SPATIAL ANALYSIS OF HOSPITAL DESIGN USING PARAMETRIC TOPOLOGICAL INFORMATION: MOLINETTE HEALTHCARE COMPLEX AND LALEH HOSPITAL CASE STUDIES

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Abstract -
The importance of the architectural design of healthcare buildings can be traced back to their particular usage, which includes administrative and clinical functions in addition to those open to the public. For this reason, the most relevant feature in the conformation of sanitary buildings is the access to the areas. According to the different architectural plan design and world-wide experiences, various hospitals styles and types were defined over time.In this article, the spatial configuration has been investigated with the aim of analysing the efficiency of spaces in functional terms. Within this framework, Space Syntax, as a theoretical and practical method, has been applied using data modelling tools. The core of the analysis relies on the mapping on the architectural plan of the level of access, including the degree of taking advantage of natural light and ventilation. Two case studies with different layout systems were analyzed and the outcomes compared. The procedure implemented represents a useful tool for studying architectural qualities in existing hospitals as well as a reference guide to screening new constructions.

I. INTRODUCTION

Architecture and architectural qualities depend on what type of building is under investigation, meaning it refers to its main function and usage (Forty, 2000). While some of these architectural qualities are important and essential for all types of buildings, some may be more significant than others in a building with a certain function and a particular user as a goal of architecture. For instance, the access and security options are the most important consideration in the airport infrastructure while in a university they can be considered as the secondary qualities (Shirley, 1974). In sanitary buildings, which contain different functions and subdivisions, several styles have been created over time to provide the greatest quality. According to this, any care building can be classified in one or two settings. In this study authors investigated hospitals case studies as they provide the most general outline in healthcare complex and worldwide examples are available. The circulation network in the building defines the concept of the architectural design and presents the mainline and division contributing to the definition of spaces and the allocation of functions. Accessibility and environmental qualities are the main factors which determine the efficiency of the system. Considering the special usage of the space, it gains value to provide maximum mental and physical hygiene for users by providing as much as possible natural lighting and ventilation. The vertical and horizontal paths through building provide access to other functions. Although there is some usage in the hospital that needs to be in the most private position, the main spaces contain activities that need the most possible access between caregivers and patients. Accordingly, the nurse station is the core of the hospital when designing the program plan. In addition, it is important to have the shortest travel time and distance between the nurse spot and other rooms. Traffic and Distance parameters are introduced to calculate the circulation value of each two points in a specific area of a sanitary building (Shirley, 1974). To calculate the spatial distance between two spaces, a measuring system with respect to the distance in meters must be considered. In fact, two points with short physical distance can have many enclosed spaces located in between. As a result, access through them is limited. To measure the relationship between two spaces in spatial configuration, in the late 20th century, the Space Syntax method was introduced, as the level of accessibility of each space relating to social behaviour and usage patterns (Hiller, Hanson, 1984).

II. HOSPITAL WARD LAYOUTS OVERVIEW

Architecture in one sight is assumed as the Form, Function and the relationship between them (Greenough, 1947). Space and its form must have certain qualities to meet the needs of the activities taking place within it in the appropriate way. According to this overview, architectural qualities vary from building to building based on their function. As sanitary buildings are built to host a various number of caregiving activities, their architecture is shaped around the main pedestrian circulation. The hospital can be considered as a city. Like the city includes different functions like shops, residential and industrial blocks; the hospital contains the departments, nurse station and rooms, caregiving rooms. All of these rooms are working as single units. According to this vision, the main pedestrian path inside a hospital plays the same role as the main street

of a city. This path connects and assembles separated elements of the unique built environment. As the traffic ofthe main street flows inside the urban zone and provides the needs and services of the city, the circulation defines the main character of urban fabrication and texture (James, Noakes,1994). Different typologiesof the circulation network can be defined as the ward layouts. In this attitude, the ward is combined with a circulation path and different spaces which are spatially organized around the main circulation path (Nazarian, Price, Demian, 2011). The capacity of the patient' space is playing an important role in the access definition. There are various roles in different national standards which allow the limits of the maximum capacity of the multi-users room (Dowdeswell et al, 2004). There is a different approach to classify the circulation systems in sanitary buildings but all of them are based on how the caregivers and patients' spaces are designed around the main access path and as the result how they are linked together (Nazarian, Price, Demian, 2011). James and Tatton-Brown recognized seven categories as Simple open or Nightingale, Corridor or Continental, Duplex or Nuffield, Racetrack or Double corridor, Courtyard; Cruciform or Cluster and Radial (Alalouch et al 2009) Another categorizing approach is presented by HBN4 as Nightingale; Sub-divided ward; Nuffield; Falkrik and Nucleus. Nazarian, Price and Demian proposed theirs on the basis of the combination of the mixture of the two attitudes aforementioned. In this research, this last classification has been used by the authors the most comprehensive and simplified at the same time. Academic background of the subject illustrates that the relationship between architectural hospitals design and their Space Syntax is not clearly defined and stated. Even though individual hospitals are studied in the field of space syntax, the comparative analysis of hospitals regarding their established design style constitutes a subject still poorly explored but of great interest for both Space Syntax field and healthcare designs.

Corridor ward

Corridor ward has transformed the shape of Nightingale ward or Long Nave ward. As the original form, it was a vast unmixed hall with no subdivision. In late 1870 this form was extended and renamed to Florance Nightingale. An improved form of this spatial strategy is what is now accepted as Corridor ward (or Continental ward). New forms are adopted to provide users with more privacy and to guarantee less prevalence of infections. The main corridor is recognized in the shape of a 'T', 'C', or 'L' (Catrambone et al 2008). The most important modification of corridor style is the centralized part which is dedicated to the nurse point, information station and stairs with a single room. This stage devised the long corridor into two parts and allows the nurse station to be out of the main path of the corridor. This style also provides division for the unique corridors, helping to separate patients in the function of their gender or other classifications (Department of Health and Social Care, 1997). As a result instead of having one long corridor, there are central points and two wings.

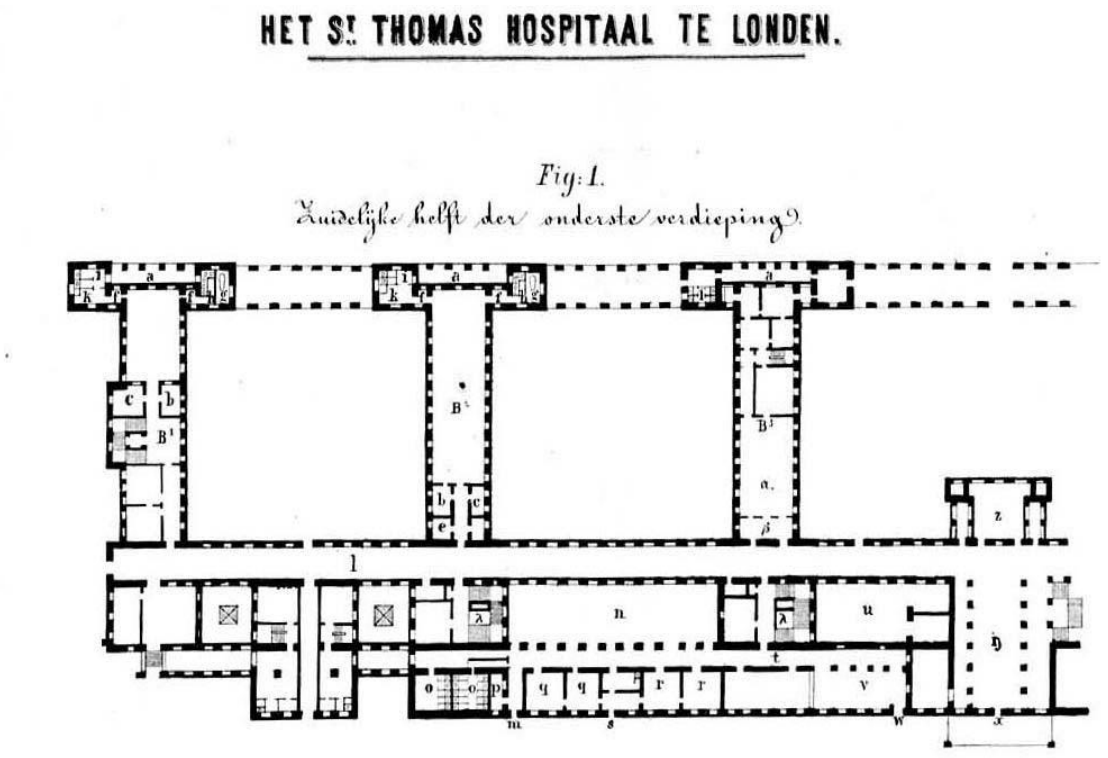

Figure 1: San Thomas hospital as an example of corridor ward style.

Duplex ward

The special ward in the 1950s. The Duplex design, also named as Nuffield, is the mixture of two separated corridor wards with their individual nurse point but the space between them is covered with both. This style has emerged after increasing attention given to the importance of sanitary division so more hygienic environment became provided.

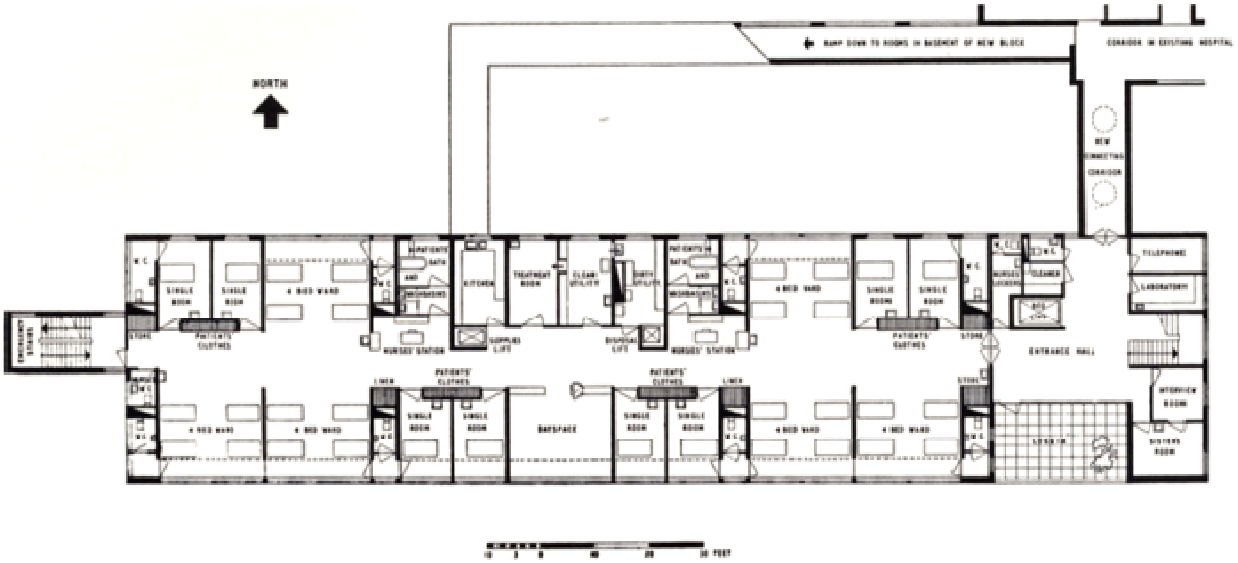

Fig. 222. Plan of experimental ward unit, Larkfield Hospital, Greenock, Scotland, 1956.

Figure 2: Larkfield hospital as an example of Duplex ward style.

Racetrack ward

The style for the years 1950s-60s with the capacity up to 60 beds providing personal privacy. In this spatial division, the centre of the rectangular plan is located for services rooms and nurse point or information station. It is a developed shape regarding the provision of more subdivision to guarantee privacy and hygiene in one hand and covering as biggest part of the plan as possible by exit/entrance access and nurse/information station. This type is also named as double corridor because in the linear plans the nurse centre divides the plan into two corridors. This style is very commonly used in the US (Page & Page, 2004). Falkirk ward is the most famous adopted design from Racetrack ward in the 1960s (Department of Health and Social Care, 1997) in this type in which the core of the plan services are located.

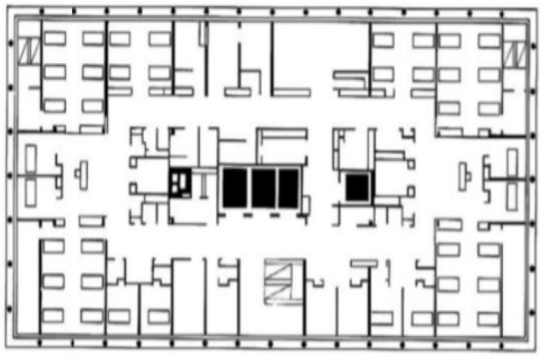

Figure 3: Wycombe hospital as an example of racetrack ward style.

Cluster ward

This style is a result of the geometric development of a rectangular core. Horizontal and vertical corridors intersect in the core station and create an axis network.

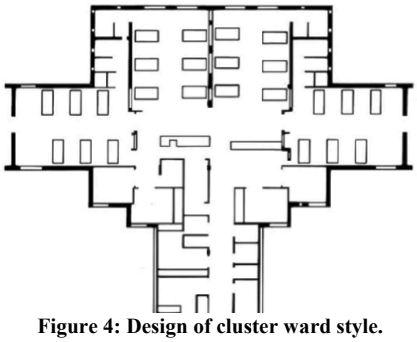

Figure 4: Design of cluster ward style.

Radial ward

Radial ward is a particular hospital style in which rooms are gathered around the circulation and nurse station in a circular form of plan.

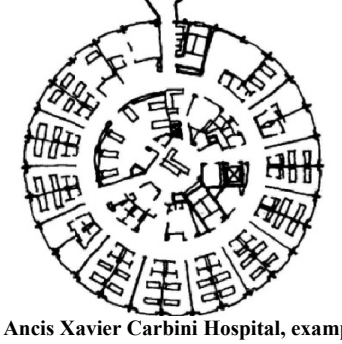

Figure 5: Ancis Xavier Carbini Hospital, example of radia ward style.

Method of Research

In architecture, many quantitative and qualitative tools and methods have been investigated to analyze and evaluate the access and circulation efficiency of hospitals (Kakola& Duenas, 2006). The main target of the Space Syntax is the relationship between two enclosed spaces in the architectural plan. It mainly discusses the "topology" of space and its classification (Bafna, 2003) which is involved in both formal and social features. A primary tool developed to represent the Space Syntax of buildings configuration is the Graph Diagram by Hillier (Hillie, Hanson, 1984). By the course of time, many tools which justified or automatized the original version of the graph theory, have been created to make the analysis more effective.

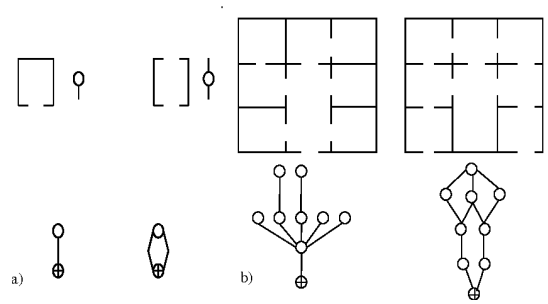

Figure 6: Graphs to support the logic of space (Hillier, Hanson, 1984).

The research intends to establish a relationship between the space syntax and the architectural design of hospitals by the use of three-dimensional parametric models to analyze the depth of spatial configuration. To achieve this goal, firstly the digital model of the building is created, secondly topological spatial information regarding the definition of Space Syntax is introduced to the spaces. Finally, BIM tools are used to analyse, represent and document the data on the model in the same environment. Thus Building Information Model and Space Syntax collaborate in a synergistic way to return a usable graphic representation. Two case studies characterized by very different styles have been chosen to test the method as well as to compare and debate the design style in terms of depth of rooms in their spatial configuration.

- "Molinette" healthcare complex in Turin, Italy. It is a representative sample of the Corridor Ward style, where the layout is shaped around the main corridor, while the secondary ones connect individual buildings to the network. The Neurology department is similarly characterized by a central distribution that connects the different environments.

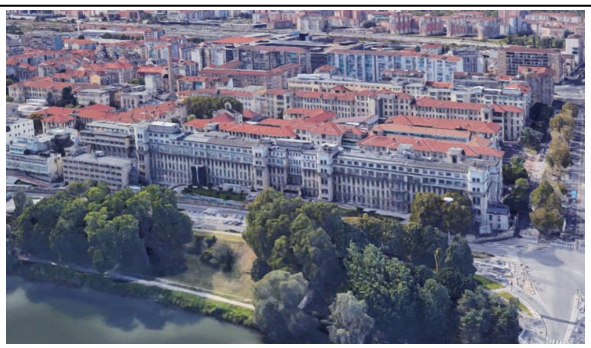

Figure 7:Molinette hospital, neurology building.

- "Laleh" hospital located in Tehran, the capital of Iran. It is selected as one of the best examples of Racetrack Ward design, especially with regard to the fourth floor. The nurse station and other interactive spaces, like information desks, are located in the centre and a circular corridor spins around the central spaces.

Figure 8: Laleh Hospital in Tehran

The Space Syntax approach is analyzed by means of the depth code which represents the number of enclosed rooms between the addressed room and the corridor. Depth of rooms represents the particular configuration of spaces in an architectural plan. Starting from the corridor, the more spaces a user must pass to reach a specific point, the deeper the point is. The depth code of each room is attached as a parameter of rooms in the BIM database.

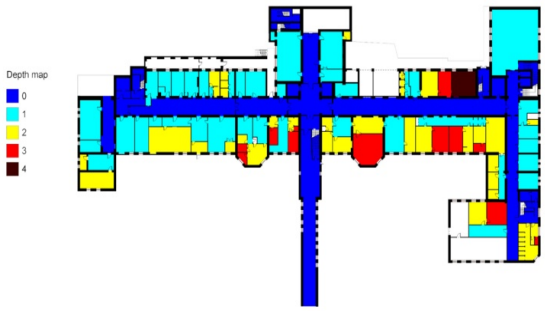

Figure 8: Depth map of Neurology pavilion.

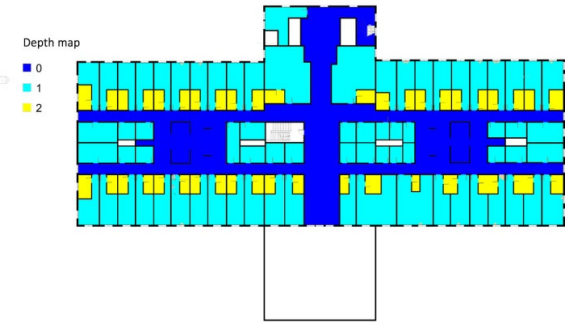

Figure 9:Depth map of Laleh hospital.

According to the parametric nature of the model, it is possible to manage information in several ways in order to obtain tabularly but also graphical outputs. Using the information inserted in the model it is possible to automatically thematize the rooms in the planimetric views and obtain an overall representation of the variation of the parameter in the different spaces. To compare different plans of the same building or different structures, the number of rooms with a particular depth code can represent a useful indicator. Figure 10shows the calculation model of the total number of rooms in the field of depth.

Area	Room ID	Depth	Level
8247 SF	114	0	Forth Floor
1			
214 SF	1	1	Forth Floor
203 SF	3	1	Forth Floor
198 SF	5	1	Forth Floor
207 SF	7	1	Forth Floor
189 SF	9	1	Forth Floor
223 SF	11	1	Forth Floor
200 SF	13	1	Forth Floor
213 SF	15	1	Forth Floor
202 SF	17	1	Forth Floor
223 SF	19	1	Forth Floor
763 SF	22	1	Forth Floor
301 SF	23	1	Forth Floor
726 SF	24	1	Forth Floor
254 SF	27	1	Forth Floor
223 SF	28	1	Forth Floor
219 SF	29	1	Forth Floor
211 SF	32	1	Forth Floor
223 SF	34	1	Forth Floor
217 SF	35	1	Forth Floor
209 SF	38	1	Forth Floor
228 SF	40	1	
209 SF	42	1	
249 SF	44	1	
246 SF	46	1	
232 SF	47	1	
111 SF	48	1	
105 SF	49	1	
85 SF	50	1	

<Room Schedule>

A	B
Depth	Level
0	Forth Floor
1	

Figure 10: Calculation of the number of rooms associated with certain depth code.

The obtained total number of rooms is not sufficient in order to make an effective comparison as this factor depends on the size of the building and the number of rooms. To obtain an independent Depth Rate, the total number of rooms associated with a particular depth code is divided by the total number of rooms in the floor plan. The rooms with a depth of 0 are not ccalculated as they are corridors and provide access to other rooms. To make it more clear, in the example of Laleh hospital, the rate of depth 1 is calculated as follows.

[1] depth rate = All rooms with depth code equal to 1 / All rooms 72/113 = 0.63
[2] depth rate = All rooms with depth code equal to 2/ All rooms 41/113 = 0.36
By proceeding in this way it was possible to compare the levels of hospitals taken as case studies according to their depth rate indicators.

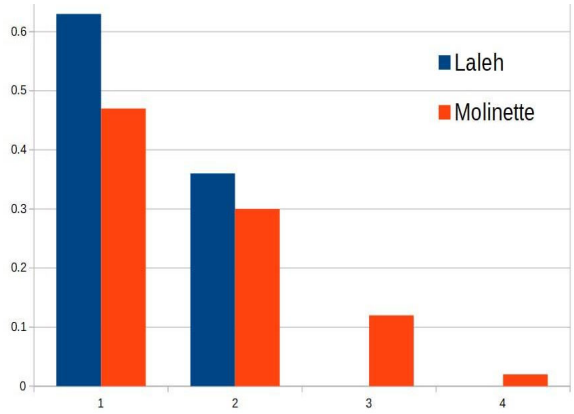

Figure 11: Depth rate comparison in case studies.

III. RESULTS AND CONCLUSION

In this article the relationship between the organization of the rooms, which defines the style of the hospital, and the Spatial Syntax that determines their architectural quality is made explicit objectively. A parametric system has been used to organize the information useful for the assessment and to quickly obtain thematic and quantitative extractions representative of the depth of the plans. This method can be used to easily compare the spatial configuration of different styles of architectural design and different cases. The comparison demonstrates the following.
- In Molinette hospitalthe variety of depth code is wider, as it reaches to depth [4], according to the logic of the corridor ward scheme.
- In Laleh hospitalmore rooms are characterized by depth code [1]. This indicates that in racetrack design more access is provided for rooms.Summing up, the main effective feature is the corridor. It can be stated that the shape of the corridor as the pedestrian circulation in the building and its morphological ordering in the plan view, alters the Space Syntax of related rooms. Circulation distribution defines the configuration of spaces around it. In this article it is demonstrated that the number of corridors in the one ward - one corridor in corridor ward style and two corridors in racetrack style - modifies the depth code of the rooms. The more corridors exist in the ward, the less deep rooms become.To assert the evaluation of SpaceSyntax applied to sanitary buildings, it is possible to identify if depth is a negative aspect of rooms or not. Efficiency of depth in healthcare facilities dependson the function of each room. In general having efficient and fast access to rooms are

essential. This requires less depth code for most rooms. On the other hand, some rooms with particular functions need to be located in a deep position. Blood stores and information supply are among the rooms that require to be in a deeper position. Considering this contrast, the most flexible style is the optimal. In addition to Space Syntax and depth code in spatial configuration, provision of natural light and natural ventilation must be taken into account. Even if the racetrack ward provides less deep room in the hospital, the long width of the ward shortens the natural light and ventilation in particular in the center of the ward. As the conclusion, it is possible to establish that design styles of hospitals matter in terms of spatial qualities of architectural plan. Regarding analysis, the corridor ward provides the best configuration of spaces around the circulation path.

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