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Urban opportunities and conflicts around street musicians: the relationship between the configuration of public space and outdoor acoustics in Ciutat Vella, Barcelona

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ABSTRACT

The practice of busking and street music performance is becoming key to the identity of cities. However, although the spatial configuration and acoustics of historic city centres are interrelated, few rigorous studies have been undertaken on this area. The paper presents the results of a quantitative and comparative analysis of the space syntax configuration and on-site sound recordings in four main open environments within the inner core of Barcelona. The aim of this work is to highlight the conflict points between outdoor acoustics and movement flows in order to inform future designs and management of those public spaces.

Introduction

After a long history of local governments treating 'street music performance' and 'busking' as an annoying or even dangerous practise, legislation has changed in recent decades to allow a more permissive approach. As these activities play an important role in the public realm and 'contribute to the vitality of everyday life of the city' (Simpson 2011), performance times and stages have been discussed. Emerging social initiatives such as *Keep Streets Live* in the United Kingdom, *The Busking Project* in New York or the *Plataforma de Artistas de Calle* in Barcelona have recently requested buskers' rights and sought agreements with the administration. In some cities, contemporary busking laws are not only tolerated by buskers, but widely embraced by them (McNamara and Quilter 2016). However, not everyone is enthusiastic about buskers' contribution to the streetscape. Some people are annoyed by the presence of street actors (Hasham 2012), while others complain about the quality of the music that is played (Koziol 2013).

Street music unquestionably influences the city and vice versa. It has been stated that 'sound, in both a regulated and unregulated capacity, has long been associated as a key defining aspect of the city' (Bennett and Rogers 2014). The public space could be considered the resonance box for this kind of music, enabling proper interactions between informal activity and the form of the space (Prato 1984; Bywater 2007; Black 2014; Kingsbury,

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Andrews, and Kearns 2014). The sequencing of sounds and performances of musicians, magicians, painters and artists has shaped the way citizens and tourists experience city centres. Street performers and street musicians add vitality to public spaces and to the interactions between people and the built environment, and enhance urban quality (Gehl 1987, 2010).

Among the urban contexts where busking is practised, historic city centres could require special attention because they contain prominent monuments, enclosed public spaces and a high demand for informal activities associated with intense pedestrian movement. The well-known city centres of Canterbury, Bath, Bristol, Paris, New York and Rome are good examples of offering pedestrians a unique sound experience in their itineraries. This is particularly relevant in Barcelona's Ciutat Vella, the old central area of the city where public spaces, numerous visitors and architecture landmarks converge in the historical street layout. Since the late 1980s, the city has excelled in its pedestrian-focused policy and has produced outstanding quality in its public spaces and street experience (Bohigas 1983; Busquets 2014). As a result, the 'Barcelona Model' (Montaner et al. 2014) is still a benchmark for urban renovation worldwide.

In recent decades, Barcelona City Council has been increasingly concerned with preserving the identity of Ciutat Vella. Policies have been implemented to integrate and control busking as part of public heritage. After intense debate between musicians and the administration (Cruz 2016), regulations on schedules, spots and sound intensity were approved in 2014 and updated in 2019 (Ajuntament de Barcelona 2019). Although there are still some illegal music performances, most official buskers cannot perform unless they follow the council's regulations (Cruz 2016).

Experience shows that legal or illegal busking stages can be affected by pedestrian movement flows or bad acoustics, which have an impact on the social and economic value of such areas. Evidence-based arguments on the suitability of stages are lacking. As stated by Bennett & Rogers in their study on the spatial and social dynamics of street music performers in Brisbane, 'the way in which music acts on and influences phenomenological perceptions of space and place is an area that still needs to be mapped comprehensively in music research' (Bennett and Rogers 2014, 457).

Hence, it would be useful to test a methodological analysis that could provide evidence-based arguments on the acoustic and spatial attributes that define busking stages. The main research question could be: are places used by buskers in Barcelona acoustically and spatially suitable for music performance? The answer to this question would support public administrations and musicians with a methodology that could help to evaluate current busking uses of the spaces and inform the public administration about other hidden spaces with similar features.

This article aims to approach this question by exploring the relationship between spatial configuration and acoustic qualities through a qualitative and comparative analysis of four of the main, central performance environments within the inner core of Ciutat Vella, Barcelona: Plaça de Sant Felip Neri, the corner of Carrer del Bisbe and Carrer de Santa Llúcia, Plaça Sant Iu and Plaça del Rei.

Background research on spatial analysis and urban acoustics

This research is based on two assumptions: movement in compact cities is deeply influenced by land use and the urban form, and the resulting built environment determines the acoustic quality of a given space. Consequently, two strands of research are used to determine the relationships between spatial layout and busking acoustics: research using space syntax theory and methods in urban settings, and urban acoustics studies. The following section provides an overview of the literature in both disciplines, to contextualize the research.

Space syntax theoretical and methodological background

The first assumption of this paper is associated with the space syntax graph-based theories and methods introduced by Bill Hillier, Julienne Hanson and their colleagues at UCL in the 1970s. They described the spatial characteristics of buildings and cities by producing accessibility maps and measuring the topological, metric and angular relationship between the elements of a given network. This approach has become a verified, widely used platform to explore interactions between the built environment and other fields of knowledge. For example, some research has elucidated strong links between social phenomena and the built environment. The causes of urban development, social segregation and ghettoes and the crystallization of pockets of poverty or crime in cities have been analysed in terms of spatial configuration (Hillier 1988; Vaughan 2005; Nubani and Wineman 2005; Vaughan 2007; Marcus 2007; Hillier and Sahbaz 2009; Psarra, Kickert, and Pluviano 2013). Similarly, space syntax is inherently connected with culture, art, phenomenology and narrative (Seamon 2007; Psarra 2009, 2018), as well as tourism and sightseeing (Li et al. 2016). It has great potential for a science-based assessment of the design process (Karimi 2012). Steps have been taken towards understanding the impact of the spatial configuration on health and wellbeing (Vaughan and Pachilova 2017) and developing a quantitative, evidence-based understanding of lighting and perception in architecture (Stavroulaki and Peponis 2005).

This paper draws on two specific space syntax's contributions: the theory of *natural movement* and the method of *visibility graph analysis*.

'Natural movement' in urban pedestrian movement

The first contribution is from the paper 'Natural movement: or, configuration and attraction in urban pedestrian movement' (Hillier et al. 1993), which described how spatial layout, rather than the presence of attractors, is the 'primary generator' of patterns of movement. This study is closely related to the first seminal book 'The Social Logic of Space' (Hillier and Hanson 1984), which argues that different types of societies adopt fundamentally different spatial forms and, conversely, the build environment might influence social behaviour. The concept of 'natural movement' refers to this interaction between space and behaviour and is defined as the 'proportion of urban pedestrian movement determined by the grid configuration itself' (Hillier et al. 1993, 32). According to this study, most urban areas show how 'retail land uses are then located to take advantage of the opportunities offered by the passing trade and may well act as multipliers on the basic pattern of 'natural movement' generated by the grid configuration' (Hillier et al. 1993, 29). In conclusion, cities could be regarded as 'movement economies' (Hillier and Penn 1996), resulting from the multiplying effects of movement patterns shaped by a particular urban grid.

Confirmation of the existence of attractors due to the spatial layout, as in the above studies, clearly makes this theory a suitable tool to analyse the potential of a given space and to stimulate future research on the influence of phenomenological aspects. However, insight into the connection between movement in cities and the geometry of the space is still required to explore the logic of temporary uses of open spaces. When applied to the analysis of busking spaces in a homogeneous urban fabric like Barcelona's Ciutat Vella, 'natural movement' theory might help to determine the suitability of the places that are officially designated for busking and to address future studies on potential locations for busking, connected to the main flows of pedestrians, which are the *raison d'être* of these activities.

Isovists and visual graph analysis

The second key contribution of space syntax to this study relates to how busking activities correlate with the potential audience's visual perception. The general premise is that street music is not only connected to direct pedestrian movement flows but also intrinsically linked to their presence or absence within the field of view of pedestrians (Bennett and Rogers 2014).

This premise is based on research described in the paper 'Making isovists syntactic: isovist integration analysis' (Turner and Penn 1999) and subsequent publications such as 'From isovists to visibility graphs' (Turner et al. 2001). In these works, derived from a pioneering study by Michael Benedikt (Benedikt 1979) on isovist fields, it is described how a graph-based analysis of viewsheds can illustrate the accessibility and visibility potential of a given space and its relationship with spatial perception attributes such as way-finding, focus of interests, patterns of flows or space use. Studies have used this approach to discuss the detailed interaction between spatial configuration and displays in museum and galleries (Tzortzi 2003, 2005; Peponis, Conroy-Dalton, and Wineman 2004; Psarra et al. 2007; Psarra 2009) or movement in workspaces (Penn, Desyllas, and Vaughan 1999; Sailer and McCulloh 2012; Aragüez and Psarra 2017). However, the application of this methodology to the analysis of open spaces has received less attention than the extensive body of visual-graph studies (De Arruda Campos and Golka 2005; Bada and Farhi 2009; Culagovski, Greene, and Mora 2014; Guerreiro et al. 2015; Morais et al. 2017). No studies in the literature have thoroughly focused on the interaction with temporary uses or, in the specific case of this research, with urban acoustics and street music.

Relevant studies on urban acoustics

The second assumption of this study refers to urban sound. For the research proposed here, a brief explanation of the literature on urban acoustics is necessary.

First of all, a distinction between 'acoustics' and 'soundscape' approaches to sonic reality is required. Murray Schafer introduced the term 'soundscape' in the 1960s (Schafer 1977), and Pierre Schaeffer defined the term 'musical object' in 1966 (Schaeffer 1966). Both of these papers indicate that the study of sonic reality can be addressed from two perspectives: the sonic signal or someone's auditory experience as the object of study. While the first concept (acoustics) usually deals with the physical properties of the sound source and its modification by the architectural environment, the second (soundscape) focuses on the human psychoacoustic perception of the sonic environment (Kang and Schulte-Fortkamp 2016).

It is also important to distinguish between indoor environments and outdoor scenarios. Indoor conditions are usually quieter and more predictable, while outdoor scenarios generally have greater variability in sound source direction. Urban outdoor acoustic analysis normally focuses on noise propagation in canyons, noise maps in cities or big areas or traffic noise attenuation in the street network. Hence, most acoustic research in open air environments provides a rough description of sound behaviour rather than a detailed depiction of its propagation. In contrast, indoor acoustic analysis has developed techniques and software with a high level of detail.

There are numerous studies on urban acoustics and new noise policies have been introduced in the EU (Union 2002), but existing techniques and software tend to provide a general, macro-scale picture of urban areas. It may be more appropriate to study the micro scale, such as streets or squares, using detailed acoustic simulation techniques, such as room acoustic measurement software (Kang 2000a).

The present research is based on study of the sonic signal in an outdoor environment so no subjective auditory experience is addressed.

Research on the relation between space syntax and urban acoustics

The relationship between space syntax and urban acoustics has been the subject of a small body of research. Some studies have explored the positive or negative effects of sensory stimuli and spatial layout in shopping environments (Soars 2009; Penn 2005). Space syntax methodologies have also inspired research on noise pollution generated by traffic in cities and its interactions with the street layout. Recent research has tested the potential of space syntax analysis to predict traffic noise exposure (Dzhambov, Dimitrova, and Turnovska 2014). At another scale of analysis, Conor Black (Black 2013b, 2013a, 2013c) has investigated comparisons between space syntax agents and the propagation of voice in enclosed spaces, known as ‘Sound syntax’. In another field, a relationship was established between space and music in studies such as a rhythm-based analysis of the Parthenon frieze (Michalopoulou and Touloumis 2015). An understanding of the temporal perception of space has also been developed (Touloumis and Michalopoulou 2009).

Although relevant studies have been undertaken on the correlation between space syntax and the use of public spaces (see the references in previous sections), no research has fully addressed the link between *space syntax* and *urban acoustics*, and no studies have examined the influence of the urban configuration on the daily activity of street music performance.

Materials and methods

The above literature review highlights the relevance of an in-depth, quantitative exploration of interactions between spatial and acoustic magnitudes. This paper seeks to combine spatial configuration and acoustics research to answer the main research question of this paper. To explore this starting point, a new methodology was tested.

The methodology involved two-step space syntax modelling of the public space in the study area, i.e., the centre of Ciutat Vella within Barcelona's Roman walls (see the grey area in Figure 1).[1] A third group of data was collected through on-site sound recordings. Finally, both spatial and acoustic data were geolocated to proceed with a combined analysis.

First step: space syntax axial analysis (betweenness centrality)

The first step was carried out using the measure of *betweenness centrality* (or *choice* as it is known in space-syntax terminology) applied to Barcelona's entire street network consisting of segments defined by the intersections of lines of natural movement and sight that are tangential to building surfaces. This measure captures the shortest paths that connect all pairs of origins and destinations, in other words, the natural through movement in the network. The value of *betweenness centrality* was calculated based on the measure of normalized angular choice (NACH, Hillier, Yang, and Turner 2012), which considers angular distance, i.e., 'the cumulative angles of turns taken between street segments in a city'. This measure is a good predictor of natural pedestrian movement (Hillier and Lida 2005; Hillier, Yang, and Turner 2012).

As shown in previous studies of Barcelona (Millán, Lazo, and López 2012; Al Sayed, Turner, and Hanna 2009) a space syntax analysis using *betweenness centrality* or *choice* at various radii is essential, as it reveals the relationships between the local and overall

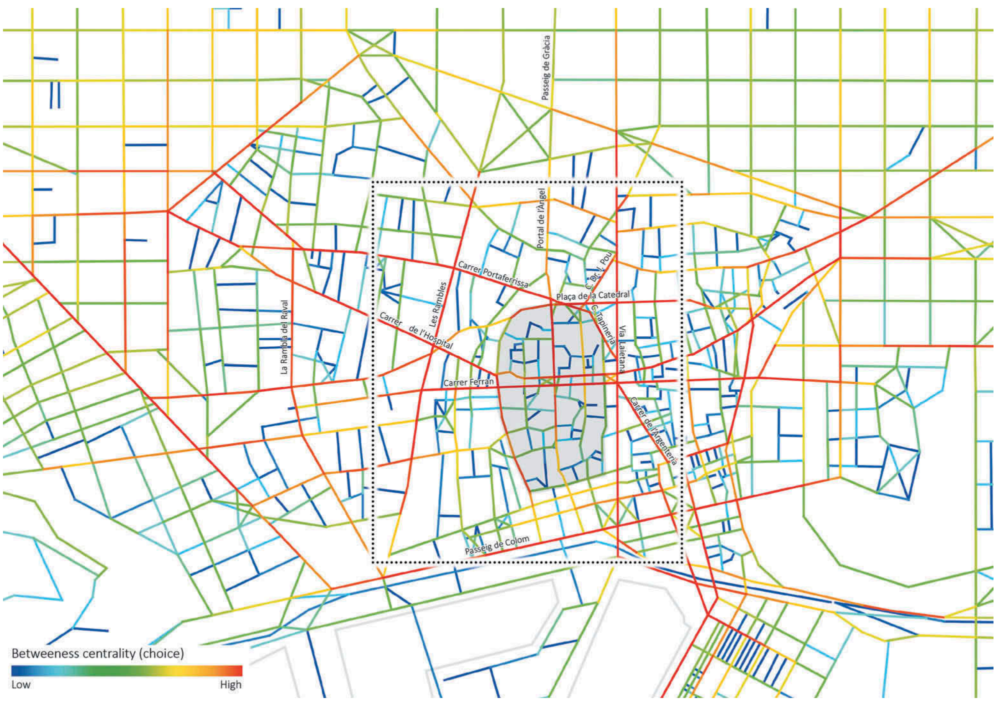

Figure 1. Detail of the betweenness centrality (choice) segment map of Ciutat Vella of Barcelona measured by least angular choice within a 1600 m metric radius. The grey area is the former Roman city of *Barcino*.

structure of the city. For the scope of this study, the algorithm was applied at a metric radius of 1600 m, i.e., the average distance of walkable and shopping areas in Barcelona. This radius corresponds to the length of Passeig de Gràcia, the Rambla de Catalunya and Las Ramblas, and is also a distance that is commonly used for the spatial layout of urban shopping malls in the city.

Second step: space syntax Visibility Graph Analysis (visual integration [HH] and clustering coefficient)

Following the general analysis of Barcelona's spatial configuration, a second, in-depth spatial analysis was conducted for each of the four selected public spaces in Ciutat Vella that function as 'open music halls' (Figure 2). The environments were chosen according to the following criteria: they have been designated recently as official performance stages (see *musica-carrer.tumblr.com*); and, despite all being located in pedestrian areas far from the noise of traffic and having similar materiality, they differ considerably in terms of geometry, size and daily-use patterns. Each space appeared to be unique and worth comparing with the others.

The in-depth spatial analysis of each of these environments was based on a *visibility graph analysis* (Turner and Penn 1999) of central Ciutat Vella. This methodology calculates spatial measures based on a graph of the visibility connections of each point in a grid of locations (1 m), superimposed on the layout, to all other points in the layout. Key measures such as *visual integration (HH)* and *clustering coefficients* were used to describe the spatial structure of Ciutat Vella and the positioning of the 4 public spaces in this area. *Visual integration (HH)* is a general measure that accounts for the mean shortest path from one point to all other points in the system (Turner and Penn 1999, 3). The *clustering coefficient* was introduced by Watts and Strogatz in the context of social network analysis (Watts and Strogatz 1998) and further developed by Schank and Wagner (Schank and Wagner 2005). Turner et al. explored the application of this parameter to measure the spikiness or convexity of a given space. According to this study, the *clustering coefficient* is 'potentially related to the decision-making process in way-finding and navigation and certainly marks out key decision points within complex configurations' (Turner et al. 2001, 111). Subsequently, the *clustering coefficient* might 'indicate the potential for perceivable co-presence in a space and therefore the potential to form groups or to interact' (Turner et al. 2001, 111).

Third step: on-site sound recordings

The study continues with an exploration of the acoustic features of each of the case studies. Five on-site measurements were made in an empty room configuration[2] with similar environmental conditions[3]. For the recordings, this research used pair-matched omnidirectional microphones[4] RODE NT 55 connected to a ZOOM H6 recorder on a stand. Once the recordings were analysed, a bicubic spline interpolation was generated to cover the entire surface of the environments. Table 1 shows the relation between every recording and environment. To obtain the reverberation time[5] and the spatial response to different frequencies, a gunshot, white noise and pink noise signals were used. Additionally, some music extracts were played back and recorded for comparison. Every

Table 1. List of measurement tracks in each environment.

Track	Plaça de Sant Felip Neri	Carrer de Santa Llúcia	Plaça de Sant Iu	Plaça del Rei
1. Shotgun	30/3/2017	24/04/2017	07/04/2017	06/04/2017
2. White noise	30/3/2017	24/04/2017	07/04/2017	06/04/2017
3. Pink noise	30/3/2017	24/04/2017	07/04/2017	06/04/2017
4. 63 Hz	30/3/2017	24/04/2017	07/04/2017	06/04/2017
5. 160 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
6. 400 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
7. 1000 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
8. 2000 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
9. 4000 HZ	30/3/2017	24/04/2017	07/04/2017	06/04/2017
10. La oboe	30/3/2017	24/04/2017	07/04/2017	06/04/2017
11. Brahms	30/3/2017	24/04/2017	07/04/2017	06/04/2017
12. Mendelssohn	30/3/2017	24/04/2017	07/04/2017	06/04/2017
13. Tchaikovsky	30/3/2017	24/04/2017	07/04/2017	06/04/2017
14. Victoria			07/04/2017	
15. Dvorak			07/04/2017	
16. Puccini		24/04/2017		
17. Stravinsky	30/3/2017			
18. Lucien	30/3/2017			
19. Orff				06/04/2017

environment was recorded between 07:00 and 08:00 h to reduce background noise. During the recordings, hardly anyone walked in the environments. Figure 6 indicates the position of the sound sources and recording points. The sound sources were located where street musicians usually play in these environments, and the recording points reflect the 4 or 5 main positions where the audience is distributed. Acoustic measurement details can be found in (Llorca et al. 2018).

Fourth step: geolocation and analysis of data

Finally, the *Visibility Graph Analysis* and the acoustic features layer were combined on the same geolocated platform to find correlations and frictions between the spatial and acoustic values per square metre. The last part of this paper presents some findings on the correlation between a combined value of *visual integration (HH)* and visual *clustering coefficient* and the *reverberation time*.

Analysis

Spatial configuration

After a long sequence of urban transformations over centuries, today's Ciutat Vella in Barcelona has a complex, rich street configuration. As explained in depth (Busquets 2003; Solà-Morales 2008), the old city is no longer an old city. It developed from its initial Roman grid on top of the *Mons Taber* with progressive densification and expansion of the city walls, modernization in the nineteenth and twentieth centuries through new *sventramenti*, regular squares and markets and, more recently, strategic opening up of areas, pedestrianization and new public facilities. Consequently, Barcelona's Ciutat Vella offers a rich urban experience for pedestrians.

To go beyond a historical reading of this palimpsest of interventions and understand its configurational properties, a street-network analysis using space syntax is proposed. Figure 1 shows the results of this analysis and indicates a preponderance of north-south streets in terms of integration, such as Las Ramblas, Rambla del Raval, Via Laietana and Portal de l'Àngel-Passeig de Gràcia. This pattern is complemented by a slightly perpendicular 'stave' of integrated streets like Carrer Ferran, Carrer de l'Hospital (former Roman *decumanus*) and Carrer Portaferrissa-Plaça de la Catedral. Some diagonal streets can also be found in the central integrated core of Ciutat Vella. These are Carrer de l'Argenteria, leading to Santa Maria del Mar, Carrer Tapineria, stretching along the former Roman walls and Carrer del Dr. Joaquim Pou which leads towards the Palau de la Música. This map also shows how the streets north of Carrer Ferran between Les Rambles and Via Laietana are potentially more integrated that the southern ones, which evidences the duality experienced in central Ciutat Vella.

This analysis also provides a general picture of streets that could support a high degree of social co-presence, which in turn fosters profitable retail activity and, in our case, a successful street performing culture. Although the visual qualities and width of each street and the attractors and distribution of land uses are not considered, many studies argue that spatial configuration, as such, is the 'primary generator of pedestrian movement patterns' and 'in general, attractors are either equalisable or work as multipliers on the basic pattern established by configuration' (Hillier et al. 1993). As referred in the previous literature review, this argument leads to an understanding of 'natural movement' as the proportion of movement that is directly influenced by the spatial layout. In an old city centre such as that of London, studies reveal a normal correlation of 50–80% between the values of *betweenness centrality* (*choice*) and on-site movement rates (Hillier et al. 1993). For the scope of our study, these results may be sufficiently relevant to justify the validity of the argument.

However, it would be worth exploring this general picture of central Barcelona considering some spatial attributes of the street network: the width and the geometry. For this purpose, this research undertook a *Visibility Graph Analysis* (Depthmap X, v. 0.5) based on a 1.0 m grid resolution and applied to relevant pedestrian areas and shared surfaces within Ciutat Vella. The size of the area of analysis was 1000 × 1500 m, which provided more accurate overall values for the central area contained within the old Roman Walls of Barcelona (300 x 500 m), but less reliable values for the surrounding area beyond Via Layetana and Rambla de Catalunya.

This produced at least two significant results:

(1) Figure 2 shows the distribution of *visual integration (HH)*. This map should not be considered an exact image of current use. Instead, it shows the 'potential' movement capacity suggested by the street space configuration, and therefore strengthens the evidence from the previous segment analysis. Given that the inner core of Ciutat Vella is quite uniform in terms of materiality, activity and uses, the hypothesis is that the spatial analysis can serve as a good proxy of movement rates, land uses, area density and attractors. However, this area may require further research that is beyond the scope of this paper. Some remarks are outlined below.

The western part of Carrer Ferran-Jaume I is strongly integrated with a progressive shift towards Carrer de la Llibreteria (former *decumanus*). This is due to the transformation of

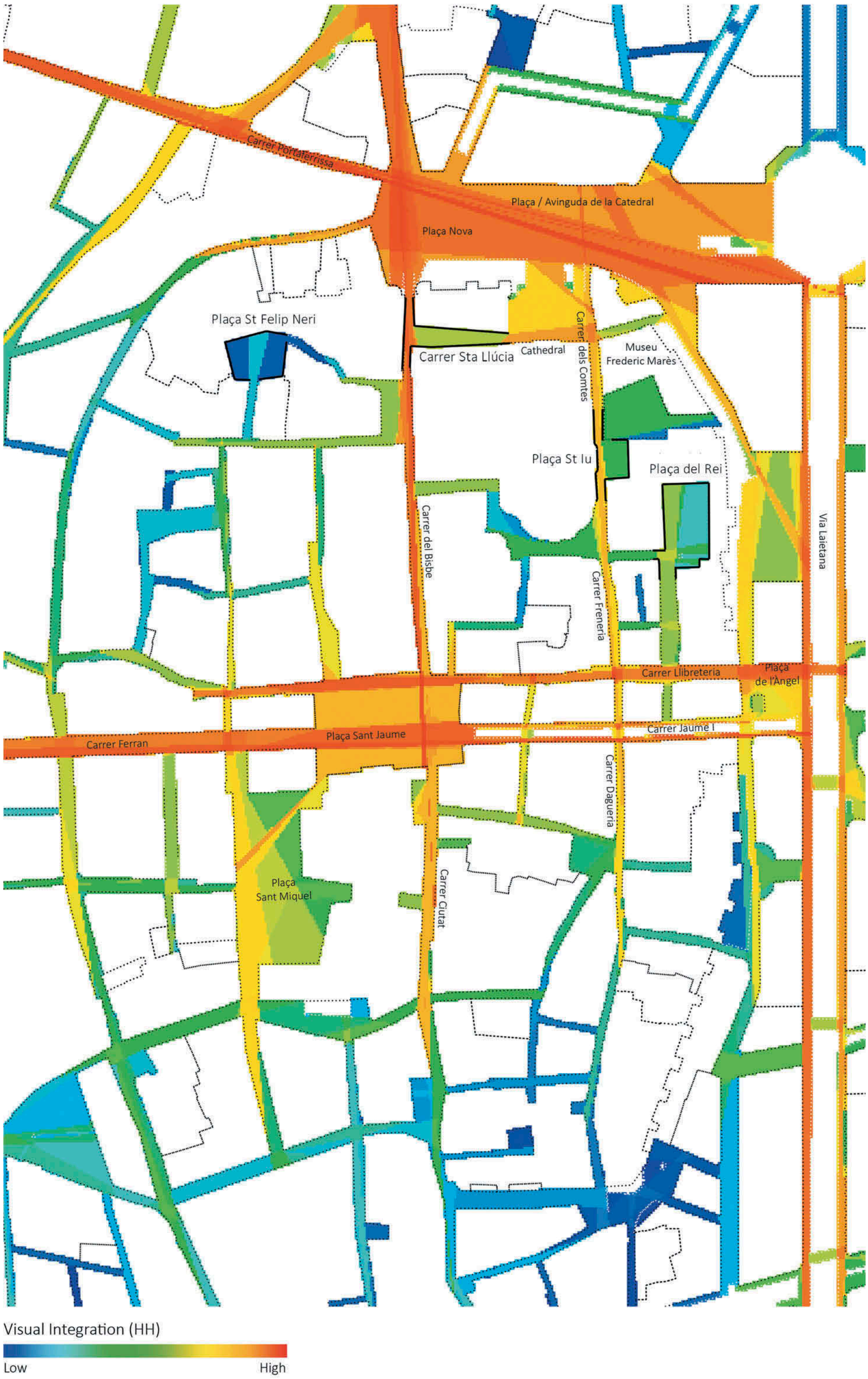

Figure 2. *Visual integration (HH)* map of central Ciutat Vella, Barcelona. The colour ranges from high values indicating well-integrated areas (red) to low values representing more secluded areas (blue).

the street section into a more car-oriented space towards the east of Plaça de Sant Jaume, which forces pedestrians to use narrow sidewalks.

Secondly, Carrer Portaferrissa is highly integrated and draws a clear diagonal across the regular geometry of the Plaça/Avinguda de la Catedral. This might be a useful consideration in a discussion of the temporary street markets and pavilions that often occupy the square, which block views and direct routes through their spaces.

Thirdly, integration along Carrer Ciutat and its extension towards Carrer del Bisbe not only confirms the role of the Roman *cardus* in the general structure of the city, but also shows a progressive decay towards the south. This pattern may be also recognized in the street parallel to Carrer Ciutat, Comtes-Freneria-Dagueria, which produces an overall decrease in integration and, consequently, potential pedestrian flow in the lower part of Ciutat Vella.

These considerations indicate that there is a grid-like structure comprised of highly integrated streets and an intricate system of streets and public spaces located in-between. This provides an interesting geography of less integrated squares and broad streets that might foster the emergence of 'open music halls', i.e., spaces of relative calmness close to the main structure. However, it would be interesting to analyse whether all the spaces are acoustically and spatially suitable for street performance stages. It gives a measure of the proportion of intervisible space within the visibility neighbourhood of a spatial point. 'It indicates how much of an observer's visual field will be retained or lost as he or she moves away from that point' (Turner et al. 2001, 110).

(2) The visibility graph analysis provides another significant measure: the *clustering coefficient* (Figure 3). The application of this measure to central Ciutat Vella revealed the sequencing of thresholds and urban corners: spaces that have a high-level of surprise and key places for decision-making on routes. Examples include the wide red area at the intersection of Carrer Ciutat and Plaça Nova, the characterization of Plaça Sant Jaume and its potential conflict with vehicular through-movement and the high level of interaction around the Plaça de l'Àngel.

If the highest 50% of values of *visual integration (HH)* are overlapped with the lowest half of the values of *clustering coefficient* that highlight the intersection areas within Ciutat Vella, the result is a heatmap of urban corners with a high potential level of pedestrian flow and decision-making (see Figure 5)[6]. At first glance, this would mean that these places could be sites of high levels of social interaction, surprise, and, therefore, successful street performances. However, on-site everyday experiences and recent research reveal that musicians usually prefer to set up their stage more or less intuitively close to the main flow (for example in the long corridors of the underground train system) but, at the same time, outside of it to avoid conflicts in narrow streets or passageways (Bennett and Rogers 2014). This suggests that good positions for street musicians are areas of high values of *clustering coefficients* (shown in *blue*) close to highly integrated street corners, which enable the unexpected discovery of a busker by pedestrians passing by and enough space for them to stop and listen.

Although the profitability of any busking activity is also linked to its strategic position within the field of view of potential consumers, musical performance obviously benefits from placement within an acoustically sensitive area for pedestrians. The open field decay of sound is 6 dB when the distance to the speaker is doubled (Beranek 1954), so any calm area within a 40 m radius from a highly integrated corner might be a suitable place for

Figure 3. *Clustering coefficient* analysis of central Ciutat Vella, Barcelona. Within this framework the values range from 0.42 (red) to 0.98 (blue).

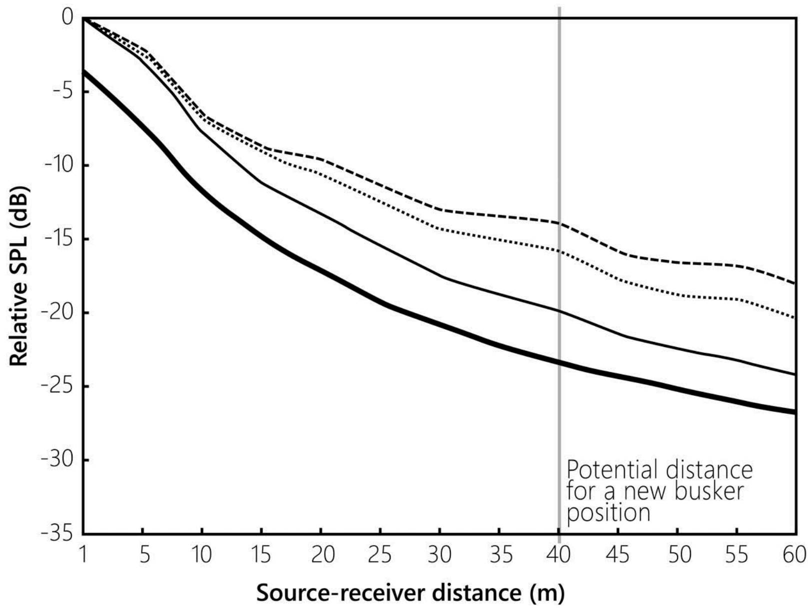

Figure 4. Sound attenuation along a street canyon (20 m) with diffusely reflecting boundaries. Black fine line, Y (distance between façades) = 6 m; dotted line, Y = 18 m; dashed line, Y = 30 m, black heavy line, free field. After (Kang 2000b).

busking. Given that the average level of a street musician is 60 dB when measured from a distance of 5 m, then from a distance of 10 m the level is 54 dB, from a distance of 20 m the level is 48 dB, and from a distance of 40 m the level is 34 dB – a sound level for a normal conversation between two people-. At this point the position could be occupied by another busker (see Figure 4).

Figure 5 shows visual overlapping of the combined measures of the *visual integration (HH), clustering coefficient* and noise levels that provide a synthetic cartography of streets and open spaces.

This deductive approach to the spatial configuration of central Ciutat Vella might help to understand the similarities and differences between the selected case studies. Some conclusions are:

- Plaça de St. Felip Neri is around 25 × 20 m wide and is in the proximity of Carrer del Bisbe, a crowded street next to the western façade of the Cathedral of Barcelona. Although it is not a regular and legal busking stage according to the council's regulation (Ajuntament de Barcelona 2019), it is often used for busking or for music events. It is a square located in a spatially and acoustically secluded area in comparison with the other case studies. However, the internal configuration given by the *clustering coefficient*, which is similar to the distribution of the *visual integration (HH)* values, reveals a very suitable pattern of blue regions that could facilitate musical activity and listening areas. Busking is here less popular or more exclusive because only pedestrians that know of the existence of the square or discover it by pure chance could become potential listeners.

- The corner between Carrer del Bisbe and Carrer de Santa Llúcia is a wide street (9 m) linking the front entrance of the Cathedral with the main street of central Ciutat Vella,

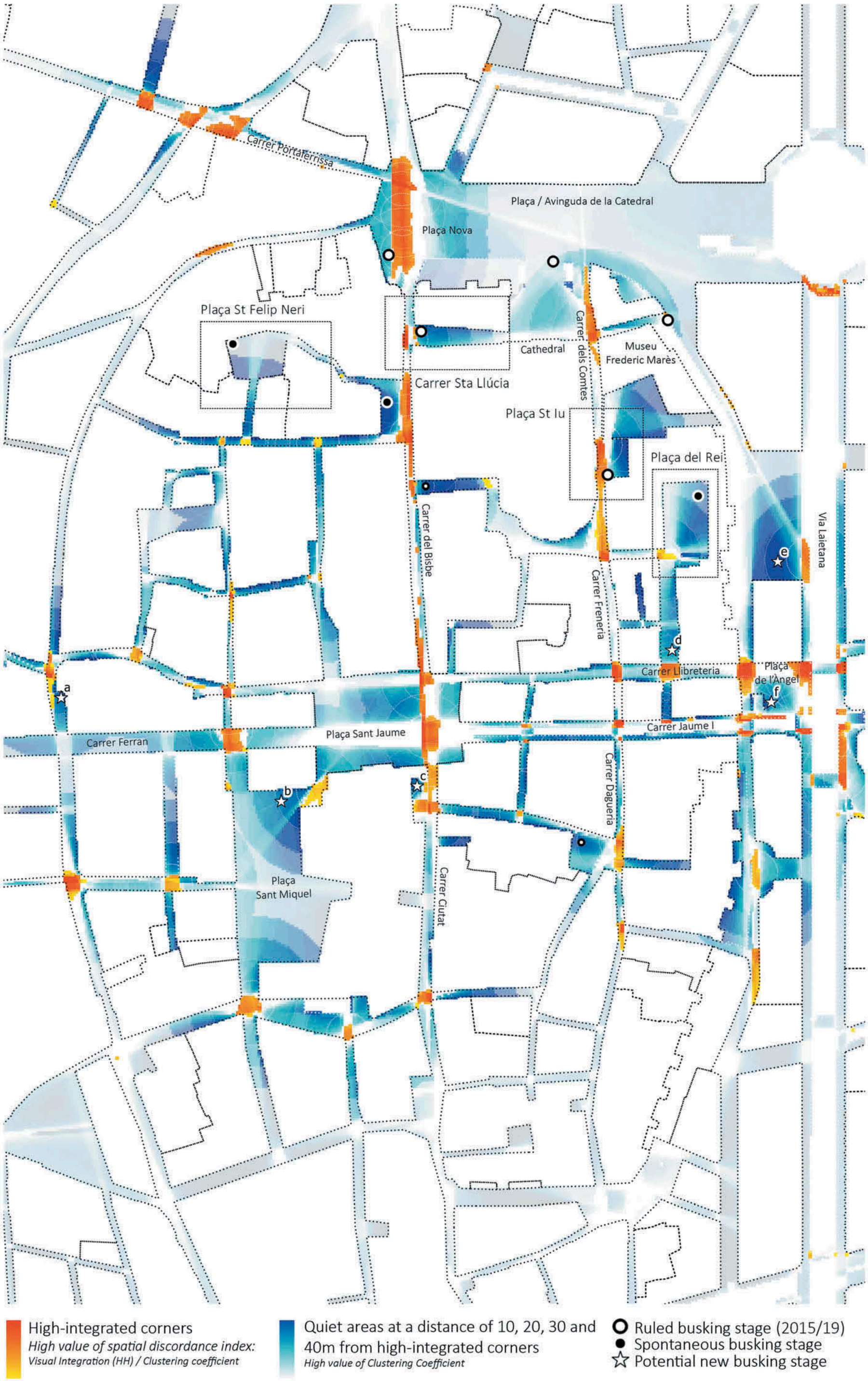

Figure 5. Acoustic influence area (radius 10 to 40 m) from highly integrated corners (red to yellow) in central Ciutat Vella, Barcelona. The intensity of the red colour is the result of the division between *integration* and the *clustering coefficient*. Blue areas are low integrated areas that might work as 'open music halls' because of their closeness to highly integrated corners.

Carrer del Bisbe. Its centrality and suitability for busking is clearly confirmed by its close position to a highly integrated corner and the size and geometry of the space available for listening (blue areas).

- Plaça Sant Iu is in front of the east gate of the Cathedral, it is 17 × 9 m wide and functions as the antechamber to the Frederic Marés Museum. This square is perhaps the most suitable 'open music hall' case study in terms of spatial configuration. As in the previous case, it is very close to a highly integrated corner but has a slightly more generous free space that is sheltered from the main flow. While the stone bench located along the largest side of the square may contribute to its success, access to the museum disrupts this general pattern during opening times.

- Plaça del Rei is a rectangular square (38 x 20 m) enclosed by the Santa Àgata Chapel, the Saló del Tinell, the Museum of the History of Barcelona and the Lloctinent Palace. The square is only accessible from Carrer de Veguer and has one semicircular staircase leading to the chapel in the northern corner. It is one step behind the main integrated streets, but is still well-connected to them. The current busking position in the furthest corner of the square not only allows for a clear visual connection with the streets connected to the square, but also provides a large quiet area in which to stay and enjoy the music.

Acoustic properties

Although the studied environments have some specific features due to their open-air nature, the study considered them using a closed concert hall acoustics method[7]. This decision was taken after considering three factors. The first is the openness of the places. Due to their three-dimensional geometric configuration, the four squares can be viewed as boxes in which the floor and most of the walls are defined, while they lack a ceiling. This configuration can be understood as if the floor and walls were made of stone while the ceiling of the box was made of the most absorbent material possible, because no audible sound can bounce back in the open air. The second consideration concerns the size of the four spaces. The smallest space, Carrer de Santa Llúcia, holds an air volume of 1,800 m^3, which is similar to a typical speech hall[8]. At the other extreme, the largest space, the Plaça del Rei has a volume of 12,000 m^3, which does not exceed the volume of a large concert hall such as the Berliner Philharmonie. Finally, the third consideration is that the sound sources change position constantly in an open-air environment. This would be significant if the sound of an everyday configuration was studied, with running children, singers, street vendors or even police sirens. However, the recordings were made with a street concert configuration, with only one player at a fixed point and the audience standing quietly listening. Therefore, although the studied environments have unpredictable noise levels as they are open-air places, the study analysed them as closed concert hall stages and hence a concert hall acoustics analysis is provided here.

The four environments (Figure 6) were studied acoustically under normalized parameters (Aenor n.d.) using a reproduction-recording system. This system consists of an impulse signal previously calibrated in the anechoic chamber of the Escuela Politécnica Superior de Gandia (EPSG) and recorded in a set of different xy locations for each case. As every recording point is subdivided into two channels: left (L) and right (R), the result is a double value for each point: 1_L, 1_R, 2_L, 2_R, etc.

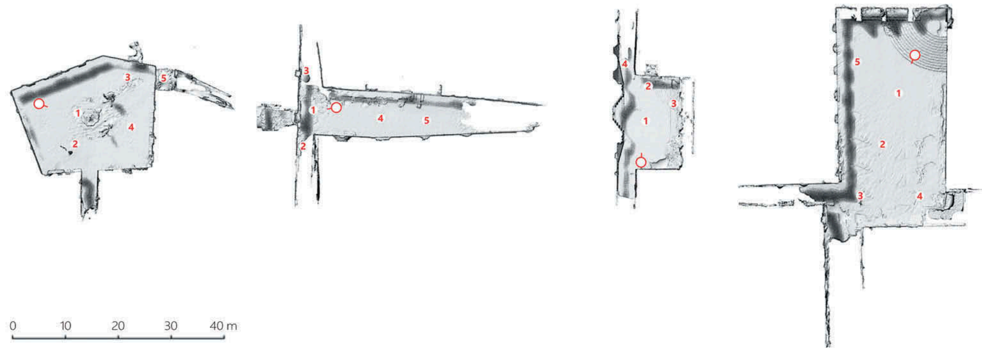

Figure 6. Plans of the Plaça de Sant Felip Neri, Carrer de Santa Llúcia, Plaça Sant Iu and Plaça del Rei with the position of the musicians and the five recording points.

Figure 7. Reproduction-recording system in the anechoic chamber of the EPSG and in Plaça de Sant Felip Neri.

Once the impulse responses of the recorded points had been obtained (Figure 7), some of the parameters of acoustic quality were extracted using signal processing. The resulting parameters were reverberation time, early decay time, speech clarity, definition, musical clarity, and sonority. This study is focused on reverberation time. This parameter is the quantitative measure of the quality of reverberance. While speech loses intelligibility when high reverberance is created in a room, for many forms of music reverberance can add an attractive fullness to the sound by bonding adjacent notes together and blending the sounds from the instruments/voices in an ensemble (Gade 2007). There is a long tradition of suggesting optimal reverberation time values for different kinds of music (Beranek 1962; Barron 1993). In Figure 8, one of the suggestions is plotted. Due to the architectural features of each environment, different reverberation time averages (from the recording points) can be measured in the four environments. Each environment tends to host a certain kind of musicians. For example, ensembles formed by 1 to 3 players in chamber music style usually frequent Plaça de Sant Felip Neri, whereas Plaça del Rei is usually a stage for larger bands. Therefore, reverberation time appears to be a measured quantity that suggests the music use of the spaces, and thus can be used to respond to both the questions established in the Introduction.

The reverberation time value corresponds to the falling time of the sound associated with the angle for the first 60 dB decrease. When a sound source that is continually

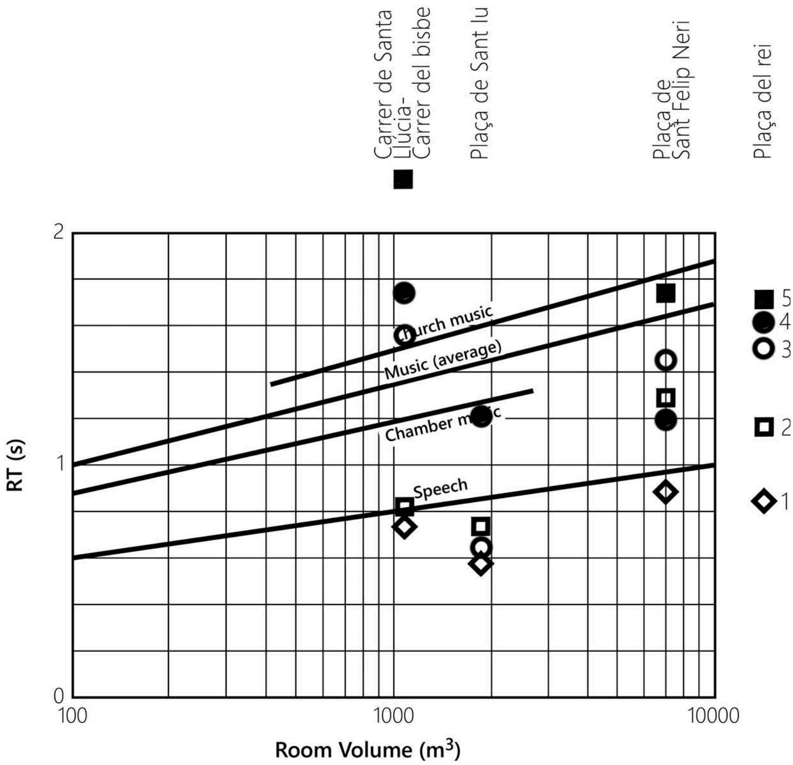

Figure 8. Reverberation times for the points (1–5) recorded in each space. The curves show the optimum reverberation time according to the volume of the hall and its use after (Turner and Pretlove 1991).

radiating suddenly stops in a certain enclosure, a listener in the hall will continue to hear the sound for a period of time while its energy is being absorbed by the surfaces of the enclosure's limits (Arau Puchades 1999). Here, the *reverberation time* values for the various environments and at the different frequencies are shown:

An analysis of the results reveals some acoustic features of the environments (Figure 9). In Plaça de Sant Felip Neri, the reverberation time increases according to the distance from the emission point. Using the reference values stated in Carrión (1998), the first recorded point values are comparable to a speech hall (Ts 70–100 ms), the second point values are similar to an opera theatre (Ts = 120–150 ms) and the third and fourth points are similar to a chamber music hall (Ts = 130–170 ms). Finally, the fifth point, which is situated in an access road to the square, presents similar values to a symphonic hall (Ts = 180–200 ms).

It can be deduced that the points that best approximate the current use of the square, i.e., chamber music, are the third and fourth recorded points. The plans in Figure 10 indicate the reverberation time values of this environment. The interpolated plans show us that, as the frequency increased, a blue area corresponding to the lowest reverberation time zone also increased. At the same time, the green area decreased when the frequency increased. These two features explain why Plaça de Sant Felip Neri has a wide range of

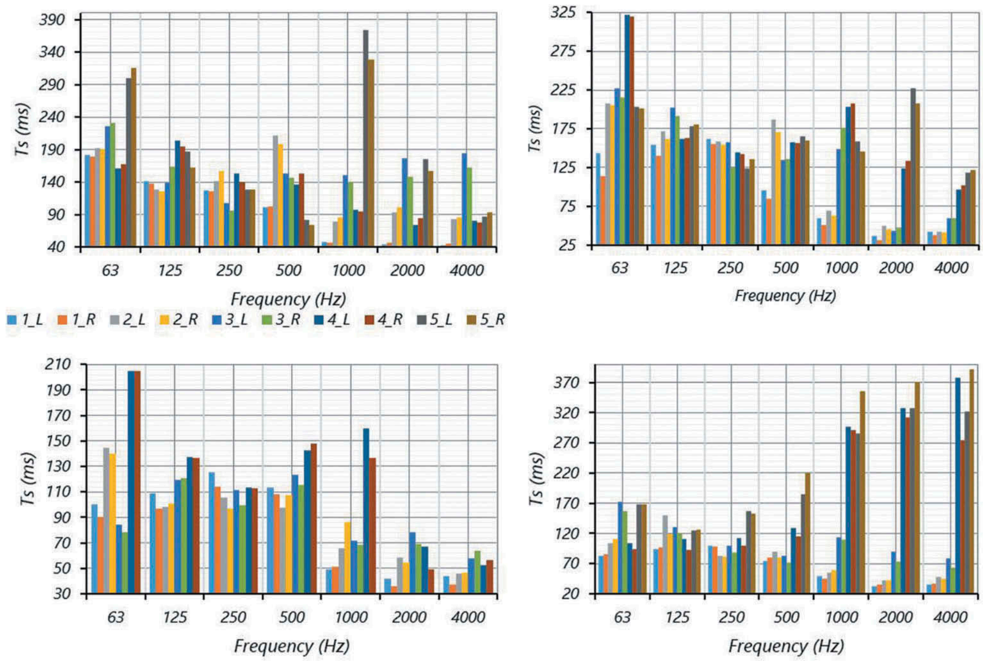

Figure 9. Reverberation time in the four environments studied: Plaça de Sant Felip Neri (top left), Plaça del Rei (top right), Plaça de Sant Iu (bottom left) and Carrer de Santa Llúcia-del Bisbe (bottom right).

reverberation time values in its low frequencies, but similar reverberation time values in the high frequencies (1 sec. approx.). In these drawings, the best place to hear the chamber music played on the stage corresponds to the other half of the square to that of the musician. This is because the reverberant field is not yet active in the first half of the square. Therefore, the spectator must move back fifteen metres from the player to obtain a proper spatial sensation of the music.

Carrer de Sant Llúcia-del Bisbe at the first, second and third recorded points has reverberation time values that do not exceed the limit of an opera theatre, corresponding to the area generally used by the audience. Meanwhile, the fourth and fifth points, which are not occupied by spectators, have similar features to a symphonic hall. If the interpolated plans are examined, it is possible to observe zones with high reverberation time values at frequencies of 1000 Hz, 2000 Hz and 4000 Hz. These odd values could be ignored in this analysis because they are caused by deformation of the interpolation generated from an accumulation set of disparate values of frequency in a very close distribution. Furthermore, there is a good reverberation zone to the left of the emitter and this zone coincides precisely with the area in which the public stands every Saturday night. This indicates that the acoustic properties of the spaces perfectly match their weekly music use.

Plaça de Sant Iu has reverberation time values on the boundary of the speech and chamber hall domains (Ts = 70–170), except for the fourth point that behaves like a chamber music hall. The interpolated plans indicate that this is the most homogeneous environment that was studied. Its reverberation time values remain very low at high

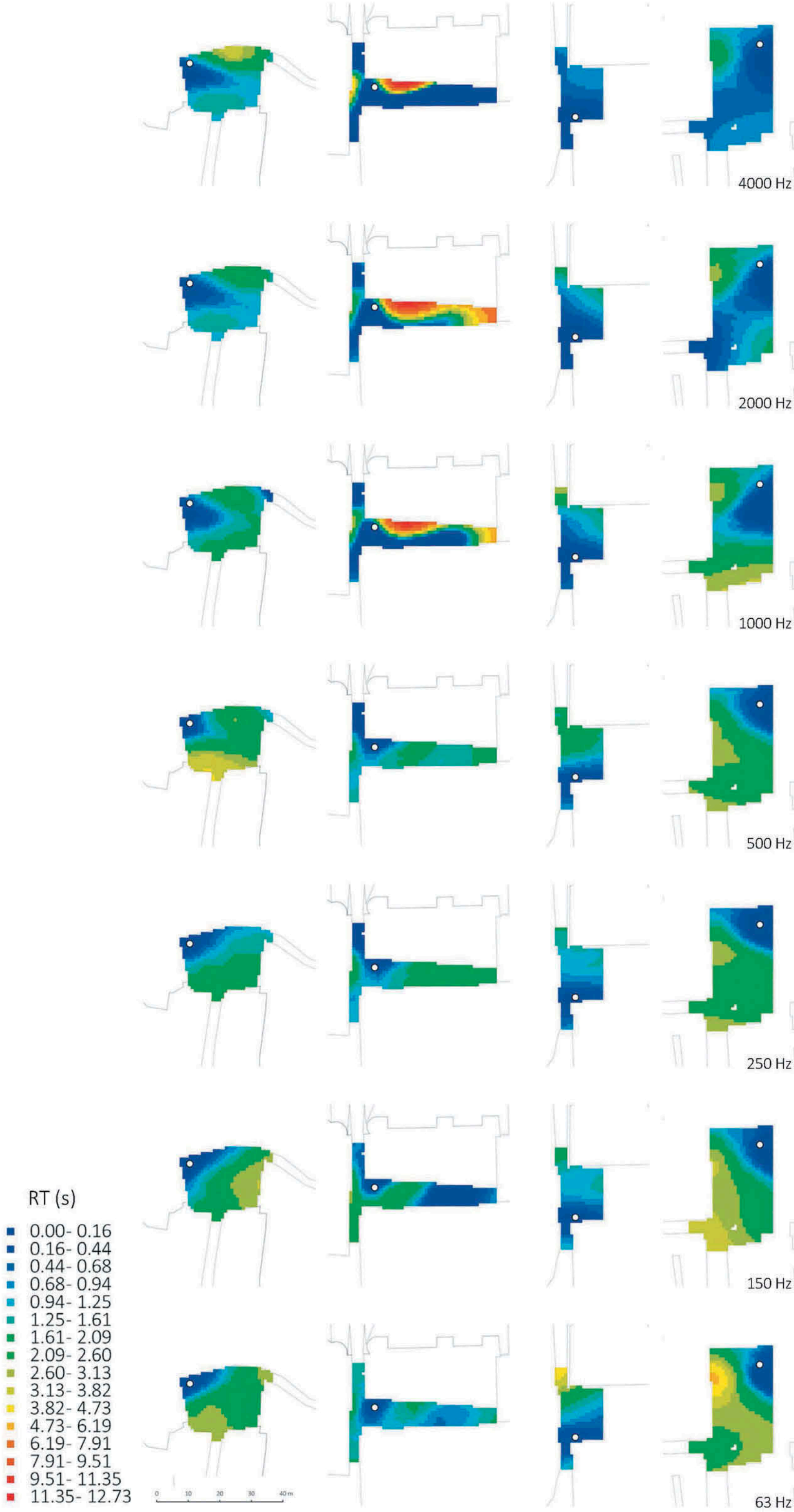

Figure 10. Reverberation time maps created for each frequency: Plaça de Sant Felip Neri, Carrer de Santa Llúcia, Plaça Sant Iu and Plaça del Rei.

frequencies and increase at distant points from the emitter once the frequencies decrease.

In Plaça del Rei, the reverberation time reaches similar values to a symphonic hall as the user walks away from the emission point. Only the first and second recording points are outside of this domain because they are too near to the source. Again, the third, fourth and fifth points are the positions with values that best approximate the current music use of the square, i.e., symphonic music. Figure 8 show the reverberation time values of this environment. The interpolated plans reveal a difference in reverberation time values between the frequencies that were studied. While a blue area (low reverberation time) is always present near the player, the green area decreases as the frequencies increase. This shows that at high frequencies the reverberation time remains at a low value. However, at low frequencies, the further the distance from the player, the longer the reverberation time is. Careful observation of the plans reveals a stain at higher values of all the frequency ranges when it is located to the left of the emitter. The most probable explanation for this phenomenon is the parallelism and flatness of the longest walls of Plaça del Rei. This point receives a concentrated number of waves from the front wall, which is totally flat and parallel to the back wall.

If the points that best approximate the current use of the environment are now considered, correlation of this information and the spatial configuration is feasible.

Results: correlations between space and acoustics

After referencing the spatial and acoustic features to the same 1.0 m geolocated grid using a GIS platform, some findings could help establish a set of correlations and mismatches between these two variables.

Regarding the spatial configuration, the best busking points are within a 40 m radius from a highly integrated corner. At the same time, a non-conflictive street performance should be surrounded by a quiet area so that people can stop and listen. To express this quantitatively, the most suitable spaces for both listeners and the musician are in the vicinity of a corner with a higher value of *visual integration (HH)/clustering coefficient*. This factor could be defined as the *spatial discordance index*, i.e., the higher the value, the more movement conflict will be produced at that decision-making point.

If the spatial data is matched with the specific reverberation time for each case study (in this analysis, the most common frequency of 500 Hz was used), outstanding output can be found. However, a high-quality acoustic area does not always match the appropriate characteristics in terms of spatial configuration. Indeed, as the case studies are considered 'open music halls', through movement generated by pedestrian flow often conflicts with the sound quality. The correlation between these two sets of values can, in turn, be used to clearly understand the *spatial-acoustic discordance* areas. This relationship is shown in Figure 11 where a graduated colour sum of spatial and sound values has been produced for each case study. The darker the colour range, the higher the level of natural movement and acoustic incompatibility that is registered. In turn, the white colour indicates non-conflictive areas that either have bad acoustics, very low pedestrian flow or a combination of both. The middle values (orange) indicate points with a good balance in terms of acoustics and spatial attractiveness, which provide suitable spaces for listening.

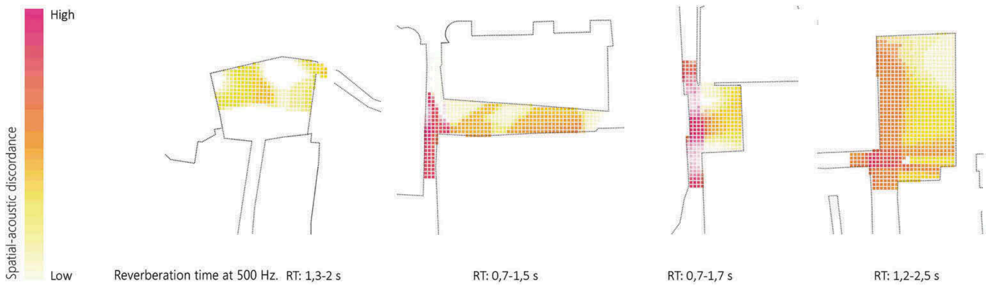

Figure 11. Spatial-acoustic discordance: visual overlapping of the spatial and acoustical properties of the Plaça Sant Felip Neri, Carrer Santa Llúcia, Plaça Sant Iu and Plaça del Rei. This map is the result of a graduated colour sum of the Spatial Discordance Index (Figure 5) and the best reverberation time for each environment for a 500Hz frequency (Figure 10). The areas with a dark colour are those specific points with good acoustics but with a conflictive position in the movement pattern.

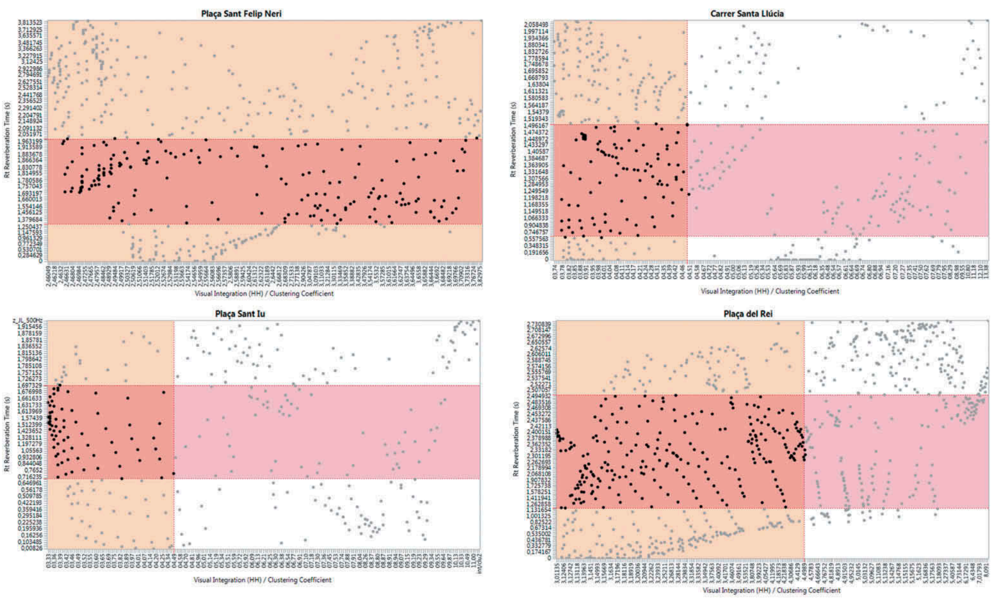

Figure 12. *Spatial-acoustic discordance*. Correlation between the *Rt* reverberation time (s) for each case-study (red) and the *spatial discordance index* (0 to 4.5, in orange).

Figure 11 can be analysed by establishing a numerical correlation between the specific Rt reverberation time (s) in each place and the *spatial discordance index* (*visual integration (HH)/clustering coefficient*). A comparison of the results reveals some important findings, as illustrated in Figure 12. For this case-study, a cut-off value of 4.5 was selected, as it points out empirically a significant distinction between points with high or low potential of spatial disturbance.

In Plaça de Sant Felip Neri, the *spatial discordance index* is very low at all points, because the values do not surpass 4.5; the threshold between a highly integrated corner and a quiet area. The chart shows that the likely flow of pedestrians will probably be broken up in this square due to its step depth from the rest of the main streets. This exceptional condition means that as much as 185 sqm (185 points in the graph) have acceptable acoustics for music purposes, particularly when the range between 1.3 s and 2 s is considered, which would fit inside both the chamber and symphonic acoustic categories. However, the square's secluded position in Ciutat Vella prevents it from becoming a convenient 'open music hall' for busking.

Carrer de Santa Llúcia presents a very different picture. It is easy to identify two large point groupings in Figure 12: those with a high index of sp*atial discordance* and those with a low value. This division indicates the high disparity between the spatial conditions of the analysed points: in a constrained domain of space the *spatial discordance* falls from a hyper-connected street to a secluded area. Furthermore, values with low *spatial discordance* (less than 4.5) correlate with very dispersed reverberation time values. Values with high *spatial discordance* (over 4.5) match the low reverberation time values (around 1.19 s) i.e., they are inside the optimum domain of reverberation. To be exact, only 98 sqm of the crossroads have good acoustic conditions and do not coincide with *spatial discordance* areas. Interestingly, points with high *spatial discordance* and good reverberation time values match the points where the audience is normally placed. This reflects the most common opinion listeners give of an enjoyable busking activity: 'to watch without being seen'. In other words, listeners prefer to stand in places with good acoustics that also provide a sufficiently high level of pedestrian movement to preserve anonymity.

Plaça Sant Iu has a different distribution of points of spatial and acoustic values (Figure 12). The acoustically acceptable domain is highlighted in the dark pink area of the graph. A heavy concentration of areas with a low *spatial discordance index* is found on the left of the graph. To the right of the chart, a smaller and more dispersed number of points shows a decrease in the *spatial discordance index*. It can be concluded that this square contains a large area of good acoustic space (72 sqm) which falls into an acceptable domain of *spatial discordance*.

Finally, Plaça del Rei has a linear relation between the reverberation time parameter and the *spatial discordance index*. When the user moves away from the acoustic source (upper right-hand corner), which is in the area with less *spatial discordance*, the reverberation time increases in parallel with the *spatial discordance*. Therefore, when maximum *spatial discordance* is found in the place where maximum reverberation time occurs, the reverberation time is too high for optimal listening. Thus, the central zone (240 sqm) of the square is the optimum acoustic area below the *spatial discordance* limit.

Conclusions

Conclusions can be drawn from the previous analysis and findings. To start with, two kinds of spaces could be categorized based on their spatial and acoustic properties. The first type are environments that are more appropriate for spontaneous street music performance, since this kind of activity accepts, encourages and relies on a high level of through-movement. The second type are more closely linked to organized musical events, because these spaces are not reliant on natural movement flow and can host a larger audience. Evidently, Plaça Sant Iu and Carrer de Santa Llúcia belong to the first type. Plaça Sant Iu should be considered more ideal than Carrer de Santa Llúcia. Indeed, given that both spaces are connected to streets with similar integration, the geometry of Plaça Sant Iu is less conflictive in terms of *spatial-acoustic discordance* than the corner of Carrer de Santa Llúcia, even though the entrance to the Frederic Marès Museum in the former splits the square and reduces the area for listening. While Plaça Sant Iu's highly integrated street and decision-making point leaves a generous, comfortable area for listening, Carrer de Santa Llúcia has almost no such area next to Carrer del Bisbe. The area close to the musician is often too difficult to reach because of the narrowness of this street. Conversely, the more secluded position of Plaça del Rei and, of course, Plaça de Sant Felip Neri might be regarded as appropriate spaces for organized musical events due to their high capacity (800 sqm and 700 sqm, respectively) and lack of free-busking as such. The fact that their acoustics are suitable for symphonic orchestras, bands and choral ensembles reinforces their appropriacy.

Secondly, as stated at the beginning of the paper, the methodology tested in this research could help to identify other new busking places. In Figure 5, the star-shaped points represent suitable spaces for busking because of their appropriate spatial configuration: (a) Carrer Avinyó; (b) Plaça Sant Miquel; (c) Carrer del Veguer; (d) Plaça Ramon Berenguer Gran; and (f) Plaça de l'Àngel. While the first three can easily be made into future busking stages, the latter two might be better understood as a potential part of an overall redesign of Via Laietana. In any case, further acoustic studies should be developed in each of these areas to provide results relating to the correlations explored in this article.

However, although the results and conclusions add to the existing literature on this topic, this pilot study has several limitations. Firstly, the number of case studies analysed in Ciutat Vella was low and the acoustic study was restricted to the 500 Hz frequency band limit. These two factors limited the conclusiveness of the results. It would be worth expanding the study to other environments and to the entire music spectrum (from 63 Hz to 4000 Hz) to develop a better account of which type of music might be more suitable for each space. Regarding the spatial configuration, the *VGA* space syntax analysis in this research uses the 'natural movement' definition as its main argument (Hillier et al. 1993). Therefore, it does not consider spatial qualitative data such as ground-floor activities, materiality, minor obstacles, topography, climate, greenery, environmental sound or peaks of accessibility in underground accesses. The hypothesis supported by previous research is that attractor-based analysis could qualify the results without modifying them substantially (Hillier and Penn 1996). In any case, attractor-based analysis could give a strong picture of the potential spatial capacity of a given street network. Further research might be developed to calibrate the influence of this argument on the specific urban layout of Ciutat Vella, Barcelona. Finally, this study could also be balanced by an on-site survey of pedestrian movement within this area in order to provide evidence for the configurational-based conclusions.

In the end, this study presents a method for analysing spatial configuration and acoustic properties in outdoor spaces in a compact public space network in Barcelona. The methodology could provide a broader view of the topic if case study sites are extended beyond the limits of Ciutat Vella to other districts in Barcelona or any other compact city. The methodology discussed in this paper could be also used to understand busking in other collective spaces with a different geometrical and movement pattern such as shopping malls, the underground system or larger open areas. Future studies on urban soundscapes could help to provide evidence-based understanding of the hidden patterns of these fluid activities, which deeply shape the urbanity of our cities.

Notes

1. Readers of the print journal can view figures in colour online at https://doi.org/10.1080/13574809.2019.1699398
2. 'Empty room configuration': in contrast to 'full anechoic room configuration', the term 'empty' describes the acoustic paradigm of a room without absorptive materials.
3. 'Similar environmental conditions': all case studies were recorded between 7:00 h and 8:00 h in the morning; they are separated from the road traffic by other buildings at a minimum distance of 100 metres; the amount of people walking through the places was between 5 people and 10 people during the measurement hours; the near sound sources were footsteps. These environmental conditions conveyed into a low background noise.
4. 'Pair-matched omnidirectional microphones': 'pair-matched' refers that the measurement microphones were two microphones with the same sensitivity; an 'omnidirectional microphone' responds uniformly to sound pressure from all directions.
5. 'Reverberation time' of a room or space is defined as the time it takes for sound to decay by being inaudible (Gade 2007).
6. Note that the clustering coefficient is a quotient that ranges from 0 to 1, and for this study, values tending to 0 are coloured in red and those tending to 1 are coloured in blue.
7. The closed concert hall acoustic method consists on playback and recording of a signal which contains all audible frequencies in the room. This method is performed with a speaker and a microphone.
8. The terms 'speech hall', 'opera theatre', 'chamber music hall' and 'concert hall', among others, are architectural typologies to describe rooms with similar acoustic features.

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