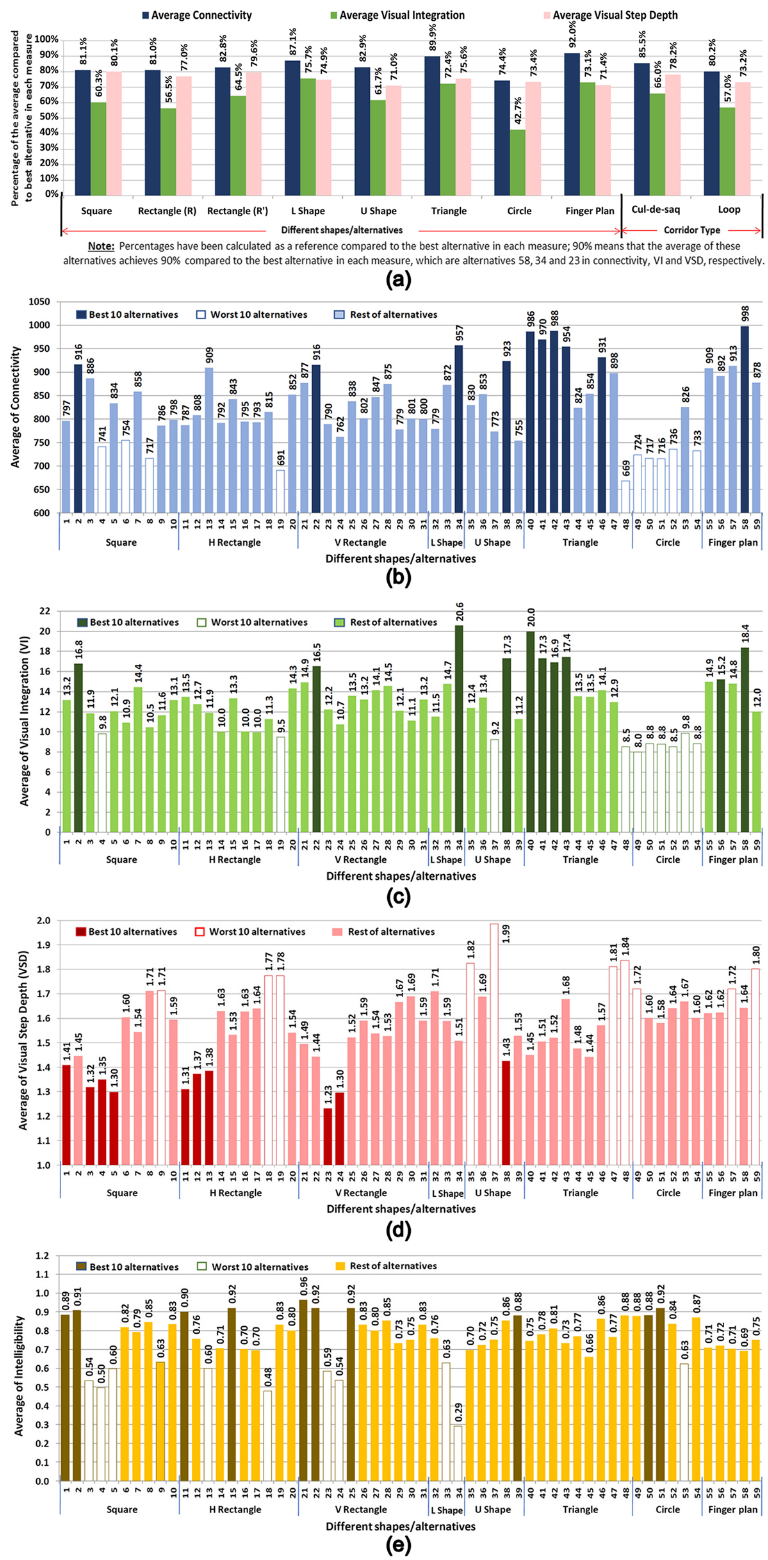


Fig. 3 Simulation results of CCAs: **a** layouts average compared to best CCAs in each measure, **b** connectivity, **c** VI, **d** VSC, and **e** intelligibility

Correlations between CCAs features and the studied measures

The correlations between simulation results have been calculated. As shown in Table 1, connectivity and VI values are strongly correlated showing how the connection between adjacent spaces would promote the comprehensibility of the entire spatial system. Also, the number of nodes, accordingly number of branches, is correlated to VSD, since the number of path edges from a root node to the chosen one is dependent on the number of nodes, and the number of segments as well. This means that the number of nodes indirectly affects the three SC measures selected in the study, i.e., reducing the number of nodes enhances connectivity and VI.

Recommended CCAs

Connectivity, VI, and VSD measures are considered in comparing the CCAs developed, while intelligibility is used for statistical purposes. Figure 4 presents recommended CCAs in each BLS. Alts 34 and 38 are the best CCAs in L- and U-shaped building layouts as per the measures selected, respectively, while Alts 2, 22, 53, and 58 can be recommended based on comparing the results of best CCAs in each measure separately. Overall, the majority of best CCAs, in view of the three measures studied, have cul-de-sac corridors.

Simulation results vs. architects' perspective: a comparison

Comparing simulation results with architects' perspective helps analyze the effect of human experience against the mathematical results. Hence, a survey has been conducted on selected professional architects and academic staff members. The aim of the survey is (a) determining experts' preferences of main circulation patterns using some of the developed CCAs and (b) comparing the preferences with simulation results.

Questionnaire design

Questions have been articulated as follows:

a) As per question 1, respondents are requested to select the best and worst CCAs among the 4 alternatives provided, in terms of wayfinding (in 6 different trials/sub-questions) as shown in Table 2. Hardness of the sub-questions varies due to the variation of the results of the space syntax analysis.
b) In question 2, respondents are requested to identify the best visible location in four CCAs as shown in Fig. 5. Different shapes, corridor types, and locations have been used for analytical purposes in sub-questions.

Overall, 38 respondents completed the survey; they have different genders, ages, qualifications, and affiliations as classified in Additional file 1: Appendix B. A percentage of 39% of the respondents are male, against 61% of female respondents. As for the scientific degree, 42% of the respondents hold Ph.D. degrees, while 34% of the respondents hold the M.Sc. degrees, i.e., most respondents have postgraduate degrees. Moreover, respondents have diverse ages; 39% of the respondents are between 25 and 32 years old, 21% are between 33 and 40, and 37% of respondents

Table 1 Correlations between CCAs feature and simulation results

		Measures				Features of CCAs			
		Average of Visual Step Depth	Average of Intelligibility	Average of Visual Integration	Average of Connectivity	Number of Dead Ends	Number of Nodes	Number of Segments	Number of Branches
Features of CCAs	Number of Branches	0.10	- 0.28	**- 0.35**	- 0.28	N	N	N	**1**
	Number of Segments	0.19	- 0.05	- 0.19	- 0.16	N	N	**1**	
	Number of Nodes	**0.46***	0.05	**- 0.42**	**- 0.42**	N	**1**		
	Number of Dead Ends	- 0.28	- 0.03	0.13	0.20	**1**			
Measures	Average of Connectivity	- 0.21	- 0.19	**0.88***	**1**				
	Average of Visual Integration	- 0.29	- 0.09	**1**					
	Average of Intelligibility	0.13	**1**						
	Average of Visual Step Depth	**1**							

N Not significant correlation
Bold numbers (*) High positive correlation
Bold underlined numbers: High negative correlation

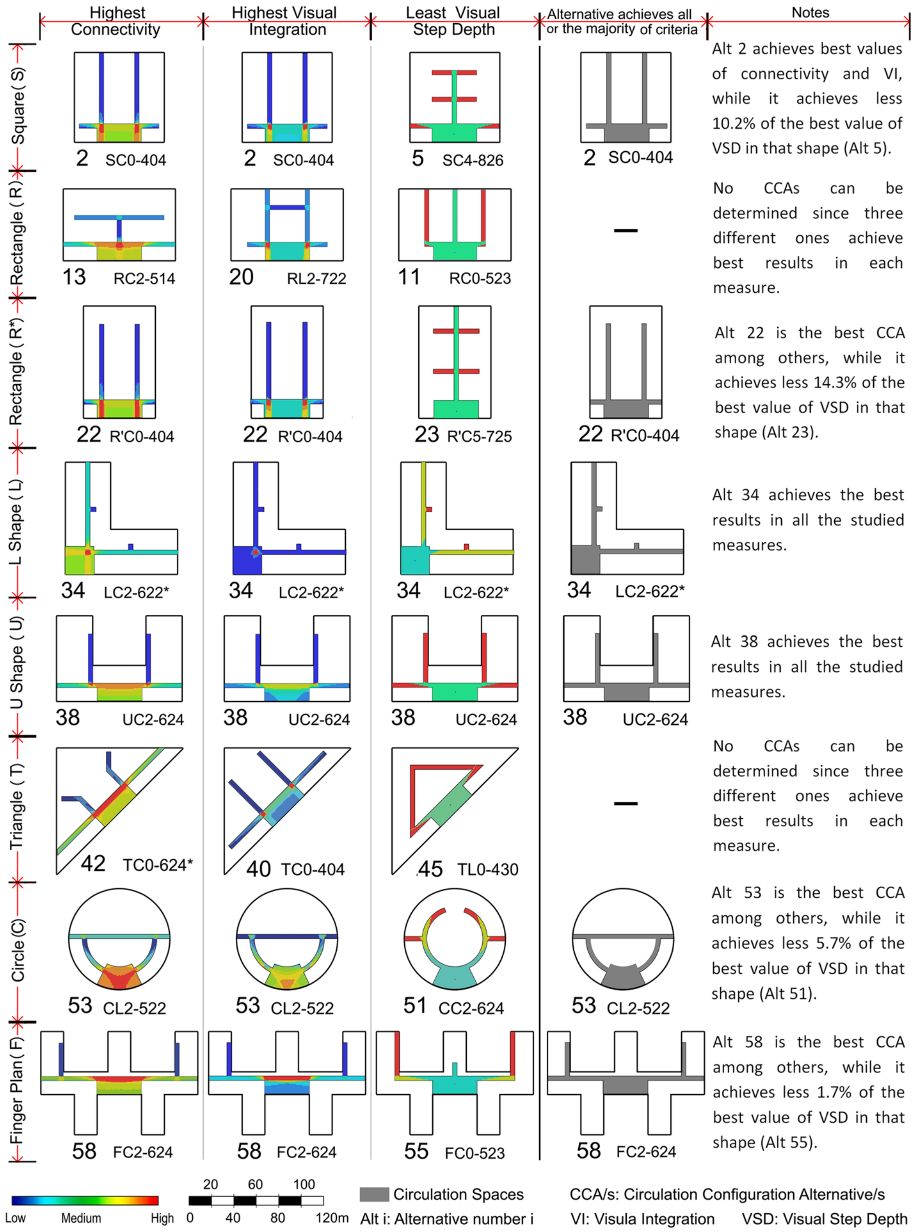


Fig. 4 Best CCAs based on the studied measures

are 41 years old or more. Summing up, the sample that responded to the questionnaire is technically qualified, diversified, and balanced.

Survey results

In question 1, sub-question 1 represents the highest right selection, while sub-question 6 presents the lowest right selections since it is the hardest question to answer as no fixed features were provided. Although many measures have been fixed in sub-questions 4 and 5, it also met weak perception to best CCAs. Most respondents failed the right answer for the sub-questions 2, 4, 5, and 6; the mutual relation between these wrong selections is that they are the simplest CCAs among others. This denotes that best CCAs

Table 2 Details of the first question in the survey (what are the best and worst CCAs among the 4 given ones in terms of wayfinding?)

Sub-questions	Fixed feature/s			CCAs (questions' options)				Difference between best and worst CCAs*		
	Shapes	Corridor type: Cul-de-sac	Corridor type: loop	a	b	c	d	Connectivity	Visual Integration	Visual Step Depth
1	-	√	-	Alt 2	**Alt 58**	Alt 42	**Alt 51**	39.3%*	109%	- 3.9%
2	-	-	√	**Alt 46**	Alt 30	Alt 6	**Alt 52**	26.5%	65%	4.3%
3	√	-	-	**Alt 15**	Alt 12	**Alt 19**	Alt 18	21.9%	40.9%	13.7%
4	√	√	-	**Alt** 35	**Alt 37**	Alt 36	**Alt 38**	19.3%	86.9%	28.2%
5	√	-	√	**Alt** 45	Alt 47	**Alt 48**	**Alt 46**	28.2%	39.7%	14.5%
6	-	-	-	**Alt 40**	Alt 36	Alt 2	**Alt 52**	34%	133.7%	11.7%

√ Fixed feature in the denoted sub-question

- Varied feature to be tested in the denoted sub-question

(blue) Best CCA in each sub-question as per Space Syntax

(dark red) Worst CCA in each sub-question as per Space Syntax

CCA/s: Circulation Configuration Alternative/s. **Alt (i):** Alternative number (i).

Notes:

(*) Differences between best and worst CCAs have been calculated as a percentage difference between the best CCA and worst one in each measure and sub-question, e.g. in sub-question 1, the difference in connectivity measure equals (connectivity value of Alt 58 as a best CCA)/(connectivity value of Alt 51 as a worst CCA) - 1 = 998 / 716 -1 = 0.393 (39.3%).

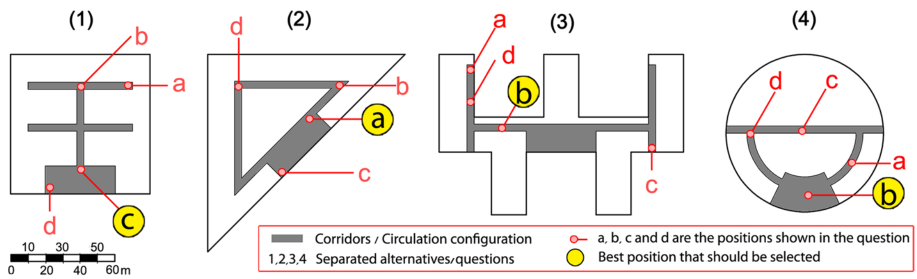


Fig. 5 Analyses of the second question in the survey (what is the best position among others in each given CCA in terms of visibility?)

cannot be found easily in general; overall, there is a weak perception and hardness in prediction of best CCAs, while the ability to find out the worst CCA is much better. In question 2, respondents showed better ability in finding the best positions; more than two thirds of the sample managed to find the best positions requested, rightly. Briefly, designers could easily find which position is better visible in single CCAs, while it needs experience to avoid worst CCAs as detailed in the survey results shown in Fig. 6. This refers to the usefulness of the study; it provides clear guidelines of how to promote SC via the configuration of CCAs.

Discussion

In general, the developed 59 CCAs represent a wider spectrum of circulation design options but with the considerations detailed below:

(1) Best CCA/s in a specific BLS can be applied to other BLSs to provide the same performance. In other words, there are no restrictions in applying CCAs to specific shapes while shapes can be selected freely.
(2) The performance of larger CCAs has the same order of basic ones in connectivity and VI values as shown in Fig. 7; CCAs can be applied widely even with a different scale with considering the lengths as a functional criterion.
(3) In-between CCAs and integrated ones may not provide better or even average values of measures as predicted, for example, the performance of polygonal CCA is not within the average between square and circle layout shapes as shown also in Fig. 7. On the other hand, the higher number of nodes in the polygonal shape is one of the main causes of lower connectivity and VI with higher VSD based on the previous correlation results; this presents why single simulations should be conducted to test each specific case as found in the literature.

Simulation results present reasonable and reliable findings in general, for example, circular BLSs represent worst cases since the vision is corrupted along the curved corridor. It also provides non-functional use for rapid trolley movement; this is why best CCAs in circular layout shapes is the one with the minimum curves. Although triangular BLS provides best measures among the studied shapes, no recommended single CCA or even specific features can be observed. CCAs in a finger plan shape present better results in connectivity and VI than most shapes; this reflects the importance of including a main

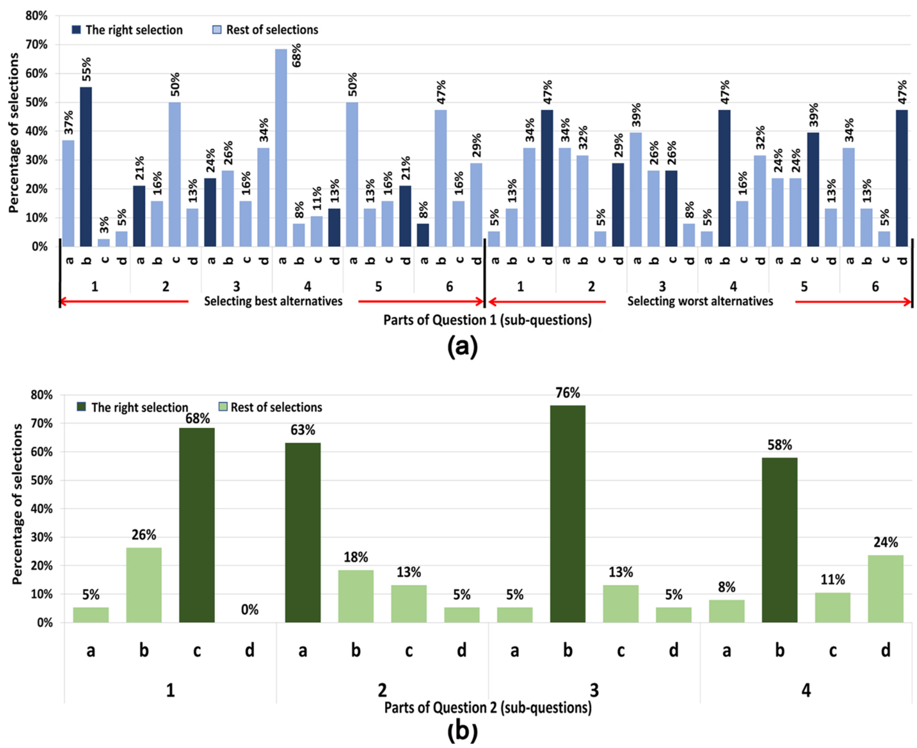


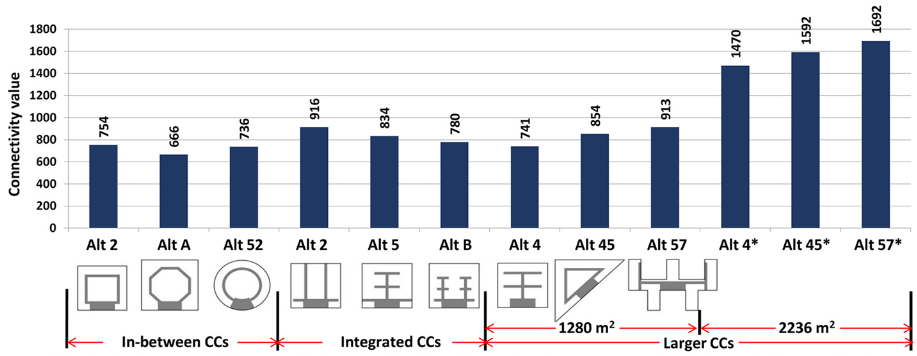
Fig. 6 Survey results: **a** Question 1. **b** Question 2

corridor through the plan to be branched to hospital zones; Alts 5, 13, 23, and others are confirming the same concept in other shapes. The majority of best CCAs have cul-de-sac corridors. Briefly, architectural designers should use finger plan BLSs and cul-de-sac corridors to promote spatial cognition, while they should avoid circular BLSs either due to functional or cognition purposes.

The survey illustrated that respondents select Alts 6, 35, 45, and 36 in sub-question 2, 4, 5, and 6, respectively; they are the simplest ones although they are not the right selections; the majority of designers in the selected sample has a confliction between simplicity and SC promotion; however, both can be achieved in Alts 34, 38, 58, and others, while others such as Alts 5, 20, and 53 are the opposite cases. The survey results reflected the ability of questionnaire takers to identify the most visible/cognitive locations in CCAs provided, while it was hard for them to recognize the best CCA when compared with others. It is important to simulate different CCAs not simulated in the study with the same methods and measures, because matching CCAs with others to predict the performance of in-between or integrated ones is not true in general.

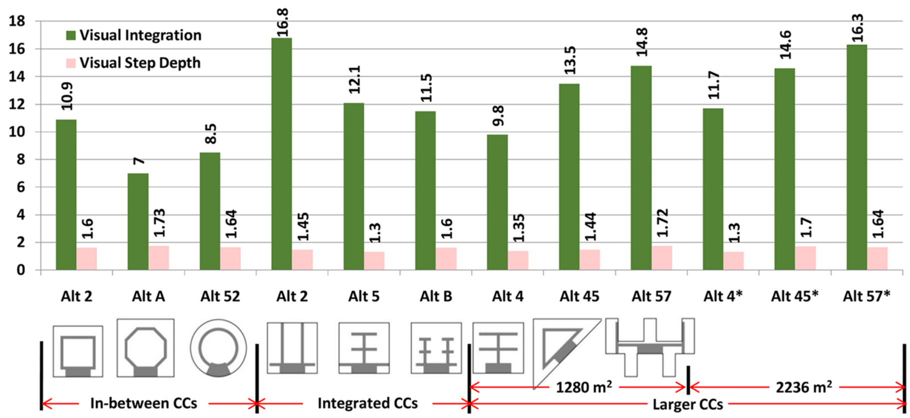
From a practical point of view, simplified CCAs are not necessarily correlated with high spatial cognition; therefore, architects are strongly recommended either to select among the successful alternatives presented in this study or perform space syntax analyses of the CCA organization they developed.

In addition to the configuration of CCAs, distances for promoting social relationships, maximizing users' safety, and preventing the spread of infections should be studied. To do so, an advanced multi-agent simulation, a virtual reality environment or



(*) refers to the shape with larger scale, for example, Alt 4 refers to the aletrnative as studied before with the same fixed area (1280 m²), while Alt 4* has the same CCA shape but with larger scale (2236 m²).

(a)



(*) refers to the shape with larger scale, for example, Alt 4 refers to the aletrnative as studied before with the same fixed area (1280 m²), while Alt 4* has the same CCA shape but with larger scale (2236 m²).

(b)

Fig. 7 Results of in-between, integrated, and scaled CCAs out of basic ones: **a** Connectivity. **b** VI and VSD

Building Information Modeling for each CCA could be prompted. This will help in virtually incorporating these variables within the design process as technically studied via other research works (e.g., Gath-Morad et al. [46] and Esposito et al [47]).

Conclusions

The aim of the study is to promote SC in hospitals testing the impacts of the configuration of circulation spaces. Three space syntax measures have been selected (connectivity, VI, and VSD). Accordingly, 59 significant CCAs have been filtered out of different eight building shapes, two corridor types, and branching possibility. DepthMapX as a simulation software has been used to compare determined CCAs based on selected measures. Certain simulation variables have been fixed, e.g., all corridors have the same width (4m), all the BLSs studied have the same floor area (6400m^2), and the entrance lobby size of all CCAs is 640 m^2, comprising for 10% of the floor area. A survey has been conducted using some developed CCAs to compare the preferences of professional architects with the numerical outputs of the simulation.

Results show that best connectivity and VI measures have been found in triangle and L shapes, respectively, while worst CCAs in connectivity and VI are circular ones. VSD results showed that CCAs in square then rectangle layout shapes provide best values, while CCAs in U shape and finger plan are the worst CCAs due to longer travel distance. Also, CCAs articulated in triangle then L shape represent best CCAs among others, while circular layout shape represents the overall lowest values. With analyzing all studied measures mutually, SC is inversely proportional with curves, number of nodes and branches, while cul-de-sac corridors present better performance than looped ones. Connectivity and VI measures are highly correlated; 9 CCAs achieved top 10 values in both connectivity and VI. Number of nodes, accordingly number of branches, is correlated to VSD, while VSD is correlated negatively with connectivity and VI. As a result, number of nodes is controlling indirectly the three measures related to SC; reducing number of nodes enhances SC with extending the VSD in general.

The survey, conducted on a sample of architects, presents a weak perception of best CCAs, while the ability to find out the worst one is much better. Although many features have been fixed through sub-questions, best CCAs have been hardly recognized. Moreover, most respondents selected the simplest CCAs rather than the right answers in some sub-questions; there is a confliction between simplicity and SC; however, both can be achieved in some Alts. On the other hand, respondents have better ability in finding out the most visible locations rather than comparing CCAs, since more than two thirds of respondents found the most visible locations rightly.

Overall, the study provides main guidelines that would help designers in developing their design proposals, although there is a need to simulate each single case if varied strongly over the studied ones. Moreover, CCAs can be applied even with different scales. Larger CCAs have the same order of the basic ones regarding connectivity and VI values. In-between CCAs and integrated ones may not provide better or even average values in the selected measures, since they have different number of nodes the fact that affects results. Briefly, architects should use finger plan shape and cul-de-sac corridors in their designs, while they should avoid circular BLSs; also they should not rely on simplifying corridors; instead, they should simulate their designs case by case. The study can be extended towards other features and options, such as different building shapes (H, X, T, and S shapes) and location of entrances. Many factors to promote SC can be further studied such as travel distance, vertical circulation consideration, distances to promote social relationships and users' safety and prevent the spread of infections, and signage. A complete computational tool, an advanced multi-agent simulation, a Building Information Modeling, or a virtual reality environment can be developed to (a) evaluate CCAs based on embedded algorithms extracted from an intensive number of predefined simulations; this essentially include many of the fixed variables such as human factors, or (b) investigate best potential CCAs for complex-shaped hospitals.

Abbreviations

SC	Spatial cognition
CCA/s	Circulation configuration alternative/s
BLS/s	Building layout shape/s
VI	Visual integration
VSD	Visual step depth
Alt/s (*i*)	Alternative number (*i*): *i* ranges from 1 to 59 in this study

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44147-022-00153-w.

Additional file 1: Appendix A. The following table illustrates the CCAs features, code, simulation results and ranking based on the studied measures. Appendix B: The following figure illustrates the specifications and classifications of the questionnaire takers (38 respondents).

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Authors' contributions
All authors contributed to the manuscript and have read and approved the final version. KAY and AMAY outlined the study idea, designed the methodology, performed the literature review, conducted the simulation and its analysis, and are responsible for writing the manuscript details, figures, and revisions.

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Availability of data and materials
All data generated or analyzed during this study are included in this published article. Additional file 1: Appendix (A) includes all raw data conducted via the used software (DepthMapX), which has been further analyzed via the paper sections.

Declarations

Ethics approval and consent to participate
The research included a questionnaire-based survey. All respondents are professional architects (above 20 years old) and agreed to participate in the questionnaire as a part of this research.

Consent for publication
The manuscript does not contain any individual person's data in any form (including individual details, images, or videos). Further, all participants are professional architects (above 20 years old) and agree to publish the results of the questionnaire.

Competing interests
The authors declare that they have no competing interests.

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