When Organic Urban Forms and Grid Systems Collide:Application of Space Syntax for Analyzing the Spatial Configuration of Barcelona, Spain

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Abstract

Many cities around the world have experienced fast urbanization with suburban development. The organic urban forms of old towns or existing city centers have been extended with modern grid systems. However, little research has been conducted to identify the impact of modern grid forms on the organic urban structure in the city center. This study aims to examine the transformation of urban morphology using space syntax for the case study of Barcelona, Spain, which is an ideal case city because of its organic city center surrounded by an orthogonal urban system.

The result showed that at the car-oriented global scale, the city center area with an organic urban form loses its importance in terms of space syntax indexes such as choice and integration values. However, the organic structure becomes more important at the pedestrian-oriented local scale. Furthermore, adding the grid structure to the original organic form increases the relative importance of the organic form in Barcelona's city center. This finding indicates that a grid system and an organic form are not in opposition to each other, but can instead be complementary. This study implies that the integration between organic form and grid system is very important and necessary for urban regeneration in many cities.

Keywords: Barcelona; grid system; organic urban form; space syntax; urban morphology

1. Introduction

The physical structure of a city is important as it can support and influence every activity of its residents. Among the physical structures, street form is one of the most important elements, as streets are where people navigate through or manage necessary activities. Since the 20th century, there has been a dispute about street design between modernists and people such as Jane Jacobs. While Le Corbusier mentioned the importance of the street as a 'medium' between people and destination, Jane Jacobs insisted that the street is a place by itself (Jacobs, 1961). To modernists who tried to transform urban structure into something that is vehicle-oriented, organic street structure is chaotic and inefficient and therefore should be changed into a grid structure. While Jacobsians did not mention the exact ideal structure for a pedestrian-oriented city, they concentrated more on street potential as a place rather than its efficiency.

Both of these aspects recognize the street as one of the important elements of urban space. This also means that examining the street structure is essential for understanding the entire urban space. However, in regeneration or redevelopment processes, radical transformation of street structures occurs. Some cities have encountered problems due to negligence when considering the existing urban structure as well as potential problems that occur as a result of the transformation of the structure. Thus, the implication of transforming street structure should be investigated in order to predict and counteract the consequences.

Barcelona is an ideal case to investigate the consequences of transforming street structures since it experienced radical change in the 19th century that combined contrasting grid and organic structures. In this study, authors compare the importance of the main thoroughfares of Barcelona before and after the combination of different street structures by applying space syntax methodology. The purpose of this study is to reveal the implication of combining grid structures with the existing organic structures.

2. Literature Review
2.1 Studies on Space Syntax and Its Application

Space syntax has been used in various studies related to urban spatial structure from urban morphology to

socio-economic matters. In space syntax, urban space is regarded as the combination of large amounts of small unit spaces. There are several indicative values that can be informative in understanding the importance of streets in urban space, such as *integration* and *choice*, which will be explained later in the Methodology section.

By analyzing the topological relationship and accessibility of unit spaces, the functional structure of the entire urban space and its influence on human activities can be better understood. For instance, urban space structure can have a relationship with poverty (Vaughan & Geddes, 2009), crime (Jones & Fanek, 1997), distribution of commercial areas (Park & Kim, 2012), and economic activities (Porta *et al.*, 2012).

It is also possible to investigate urban development patterns and their consequences. For instance, Lee and Shim (2013) investigated the Japanese influence on Seoul's structure. By comparing measurement values of different scales before and after the Japanese occupation period, they found that the attempts to destroy Seoul's original structure did not have a significant influence on its essential urban structure. Other studies have focused on the transformation of the urban structure and its function in terms of urban growth. Kong *et al.* (2009) examined how the urban structure of Jinju has changed by analyzing the transformation of street structures and the hierarchies of urban cores. The study found that the city's expansion is spatially correlated with the city's linear main axis. It also found that global integration of the oldest core is decreasing as new cores are emerging, and due to this phenomenon, city functions are spreading to other cores. As stated above, space syntax can provide useful insight for understanding space and its relationship with socio-economic activities.

2.2 Barcelona's Spatial Structure

There are several studies that analyzed Barcelona's spatial structure. Milan-Gómez *et al.* (2013) analyzed the old city of Barcelona by measuring the movement of centrality with axial analysis and segment analysis. They concluded that the center of the city has moved from east to west and towards the north. Land uses have also changed drastically and, as seen by the large decrease in node count, residences are no longer dense, and new cultural and administrative uses have established a new pattern. However, the study only analyzed the old part of Barcelona and the change of land uses without considering new urban structures that were combined later.

Another study by Milan-Gómez *et al.* (2012) investigated the transition of centrality in *Ciutat Vella* at different times. *Ciutat Vella's* development process was divided into four phases, and the centrality of each phase was analyzed. Metric integration and metric choice were measured at different scales in order to determine the movement of centrality, showing that there were movements of centrality as well as

multiple cores. Mora (2003) tried to understand the influence of spatial configuration on land use locations in the context of the new part of Barcelona, which has an orthogonal form. Mora determined that the grid configuration's effect on land use patterns is not necessarily weak and contains some pattern. Also, it appeared that Barcelona's land use distribution is affected by disruptions to the grid, planned infrastructures that attract people, and the city's cultural particularities. However, Mora mainly focused on the new structure in the north side of Barcelona, revealing the factors that made the land use pattern in Barcelona.

The research by Al-Sayed *et al.* (2009) is notable as it analyzed the morphological change of Barcelona from the 13th century to the present by segment angular analysis with a 500-meter radius. The study determined that *Ciutat Vella* maintained the highest local *integration* values. On the other hand, in the analysis with a 2,000-meter radius, which is almost a global scale analysis, *Ciutat Vella* lost its *integration* values, and the highest *integration* values appeared in the areas with a grid. The simulation that changed *Ciutat Vella's* organic form into a grid form resulted in a loss of most of *Ciutat Vella's* high *integration* values. As several studies have found, Barcelona's case is unique, as a new structure was suddenly adopted but did not ruin the city's original form and function.

2.3 Research Contribution

As stated in the introduction, the main research question of this study is "what would happen to the existing streets and their structure when new structure is suddenly connected?" There are some previous studies with similar research questions.

Al-Sayed *et al.* (2009) investigated the impact of the new grid system by a segment analysis of space syntax focusing on *integration* value, and simulated the consequences that could have happened if the organic structure was changed to a grid structure. Milan-Gómez *et al.* (2012), who chronologically analyzed the change of street centrality, have similar interests. However, they focused more on the correlation between connectivity and integration, and compared the average value of areas in different time phases in chronological order.

Unlike the existing studies, our study focuses on the consequences of combining a new grid structure to the existing organic form, and how the relative importance of main streets changes. Thus, instead of investigating chronological changes, this study compares the main streets before and after the combination of organic street and grid street forms. In addition, this study analyzes *choice* value as well as *integration* value in order to investigate the street not only as a destination, but also as a route.

3. Case Study and Methodology
3.1 Brief History of Barcelona

Barcelona is the second biggest city in Spain, and is

widely known to have been founded by the Romans. In 100 BC, the Romans built a small city named Barcino. At the time of Caesar Augustus, Barcino became a *castrum* with forum at the center and perpendicular main streets. The remains of the Roman *castrum* can be still found today and is called *El Gotic*, which means Gothic Quarter. After the fall of Rome, Barcino's residents changed several times. In the 9th century during the Muslim era, Barshiluna (Barcelona) was captured by the Franks, which was the beginning of Medieval Barcelona. The area called *El Born* was constructed during this time, and until the 14th century, Barcelona consisted of it and *El Gotic*.

At the beginning of the 14th century, *El Raval*, which is the area west of *La Rambla*, was developed and the wall that forms the boundary of *Ciutat Vella* was built in three phases. In the first phase, the wall only surrounded *Barri Gòtic* and *El Born*. *El Raval* became protected by the second construction phase, but was separated by the wall constructed in the first construction phase. In the third phase, the south side, which is directly connected to the port, was fortified and the boundary of the *Ciutat Vella* was finally formed (see Fig.1.).

In the early 18th century, *La Rambla,* which is a famous promenade and important landmark, was turned into a promenade from a sewage-filled streambed. A boundary was formed between *Barri Gòtic* to the east and *El Raval* to the west along the wall. Today, this promenade has heavy pedestrian flow.

The boundary of *Ciutat Vella* was formed by a wall that existed until the late 19th century. Before the wall was destroyed between 1854 and 1856, Barcelona's growth was limited due to its presence. After destruction of the wall, Barcelona began to expand, as massive immigration came with the factory jobs of the Industrial Revolution. *Eixample*, a huge planned area with a strict orthogonal form, was introduced to

fulfill the needs of a changing Barcelona. Although there is an extreme contrast between *Ciutat Vella* and *Eixample*, Barcelona's unique structure is famous and has become a source of fascination for many architects and urban planners.

3.2 Methodology

There are two main methodologies in space syntax. The first method is axial analysis, which uses a spatial representation called an axial line and the topological distance between axial lines based on the number of steps from one line to the other (Charalambous and Mavridou, 2012). The other method is segment analysis, which uses maps consisting of segments. The segment map is a broken description of the axial representation where each segment element between two street inter-junctions is considered as a separate element in the network. Each methodology has its strengths and limitations. While some researchers have recognized the function of axial lines, others have expressed doubts. Recently, segment analysis has been regarded as more effective and accurate according to studies comparing the methodologies with traffic or pedestrian flow. For instance, Xia (2013) compared the result of axial analysis and segment analysis based on road-center lines, with segment analysis showing higher correlations between traffic flows and the resulting analysis.

In order to examine the influence of grid structure on the organic structure's centrality, both *integration* and *choice* values of the main streets of *Ciutat Vella* (old Barcelona with organic street structure) are compared, before and after the *Cerda* plan. The study applies Angular Segment Analysis by Metric Distance (ASAMD), which is a common methodology for space syntax. ASAMD analyzes the axial line segments between junctions (Charalambous and Mavridou, 2012). Unlike axial analysis, ASAMD is mainly concerned with travel distance rather than directional
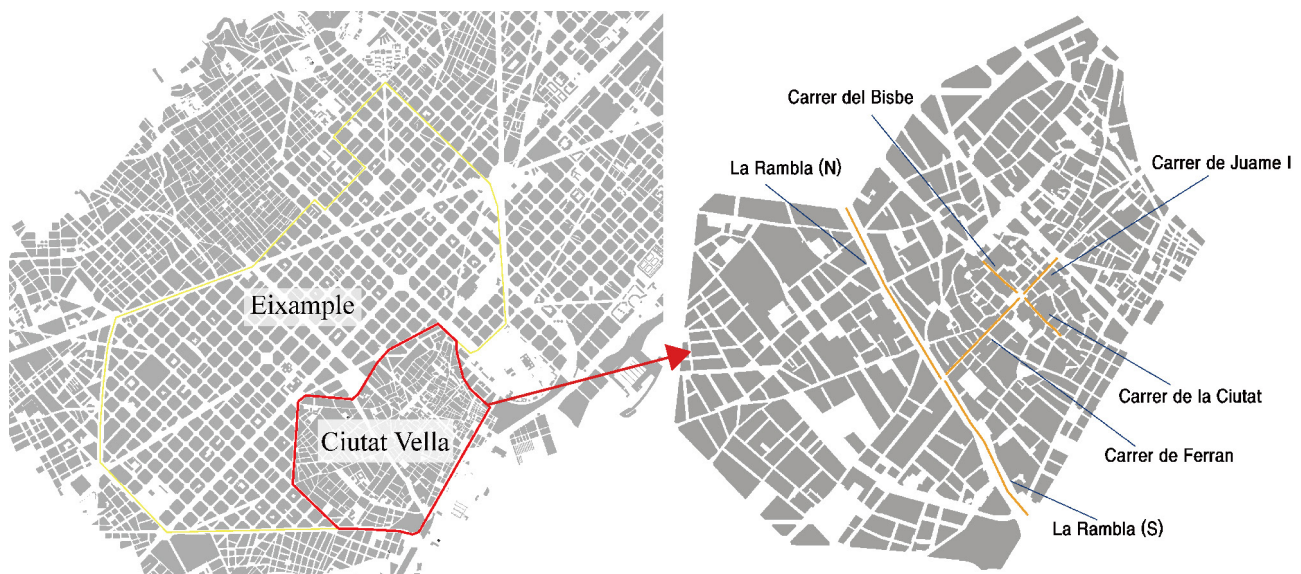

Fig.1. Map of *Eixample*, *Ciutat Vella*, and Historic Main Streets of *Ciutat Vella*

changes in pedestrian path choices. Two values of accessibility can be calculated by ASAMD: *choice* and *integration.*

Integration value illustrates how close each segment is to all others under different types of distance and at different scales (Charalambous and Mavridou, 2012). Integration is important as a destination, while choice is important as a route. Thus, analyzing these values can be helpful in defining the spatial attributes of streets. *Choice (Betweenness)* value implies the probability of being selected as a route by people who are aware of the area's layout (Hillier and Iida, 2005). Both values are calculated by the formulas below, introduced by Hillier and Iida (2005).

$$Integration = \quad 1/\sum_{k} d_{ik}$$

$$Choice = \sum_{j} \sum_{k} \frac{d_{jk}(i)}{d_{jk}}$$

d_{ik} = shortest path between line *i* and line *k*
d_{jk} = shortest path between line *j* and line *k*
$d_{jk}(i)$ = shortest path containing line *i* between line *j* and line *k*

In segment analysis, the road centerline is applied. The road centerlines for the analysis are constructed based on the data obtained from GeoPortal BCN (Barcelona City Council Geoportal), and in reference to the maps at the time before the *Cerda* plan. Since the purpose of this study is to examine the influence of grid structure, this study delimits the area of *Eixample* to be south of the diagonal road, because north of the diagonal road combines other cities.

Six historical main streets of *Ciutat Vella* are analyzed: *Carrer de Ferran, Carrer de Juame I, Carrer del Bisbe, Carrer de la Ciutat,* and *La Rambla (N and S). Carrer de Ferran, Carrer del Bisbe, Carrer de la Ciutat, and Carrer de Juame I* have had vertical and horizontal axes since Roman Barcino, while *Carrer de la Princessa* and *La Rambla* have become main axes since the wall was destroyed. *La Rambla,* the longest segment, is divided into two streets from the intersection with *Carrer de Ferran* and measured. Thus, a total of six streets are analyzed by Depthmapx 0.29 to obtain *integration* and *choice* values.

For streets with multiple segments, the average *choice* and *integration* values of the segments are calculated. The analysis compares the values at different scales (i.e., global and local), since the centrality of streets can depend on the scale. For instance, a local main street can be only a secondary street at the city scale. Therefore, different scales (i.e., 500 m for the local scale, which is widely accepted as a walkable distance, and the global scale) are applied in the analysis for comparison of *integration* and *choice* values. Comparing only the absolute values can be inappropriate, since *integration* can increase when the

structure for analysis becomes larger. Thus, the study compares the absolute values and also the ranks (%) of the streets' *integration* and *choice* values.

4. Analysis

The results show that all of the main thoroughfares have the top 20% of *integration* and *choice* values among the analyzed segments prior to their combination with the grid structure. After the combination, the main thoroughfares still had values among the top 20%. As the structure of the analyzed area expanded, it is natural that the absolute values increased. However, the relative values (percentage) of some thoroughfares increased, while others decreased.

4.1 *Ciutat Vella* Before Being Combined with *Eixample*

Figs.2 to 5. show the *choice* and *integration* values. There are a total of 2,354 segments in *Ciutat Vella. Choice* values at both the global and local scales were not high enough to be recognized, while *integration* values are recognizable at both scales. In global analysis, most of the thoroughfares have *choice* values in the top 20% among all the segments, except *Carrer del Bisbe*, which has the top 29.4% and 48% values compared to the others. Other thoroughfares, particularly *Carrer de Ferran, Carrer de JuameI,* and *La Rambla (N and S)*, have *choice* values higher than 10% among the others. *Integration* values have similar tendencies as *choice* values. Four thoroughfares (*Carrer de Ferran, Carrer del Bisbe, La Rambla N and S*) have values higher than 20% compared to the others. In local analysis, five thoroughfares have *choice* and *integration* values higher than 20% among the others. *Carrer de Ferran, Carrer Bisbe, Carrer de JuameI,* and *La Rambla (N and S)* are high in both *choice* and *integration* values, while *La Rambla* is only high in *integration* value. Exact values and the percentage of rank are shown in Table 1.

4.2 Old Barcelona After Being Combined with *Eixample*

Figs.6. to 9. show the *choice* and *integration* values when *Eixample* is combined. The total number of segments is 4,124. In global analysis, *choice* values of thoroughfares are mostly higher than 20%, although there are small variations. Notably, most *integration* values' rank as drastically decreased after the combination except *La Rambla*. This can be explained that when there are more segments introduced in the whole system, they are relatively less integrated compared to the others.

In local analysis, all of the thoroughfares have *choice* and *integration* values higher than the top 20% except *La Rambla (S).* Also, in general, these values have a higher rank compared to the values before the combination. In particular*, Carrer de la Ciutat* has values higher than the top 1%. The exact values and percentage of rank are shown in Table 2.

4.3 Comparison Before and After the Combination

The result shows extreme contrast between global and local analyses. Most of the streets lose their

Table 1. Segment Values of *Ciutat Vella* Before Being Combined with Grid Structure

Category	Carrer de Ferran	Carrer del Bisbe	Carrer de la Ciutat	Carrer de Juame Ⅰ	La Rambla (N)	La Rambla (S)
Choice (Global)	313,783 (3.6%)*	30,008 (29.4%)	59,901 (17.2%)*	354,710 (2.7%)*	378,322 (2.3%)*	205,483 (5.2%)*
Choice (500 m)	12,439 (10.6%)*	14,307 (8.3%)*	12,216 (11.3%)*	16,554 (5.5%)*	6,075 (27.3%)	3,146 (44.8%)
Integration (Global)	616 (1.3%)*	520 (12.6%)*	488 (27.4%)	577 (3.7%)*	617 (1.3%)*	628 (0.6%)*
Integration (500 m)	199 (9.9%)*	204 (8.1%)*	173 (21.3%)	252 (1.0%)*	195 (11.4%)*	154 (36.4%)

* Higher than top 20%

Fig.2. Global Analysis of *Choice* Measure

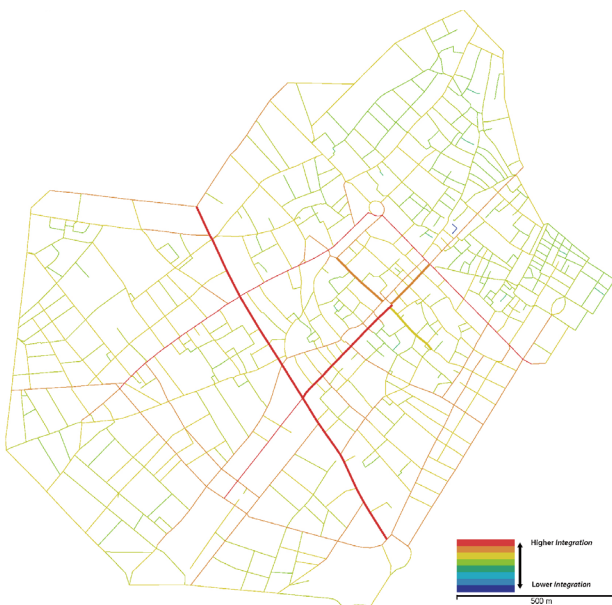Fig.3. Local Analysis (500 m) of *Choice* Measure

Fig.4. Global Analysis of *Integration* Measure
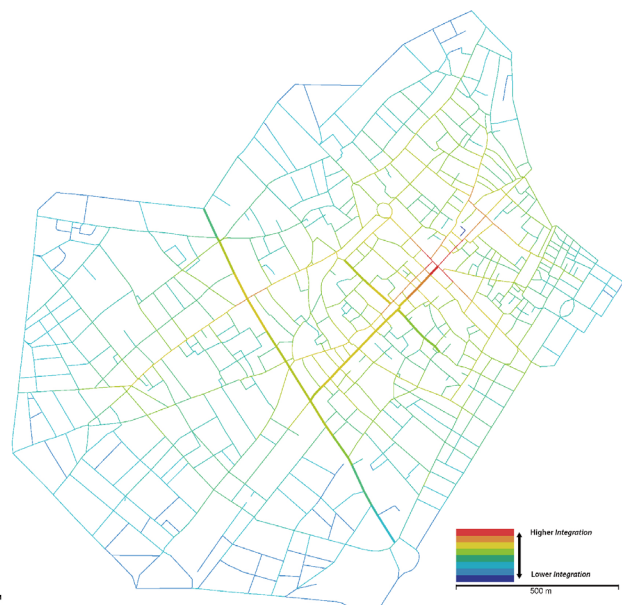

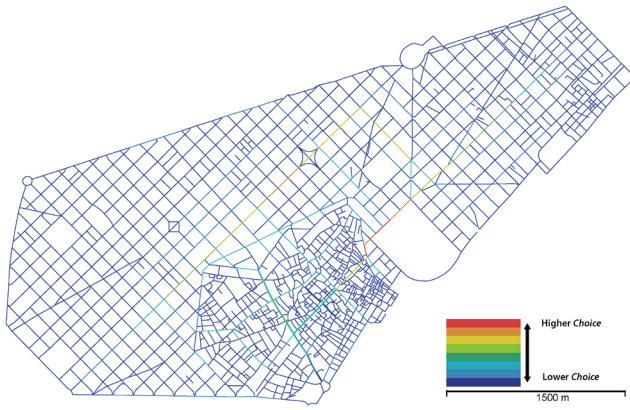Fig.3. Local Analysis (500 m) of *Integration* Measure

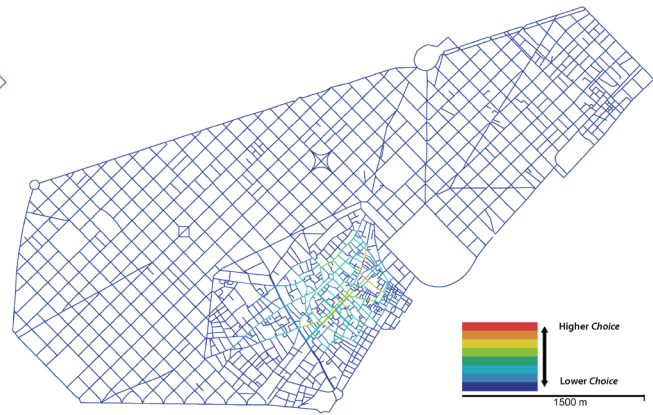Fig.6. Global Analysis of *Choice* Measure

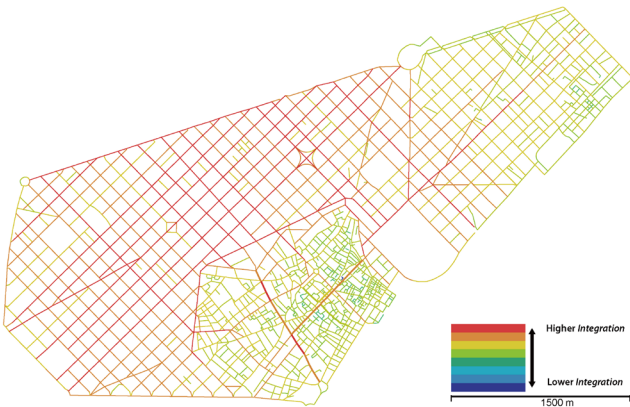Fig.7. Local Analysis (500 m) of *Choice* Measure

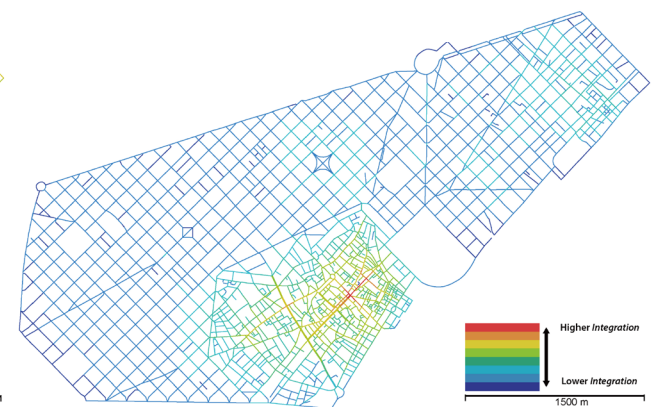Fig.8. Global Analysis of *Integration* Measure

Fig.9. Local Analysis (500 m) of *Integration* Measure

importance in the whole system in global analysis. In contrast, all streets have greater importance in local analysis with a 500-meter radius.

The changes of values in the *integration* analysis are extreme. All of the streets' global *integration* values decrease when *Ciutat Vella* is combined with *Eixample*. Although the values and the ranks decrease, those thoroughfares still have higher values than other streets in *Ciutat Vella*. However, when these streets are analyzed with a 500-meter radius, which is widely accepted as a walkable distance, *integration* values and their rank increase as shown in Tables 3. and 4.

5. Conclusion

This study evaluated Barcelona's *choice* and *integration* values of space syntax at different scales to reveal the implications of a new street structure upon an existing one. The results showed that both *choice* and *integration* values decreased their ranks in terms of multiple global analyses. However, when the analysis areas are set to 500 meters for local analysis, which is generally accepted as a walkable distance, the ranks of values increase. This means that the organic structure loses its relative importance at the global car-oriented scale, while the organic structure becomes more important at the pedestrian-oriented scale. Also, at the pedestrian-oriented scale, the grid structure increases the relative importance of the organic structure, which

means that these two disparate structures are not opposed to each other. In other words, they can be complementary to each other. This finding indicates that when we organize urban space, organic structures can be appropriate for pedestrians while grid structures can be designed in areas where vehicle traffic is needed the most.

In the 20th century, as vehicles were popularized, there was a movement by the modernists to reorganize a city's structure to be more vehicle-oriented. With this movement, streets were regarded as a 'medium' of travel for people to their destinations. From this viewpoint, organic structures were treated as being 'chaotic' and 'inefficient', and there were many attempts to change these structures into grid structures. Moreover, new towns were mostly built in grid structures. These attempts were not only made because of the economic benefit of grid structures that were easy to divide, sell and buy, but also because of consideration concerning vehicles and traffic efficiency. However, like Jacobsians, some urbanists have started to consider the street as an actual place, rather than as a route to a destination. Therefore, the importance of city walkability has become an important issue. Recently, a variety of attempts have been made to reduce car traffic in cities in order to reform them into a less vehicle-friendly place for pedestrians.

Table 2. Segment Values of *Ciutat Vella* After Being Combined with Grid Structure

Category	Carrer de Ferran	Carrer del Bisbe	Carrer de la Ciutat	Carrer de JuameI	La Rambla (N)	La Rambla (S)
Choice (Global)	549,903	46,582	96,008	564,231	719,949	387,949
	(3.2%)*	(36.1%)	(19.9%)*	(3.0%)*	(1.8%)*	(5.2%)*
Choice (500 m)	13,696	14,307	12,217	16,555	6,354	3,146
	(5.3%)*	(4.8%)*	(6.6%)*	(3.2%)*	(15.4%)*	(26.5%)
Integration (Global)	961	809	782	1,016	1,068	1,057
	(26.9%)	(57.9%)	(64.7%)	(18.3%)	(10.8%)*	(12.0%)*
Integration (500 m)	216	204	173	252	198	154
	(2.7%)	(4.8%)*	(13.0%)*	(0.7%)*	(5.9%)*	(21.7%)

*Higher than top 20%

Table 3. Segment Values of *Ciutat Vella* Before and After Being Combined with Grid Structure (unit: %)

Category	Carrer de Ferran			Carrer del Bisbe			Carrer de la Ciutat		
	Before	After	Variation	Before	After	Variation	Before	After	Variation
Choice (Global)	3.6	3.2	0.4	29.4	36.1	-6.7	17.2	19.9	-2.7
Choice (500 m)	10.6	5.3	5.3	8.3	4.8	3.5	11.3	6.6	4.7
Integration (Global)	1.3	26.9	-25.6	12.6	57.9	-45.3	27.4	64.7	-37.3
Integration (500 m)	9.9	2.7	7.2	8.1	4.8	3.3	21.3	13	8.3

Table 4. Segment Values of *Ciutat Vella* Before and After Being Combined with Grid Structure (unit: %)

Category	Carrer de JuameI			La Rambla (N)			La Rambla (S)		
	Before	After	Variation	Before	After	Variation	Before	After	Variation
Choice (Global)	3.2	3	0.2	2.3	1.8	0.5	5.2	5.2	0
Choice (500 m)	5.3	3.2	2.1	27.3	15.4	11.9	44.8	26.5	18.3
Integration (Global)	26.9	18.3	8.6	1.3	10.8	-9.5	0.6	12	-11.4
Integration (500 m)	2.7	0.7	2	11.4	5.9	5.5	36.4	21.7	14.7

This study revealed the implications of combining multiple structures in a city with the case study of Barcelona. This study finds that organic structures are more appropriate at a pedestrian-oriented scale, while grid structures are more appropriate at vehicle-oriented scales. City space should fulfill the needs of its inhabitants, now that cities need to use more pedestrian-oriented space.

Based on this, here are the implications of our study. First, as there are many attempts to make city space pedestrian-oriented, unconditionally changing urban structure into grid structure while eliminating its organic structure should not be encouraged. As the results show, both organic and grid structures are not absolutely good, as there are better structures that can be implemented in certain circumstances. Second, both grid and organic structures are not unconditionally opposed to each other, but can be used as complements in a city where various needs should be satisfied. Grid structures can make organic structures more important at the scale of pedestrian-oriented locales. This implies that grid structure does not have to be eliminated in the reformation of city space. As both vehicle and pedestrian activities should be supported in city space, the combination of these two structures should be considered as together they could form a synergy.

Despite interesting findings, this study has a few limitations. First, since Barcelona's urban form is a unique case, we should be careful not to generalize the results of this study, and future studies should consider more case cities for generalization. Second, this study only considered a few quantitative measures of space syntax in investigating the importance of streets. Researchers should consider a variety of quantitative measures of space syntax. Finally, future studies should consider the integration of space syntax measures with other important built environmental factors such as surrounding land use and street layout.

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