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The Use of Network Theory in Heritage Cities

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***Abstract*—**This paper aims to demonstrate how the use of Network Theory can be applied to a very interesting and complex urban situation: The parts of a city which may have some patrimonial value, but because of their lack of relevant architectural elements, they are not considered to be historic in a conventional sense. In this paper, we use the suburb of La Villaflora in the city of Quito, Ecuador as our case study. We first propose a system of indicators as a tool to characterize and quantify the historic value of a geographic area. Then, we apply these indicators to the suburb of La Villaflora and use Network Theory to understand and propose actions.

***Keywords*—**Data visualization, historic value, spatial analysis, urban networks.

I. The City of Quito and the Villaflora Suburb

THE city of Quito that we find today was founded in the 16th century by the Spanish colonists following a *damero* model [1]. This model imposed, as it was usual, a very strict geometrical order over a natural topography, which in this case was particularly complex: The city is placed at the foot of the *Pichincha* and *Guagua Pichincha* volcanos – among other mountains – in a terrain full of ramps, valleys, ravines and other irregularities [2]. One of these natural elements is a hill popularly known as *El Panecillo*, which limited the growth of the colonial city on the south side for centuries, and helped to establish in many ways a clear difference between the north and the south sides: This difference had a socio-economic dimension as well, which is still possible to observe today.

At the end of the 19th century and the beginning of the 20th century the city of Quito in general and the southern part of the city in particular experienced a number of deep urban transformations, mainly because of the rise of the export economy in the country. For example, the need to connect the two main cities in the country –Quito placed on the mountains, and Guayaquil on the coast as the main commercial harbor– led to the construction of the railway terminal in this area of the city in 1908, promoting some developments, such as the Chimbacalle suburb [3]. In the case of Quito, these transformations were extreme in some moments –in their speed or their nature– as it happened e.g. in the forties with the relocations of people caused by the crisis with Peru [4]. At the time, the city was growing rapidly and needed a global urban plan to control the process. Thus, in 1940, urban planners Jones Odriozola and Gilberto Gatto Sobral were commissioned to design a new Master Plan for the city, which is known as the "*Odriozola Plan*" [5].

The plan proposed by Odrizola modelled the city as a polycentric system, distributed per dominant uses: Administrative and government buildings placed in the old city with a central position, the bourgeois dwellings and leisure facilities in the north side, and the industrial buildings and working-class neighborhoods mainly in the south side [6]. In this context, the plan proposed to create a new suburb in the south side --thus initially intended for workers-- with the name of *Villaflora.*

The Villaflora suburb was probably designed by Moreno Loor [7], who was part of Odriozola's team of architects and engineers. The aim of this design was the *garden movement* one, which in other cities in North and South America – and other parts of the world – had been taken as a response model to confront certain urban situations. The architectural report of Moreno Loor's project described a terrible situation in the city of Quito, plagued by crime and disease. He attributed these problems to Quito's urban planning [8]. Therefore, instead of using an urban model that he considered to be a failure, he proposed to grow the city by following the *garden city* model, hoping that it would contribute to the rising of a new kind of citizen. With this goal in mind, he applied the main principles of the garden city model and proposed a Master Plan for the Villaflora neighborhood where its inhabitants could find the conditions for a new way of living: Homes in connection with nature – in a space full of trees and clean air— but also near key services, such as a school, a hospital and commercial facilities. Hence a new urban model was implemented in the city of Quito in the 1940s [9]. Therefore, the interest and patrimonial importance of the Villaflora neighborhood lays in its *urban model*, which is still today in many senses unique in the city of Quito. Note that the buildings that were developed were modest as were their intended inhabitants. While they were built with dignity, priority was given to providing a new way of living in a very functional and in a cheap way. Thus, we do not find the types of monumental elements that characterize patrimonial architecture: The buildings of Villaflora are neither *old* enough nor *artistic* enough to be included as part of the city's patrimony in a traditional sense. Hence, in order to measure the patrimonial value of this part of the city, we need to define a new framework that allows us to identify and understand the elements that are relevant for the area's urban model, which is what leads to its patrimonial relevance.

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II. Patrimonial Quality and Patrimonial Value

For our purpose, we need first to map to a numeric value the patrimonial value of Villaflora, which is an abstract concept. Even if we use a wide definition of the concept of "*patrimony*" [10], this part of the city has not traditionally been considered of value. In fact, thus its nowadays situation is quite damaged and distorted.

Many different theories about the patrimony and how to deal with it have been proposed in the literature. The discipline shows a vast production in this field from the time of Viollet-le-Duc or Ruskin [11]. And from the *Venice Charter* [12] to the *Charter of Krakow* [13], the discipline admits now that not only the great architectonical works from the past are valuable patrimony, but also other modest expressions of architecture may be so. The key challenge is, in this last case, how to find and define the attributes which capture this kind of value in such architectural elements. And the value might arise from different perspectives, including social, cultural and artistic.

In our case, as we said, the value of the Villaflora suburb is in its *urban model*. The architecture is modest –homes initially planned for public workers, without any relevant building in the ensemble, with unremarkable building techniques and used materials. From this perspective, the buildings in Villaflora could not be included as part of the city's patrimony in a traditional sense. However, Villaflora is valuable because it is the result of applying an urban model which is in many aspects unique in the city: While there might be other areas where this model was partially used, the *garden suburb* model was applied with deepest and strongest results in Villaflora. Hence, we will measure of the *patrimonial value* of each architectonical element based on its capacity to *express* this model: The higher the contribution of a building to the garden suburb model, the larger its patrimonial value.

In order to quantify Villaflora's patrimonial value we use a *system of indicators* that we apply to Villaflora's graph. We first define a list of categories which are relevant for Villaflora's morphology. Next, we assign a value to each of them. Our methodology is similar to that followed by previous authors, such as Gehl [14] and Salvador Rueda --head of the *Agencia de Ecología Urbana* in Barcelona. However, they apply the methodology from an urban perspective and we do from a heritage perspective.

We consider a list of categories formed by all the elements that play a relevant role in the garden suburb model. Hence, we analyze building elements which can be *perceived* by walking in this space, and they play an important role in the process of understanding such urban model [15]. We propose a list of *nine* elements, namely: Roof's shape, cover material, surface material on the façade, colors, windows, ornamentation elements, garden fences, scale and global volume. All of them are concepts present in a phenomenological approach to the city, somehow related to Kevin Lynch's thinking.

We assign a numeric value to each indicator according to how much it contributes to the garden suburb model. Table I depicts the nine elements, the three categories associated with each element and the numeric value attributed to them. Given this framework, we carried out extensive fieldwork to identify each architectural element in every building of the Villaflora suburb and its associated numeric value. Note that we altered the value of some of the concepts by applying a correction factor, which measures the relative importance of each element for the global evaluation, because they do not play the same role in a perception process. As a result, we have created a record for each building –resulting in hundreds of records for the entire Villaflora suburb—with a similar format to that used in heritage catalogues, as shown in Fig. 1. We apply this framework only to the buildings in Villaflora which are in accordance with the garden suburb model. Note that we assign a null value to all the elements that do not belong to the garden suburb plan, do not support this model or promote a wrong reading of the model. Finally, also note that the number of properties is not the same as the number of values, because part of the elements are evaluated as isolated houses, and part as semi detached houses according to their present situation.

TABLE I
Proposed Nine Architectural Elements, Associated Indicators and Numeric Values Based on Their Contribution to the Model

Element	State	Indicator value
Form of the roof	Original hip roof	10
	Other hip forms	5
	Flat roof, others	1
Cover material	Curved old tile	10
	Other in hip roof	5
	Other materials	1
Coating	Continuous painted	10
	Other continuous	5
	Uncontinuous	1
Colour	Clear colours	10
(Factor of unification: 1 / 0,5)	Soft colours	5
	Other colours	1
Windows	Original windows	10
(Factor of carpentry: 1 / 0,5)	Altered until 50%	5
	Other situations	1
Ornaments	All original elem.	10
	Some elements	5
	None elements	1
Fences	Height until 80 cm	10
	Over 80 cm with permeable materials	5
	Over 80 cm with opaque materials	1
Scale	Original	10
	Altered until GF + II	5
	Other situations	1
Volumetry	Original (detached and singles)	10
	Some alterations	7
	Added volumes	4
	Other situations	1

Concept	Value	Factor	Corrector	Indicator
Roof	7		1	7
Cover	7		0,7	4,9
Coating	7		0,6	4,2
Colour	7	3,5	0,9	3,15
Windows	7	3,5	0,5	1,8
Ornaments	5		0,9	4,5
Fences	5		1	5
Scale	10		1	10
Volumetry	7		1	7
TOTAL				47,5

(a) (b) (c)

Fig. 1 (a) Current photograph of the building, (b) The location of the building on map, (c) calculating the numeric value for each of the nine indicator elements that characterize the building

III. Data Visualization

As a result of applying our methodology to the Villaflora neighborhood, we generate a large amount of data which may not be operational for architects, politicians, urban planners, citizens and the rest of agents involved in the management of the city and its heritage. Data visualization techniques can greatly help make sense of this data. As a first step, we generate maps that illustrate different aspects of the data, as shown in Fig. 2.

Fig. 2 Part of the map of Villaflora suburb with the values assigned to its elements

Next we translate into a color scale the numeric values, such that the resulting map may then be manipulated by appropriate programs, such a Rhinoceros. This methodology allows us to very easily change not only the types of colors that we want to use, but also the style (*e.g.* solids, blurs …) to express the information in different ways (Fig. 3). These types of maps are interesting because they express the situation of any building in a certain moment. But they also have a significant limitation. In a complex system like this one, the addition of the parts does not express the global situation. In other words: Every element also has an influence on its context. And for this reason, it is necessary to consider them not as isolated cells, but as a part of a network, as described below.

IV. The City as a Complex Network

Today we interact with different networks as part of our daily lives: We are connected to each other and to the digital world using networks, we travel and transport goods by means of global transport networks, we get the energy we need from networks, etc. Cities can also be seen as networks, as e.g. Salingaros proposes in his book *Urban Network Theory*: any urban expression may be understood as nodes of human activity and connections between them [16].

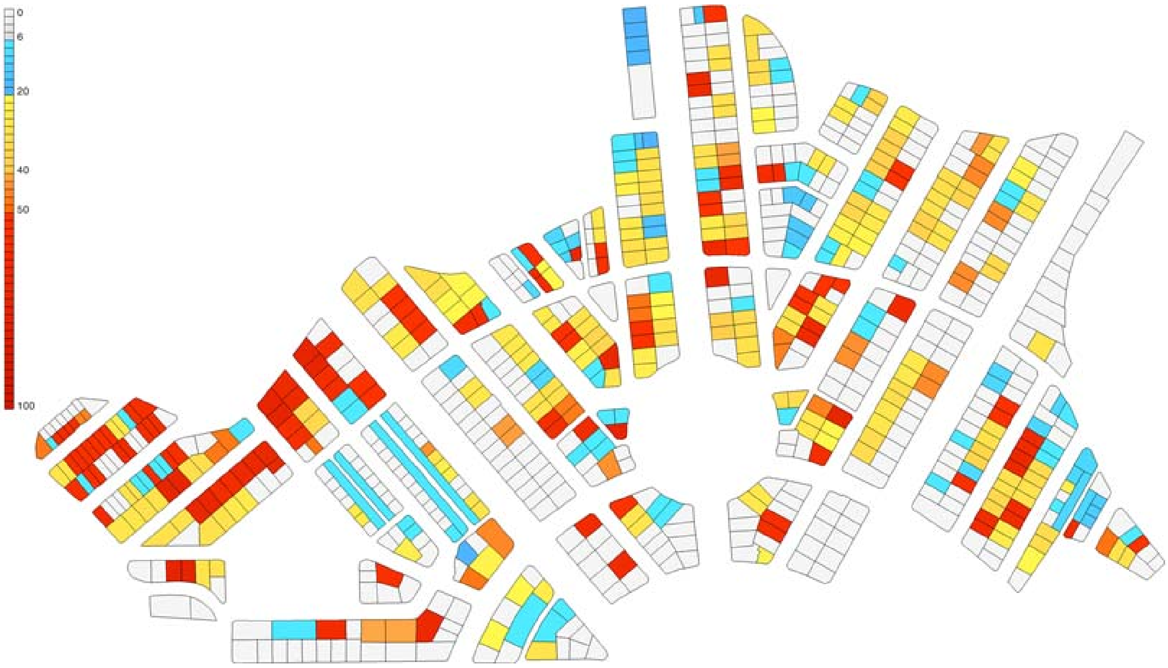

Fig. 3 Villaflora suburb map where the colors reflect the contribution of the different buildings to the garden suburb model (red: maximum contribution, blue: minimum contribution, grey: null)

In this paper, we propose to apply network theory to the Villaflora neighborhood as the mathematical framework that enables us to characterize and quantify its patrimonial value.

In order to model Villaflora as a network, we need first to build its *primal graph.* With this purpose, we draw a geometric model such that the intersections of the streets in Villaflora are the nodes in the network, and the streets are the edges connecting the nodes. Fig. 4 depicts the primal graph of Villaflora. As can be seen in the figure, most of the nodes in the graph have between 2 and 4 edges of connectivity, and the distribution of degrees of the nodes is very uniform. The average node *degree* in the network is 3.08 with a graph density of 0.031. Hence, from a topological point of view, the Villaflora network seems to be quite limited: it has low degree and high homogeneity.

Once we have built the primal graph, we can apply Network Theory tools to understand key properties of the network, using concepts such a centrality, density or community. The measure of *centrality*, for example, tries to identify the most relevant nodes in the graph, given that not all of them are equally important for the system. Thus, if we quantify the relevance of each node in the network, we can infer the impact that actions taken on each node would have in the entire network. This information may be quite useful, because in any kind of public operation of renovation, public money is always limited. The knowledge of the importance of a node might help decide where to carry out an intervention, knowing that in nodes that are important the impact for the neighborhood will be larger than in less important nodes. We can also identify where a destructive action would have a higher impact in an area.

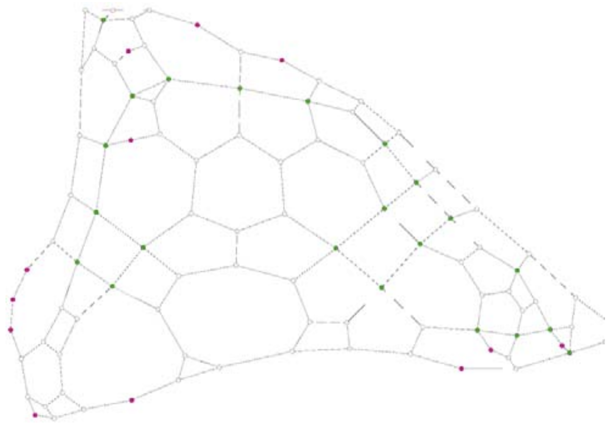

Fig. 4 Primal Graph of the Villaflora neighborhood

There are different ways to compute centrality, including *degree centrality, closeness centrality, betweenness centrality* and *PageRank.* Given the characteristics of the Villaflora network, we apply anyway three classic measures of centrality: Closeness centrality, harmonic closeness centrality and betweenness centrality as a first approach. Based on our empirical results we select betweenness centrality as it is the measure that better characterizes the network of study for our purposes. Fig. 5 shows the *betweenness centrality* of the nodes in the Villaflora network, where the larger the node, the higher its betweenness centrality.

Fig. 5 Betweenness centrality of the nodes in the Villaflora network

Up to this point, we have been able to characterize the topology of the Villaflora neighborhood. The network formed by streets and intersections is not particularly complex such that common centrality measures will not be helpful for our purpose. For this reason, we have developed centrality measures which are able to take into account relevant information in the nodes beyond just their topological conditions: e.g. the Adapted PageRank Algorithm (APA), the New Betweenness Adapted Algorithm or the Eigendata centrality [17]. With these tools, we can run simulations where we apply a variety of conditions or actions to the nodes and observe the impact that such actions when applied on the nodes would have in the entire network. We have been able to use this methodology for example to study the impact of commercial activity in the city of Murcia, Spain [18]. We assigned numerical values to each node of the city which were proportional to the commercial activity available in the node. With the use of the APA algorithm we classified the nodes according to their importance in the network, and after this process we can represent graphically the system and distinguish the important points. Once stablished, we can estimate the impact in the city of a variety of potential interventions, such as building of a new mall, and where this will have a larger or smaller effect.

In the case study, we assign to each node its heritage value as per the methodology explained in the previous section. We then run the APA algorithm and then obtain the position of the critical nodes in the network from a heritage point of view. These nodes would be the places which may need a highest protection given their influence in the context, or could be the best ones to act on to maximize the impact of the intervention in the area.

We can also apply so called *visibility algorithms* to the urban area. In this case, we form a *visibility graph*, where a node represents a vertex, and the edges are the visible connections between the vertices. There are several algorithms to identify the nodes with the highest visibility in the network. This representation lets us identify where an action will be more visible. Again, this may be a very useful argument in order to stablish a priority in the order of rehabilitation in the area. In order to achieve this information, we have produced a 3D image of the Villaflora suburb which will allow us to develop the visibility study (Fig. 6). With this visualization, we can display the areas that are the most visible and exposed. This information is of great importance to understand the heritage value of a region, particularly given that we are interested in characterizing the urban model. Moreover, this approach might be very useful for touristic purposes, as it enables to define itineraries that maximize the visibility of the patrimonial complex; and for efficiency studies in terms of energy: we can also identify where it could be more effective to concentrate the illumination to put in value some points of the suburb, for example (Fig. 7).

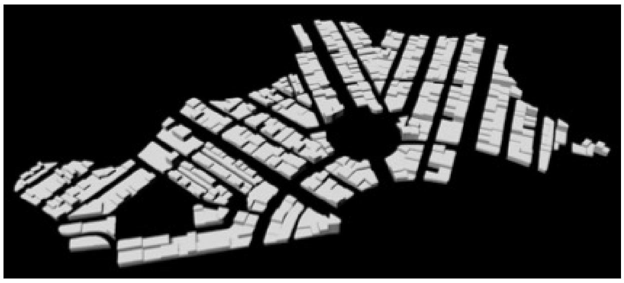

Fig. 6 3D image of the Villaflora suburb

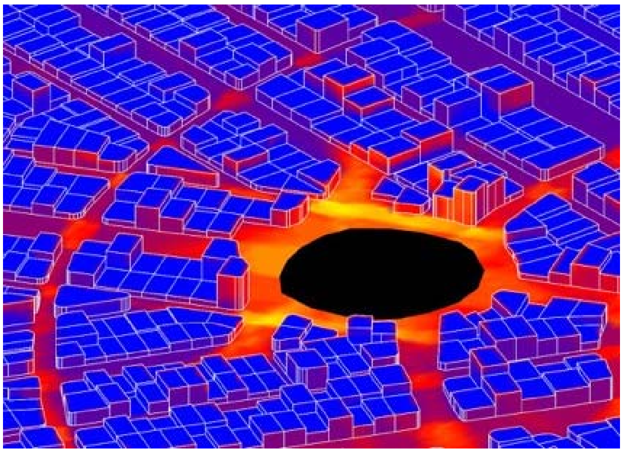

Fig. 7 Data visualization of visibility

V. Conclusions

In this paper, we have proposed the use of network science to represent relevant elements in a city and to quantify their importance for a variety of purposes. In this case, from the point of view of the heritage value.

The presented framework represents the city as a network or graph. Hence, well known network theory algorithms and network data visualization techniques may be applied to characterize, model and visualize the city. In addition, the proposed framework offers key features that are not available in other methodologies: it enables us to assign numeric attributes to different elements in the city and to model their importance and interactions with the rest of the urban infrastructure. Finally, it allows for simulations of different scenarios of *e.g.* urban interventions in historic parts of the city, or population growth, which is of great value to urban planners, city officials and practitioners, particularly given how cities are a constant transformation.

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