Understanding the Role of Spatial Connectivity in Integrating Informal Settlements, through the Case of Medellin's Urban Cable-cars.

Paul Goodship
1 The Bartlett School Of Architecture, University College London
1 ucftp@g.ucl.ac.uk

Throughout Latin America urban cable-cars are fast becoming a normal sight with urban transport systems, taking residents and tourists to and from previously isolated locations and providing a new form of accessibility that was not possible before. As its popularity grows, it is important to understand the role that improved spatial connectivity plays in transforming these communities and discuss how this can be best measured. This is because the spatial conditions of informal settlements are often forgotten about when planning large scale upgrading programs. Therefore, the aim of this article is to explore ways to interpret the role of spatial connectivity in the transformation process of informal settlements, through the case of Medellin's Urban Cable-car and the exploration of 'speed' as a measurable variable.

Keywords: Spatial Connectivity, Space Syntax, Speed, Urban Cable-cars

MEDELLIN AND THE URBAN CABLE-CAR
Medellin, the second largest city in Colombia with a population of around 2.5 million, has recently become one of the most talked about cities in the world, due to its rapid transformation from a violent, drug cartel controlled city to a city that aims to be more socially inclusive. This transformation has been encapsulated by new forms of urbanism that aim to engage the poor and a municipality that inspires to integrate all of its citizens into one city. When Sergio Fajardo was elected Mayor in 2004, one of his main goals was to create an 'equal city for all and were all citizens can construct relations stimulated by a city rich in services, culture and public space' (Brand and Davila 2013). This ambition developed into a new approach to implementing urban projects combining simultaneously physical transformations, social programs and participation. To do this the term 'Social Urbanism' was used, which was 'a metaphor for an integrated approach to transport and urban development, and for the power of the strategic potential of this integrated approach to address urban inequality' (Levy 2013). Yet, whilst it was only a metaphor, it helped to enable a large-scale urban upgrading project for the whole city, with a focus on the urban poor.

The most important urban project to develop from this was 'Proyecto Urbano Integral' (Integral Urban Project) or PUI. It was, and still is, an urban upgrading project created and administered by the municipality with the aim of increasing the quality of life of inhabitants, focusing on areas where poverty...
and violence is most visible. Its strategy focuses on an integral and comprehensive approach, providing each project with three main components - a physical, social and institutional component. This can be best observed in PUI Noriental (North-east), which oversaw the construction of large community facilities such as a Library-Park and Business Development Centre, 15 new or upgraded public spaces and streets, 3 new bridges offering connections between local neighbourhoods, new housing including the upgrading and consolidation of existing homes, a wide range of community meetings, workshops and events, a series of social and participatory programs (Calderon 2009). One of the essential elements to its success was the newly opened urban cable-car (figure 1), which connected the previously isolated neighbourhoods.

Yet it became more than just a simple transport connection, it enabled the upgrading projects to become a part of the citywide transformation process and opened up the neighbourhood (and the realities within) to all citizens of Medellin. Intriguingly the cable-car was never conceived as a part of the overall upgrading process, nor was it implemented by Sergio Fajardo the mastermind of 'Social Urbanism'. It was instigated by Luis Perez, the previous mayor, and was initially intended to be a mechanism to transport workers in the north of the city to the factories in the south, via the heavily underused existing metro train (Brand 2013a). Soon after it opened in 2004 it became clear to many that this could become the focal point for the PUI Noriental, with interventions seemingly adjoining it. As ‘in the four years following its introduction, the city invested seven times the cost of the cable-car system in complementary urban projects’, harnessing its potential to not only spatial connect the poor, but also socially and economically improve lives (Brand and Davila 2013). This saw major changes occurring in some of the most violent and poor neighbourhoods and with it brought much international acclaim.

This predictably led to a second cable-car line in 2007, connecting hillside settlements in the west of the city to the main metro train line. However, whilst the first line ended up being supported by complimentary urban projects, this was not the case with the second line, where a lack of investment in secondary projects meant there was an over reliance on its transportation value. Peter Brand, a local academic, points out "it should not be assumed that aerial cable-car systems [alone] will lead directly to the integration of poor neighbourhoods with the rest of the city" (Brand 2013b). This is clear when comparing Medellin’s cable-car lines as ‘what has happened around the K and J lines makes it abundantly clear that integrated, localised, parallel and coordinated strategies of intervention generate far greater benefits that the sum of independent, diffuse and sequential projects'. Yet, even with this realisation that cable-cars alone can not automatically resolve problems of urban poverty, two new lines are currently being built in the east of the city and another line is proposed in the northwest.

This symbol of Medellin’s transformation and its initial success led to its replication in other cities across Latin America, including Caracas, Rio de Janeiro and La Paz, and is currently being proposed in Quito and Lima. Yet, whilst this new form of transportation works with the existing urban grid to create a solution that prevents the demolition of homes and local businesses, there are still many uncertainties, including the role its spatial connections play in
the whole transformation process.

**THE SPATIAL NETWORK**

Within informal settlements, 'there are certain parameters and elements which, are increasingly present and should be part of any serious attempt to address issues of poverty' (Serge 2009). Such parameters maybe understood as spatial and can be explained within Bill Hillier's paper 'A theory of the city as object', where he explains 'a local process generates differences in local grid patterns and apparently reflects differences in spatial culture; and the other a global process generates a single overriding structure that seems to reflect a more generic or universal process'. Highlighting that whilst socio-components create the underlying pattern of differences, there is a set of 'autonomous spatial laws that are governing the affects on spatial configuration' and it is these 'invariants' that allow for greater spatial integration (Hillier 2002). These principles can be observed in informal settlements, as often the lack of global integration leads to isolation, encouraging local socio-components to dominant, making them turn their back on the city.

These spatial laws are further explored in Hillier et al. (2000), extensive study of 17 informal settlements in Santiago, Chile. Were pedestrian and vehicular patterns of movement and land uses was studied alongside typical spatial configuration models, to critical assess the spatial aspects that lead to consolidation. This established the settlements that were better equip to develop 'edge orientated commercial activity, can participate in the wider local economy' and would therefore consolidate quicker, whereas settlements that have no, or little, edge-activity consolidate a lot slower. (Hillier et al. 2000.) Karimi et al. again explore these issues in the paper, 'Evidence-Based Spatial Intervention for Regeneration of Informal Settlements'. This examines how limited physical interventions can facilitate the spatial integration of informal settlements, with the case of Jeddah. It attempts to demonstrate that with a deeper understanding of the elements and invariants that consolidate informality, the upgrading process can be greater improved. This led to an analysis-driven, evidence-based proposal that analyses the different spatial and socioeconomic factors, using a multi-criterion GIS method to form a composite indexing system, which is then used as a guideline for design decisions. (Karimi. 2007.)

These types of analysis use Space Syntax to explain and predict the spatial networks of informal settlements. Space Syntax has a long established connection to urban theory that can 'link physical aspects of the urban system with its functional, social and behavioural aspects, directly and seamlessly' (Karimi et al. 2013).

However, as Vinicius Netto points out 'few sociospatial approaches have been quite so polemical and stirred quite so many different responses from scholars of the city as space syntax'. So whilst Space Syntax has established itself as a both a reliable methodology and a well respected urban theory, there are still many detractors. Netto explains that many cite its epistemological limitations and 'accuse the theory of excessive formalization and geometric reduction, questioning its capacity to represent the city, its morphology and transformations, and the partial way in which it captures the complexity of the social world'. This suggests that Space Syntax can be seen to create a world that is almost exclusively pure geometry and structure, to allow its analysis to focus on configuration and hierarchies. Then another commentator Stephen Read points to two commonly stated weak features, 'one is its tendency to treat the urban object as a thing bounded by the limits of the densely built fabric of the centre; the other, to treat all movement spaces equally when it is quite clear that different classes of physical space in the fabric of the city perform quite differently at the levels of urban speed and function and at the level of the human experience of space and time' (Read 2005). This demonstrates that Space Syntax can be seen to negate the way that urban mobilities and everyday dynamics affect the space of the city, especially at the level of the individual (Read 2005).
When we consider how we connect between the spaces, walking is of the most basic form of human movement. However, people do not simply overcome distances, 'they move within cities with different objectives, such as to do shopping, to socialize, to go to some particular space or only to wander. Everyone moves in his own way, with their unique mental and physics distinctive peculiarities and motivations. However, human behavior is based on a number of shared decision-making parameters and spatial accessibility restrictions imposed by the environment where it occurs. Yet, it can be said that this dynamism and individuality is generalised within Space Syntax with the analysis instead the focusing on the larger object (Zampieri et al. 2009). If we do not consider movement in all its dimensions we are simplifying the reality by 'reducing the way we understand the pedestrians behavior, disregarding important attributes like: ambiance; socialisation elements; health and rest; and aesthetic' (Zampieri et al. 2009). With this we start to understand the complexities that surround the simple act of walking from one space to another and whilst Space Syntax map these conditions depending on connectivity, for the individual there are many local factors that influence the simple act of walking between two points.

Stephen Law et al. (2012) point out 'in an age where citizens are connected in an endless city of intertwining social, transport and communications networks, there is a need for Space Syntax analysis to look beyond the street network in exploring how different networks impact upon today's society'. Thus arguing that 'the decrease in travel time through faster modes of transport, allows for a further accumulation of towns and the emergence of the metropolis. Underground stations emerge as multi-modal hubs with high volumes of pedestrian activity, land use intensity and specialization. They play an important role for the spatial economy and shift town centres from the original location' (Law et al. 2012.) To prove this Law et al. (2012) created a series of experiments to demonstrate how certain neighbourhoods in London, located next to an underground stations, where better integrated. This is not attempting to reinvent Space Syntax, but instead build upon what is successful and push for a for stronger integration between the traditional configurational analysis and geographical analysis from other sources, to create more dynamic analysis. (Law et al. 2012.)

For many critics Space Syntax is 'not fulfilling its potential as a manner of thinking the dynamical forms of the contemporary city' (Read 2005). However, both Read and Netto clearly conclude that Space Syntax in its ambition is a way to understand complex effects, on the horizontally distributed social body of the city and its physical infrastructural movement. It ability to focus on and fully understand one key element of city - space - and connecting it to various socio-political and economic conditions has made it a very power theory in recent times. Therefore it should be understood that whilst its neutrality in measuring space maybe seen as a weakness, it is also its greatest asset (Netto 2015).

**THE OBJECTIVE**

To understand the role spatial connectivity plays in the transformation process of an informal settlement, it is important to understand what is meant by spatial connectivity. The typical Space Syntax approach measures connection points, which can then be associated with certain local conditions. However, the way each individual moves between these points varies dramatically. In order to further understand these connections, this article explores the worthiness of weighting the dynamic measurement of 'speed' to the traditional connectivity measurements of Space Syntax. At its purest form speed represents the simplest method for measuring connections between of different parts of the city and can represent multi forms of movement, such as public transport. This is also an important measurement when calculating the impact of walking in areas of extreme topologies, of which Medellin is located, allowing for a clearer understanding of how topology may affect spatial integration. It is for these reasons this
This article explores how 'speed' may be combined with typical Space Syntax analysis to provide a clearer picture of spatial connectivity.

Therefore this article examines the influence that extreme topologies and unhindered transport systems have on the connectivity of the city, through the case of Medellin and its cable-car systems. This city provides a topology that is extreme with its steep valley edges, where many informal settlements are located and offers an unique form of transport that floats over homes, providing a non-standard form of spatial connectivity. The aim is to further our understanding of the role space plays in connecting neighbourhood and in doing so how different forms of connections influence the ways we move. This is not aiming to create a new methodology or contradict past ones, but instead explore and discuss how the dynamism of space can be better understood to allow the varying movement of the individual to be included in the spatial analysis of a city.

**DATA AND METHOD**

To achieve this an evidence-based methodology is used, based upon the methods and principles of Space Syntax and is formed of three parts.

The first part is a typical Space Syntax analysis of the city, including the transport connections. It uses the two most common measurements, 'integration' and 'choice', which is often referred to as 'to' and 'through' spaces, respectively. These are typically used to measure the spatial impact of new interventions.

After the results of the standard measurements are discussed, the article explores how these can be weighted against the measurement of speed. To do this an average 'speed' is calculated for both walking and public transport. To achieve this an evidence-based methodology is used, based upon the methods and principles of Space Syntax and is formed of three parts.

First the public transport speed is simply taken from the average speeds provided online (www.metrodemedellin.gov.co) and verified onsite. Then secondly, walking speed is calculated using the 'Tobler's Hiking Function'. This takes into account steepness, the length of walk and your average speed on a flat surface (5km/hour) to calculate the average time needed to walk the route, which can then be converted into an average speed. This is done for every segment of the spatial model, by converting a contour map into an elevational raster image (ie each pixel has an elevational value), which allows the start and finish point of each segment to have an elevational value, then the 'Tobler's Hiking Function' can calculate the time needed to walk each route (in both directions). This creates a map of the city showing the speed values of each segment. Thus, the segments of the city that are located on the flat have the fastest speed and the segment located on the steep slopes the slowest. This map is then weighted against the Space Syntax results at varies scales, to examine if there is any improvement in the spatial connectivity results.

**Tobler’s Hiking Function**

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\text{time (hours) to cross 1 meter} = 0.000166666 * (\exp (3.5 * (\text{abs} (\tan (\text{radians (slope_deg))) + 0.05)))
\]

The final part uses Space Syntax observations methods to measure pedestrian movement at a local scale, using the technique of gate counting. This simply counts the number of people moving in a certain direction and at different times of the day, through an imaginary gate. This is used to form the basis for testing spatial analysis results.

These methods allow the results be examined against each other, in order to develop a discussion about the worthiness of the speed of movement being a part of the analysis of cities like Medellin and allowing a greater understanding of the impact of dynamic forms of spatial connections. The aim is not to provide a full-scale comprehensive model but to test the feasibility of the methodology, to enable future exploration.
RESULTS

When the city is modeled using standard Space Syntax, the results are as expected and have been discussed in previous publications (Goodship 2015). These show the key global integration zones concentrating around the city centre and to the west, reflecting the main central areas where most people congregate. However, the areas to the north and east of the city centre, are highlighted as having high integration, yet from local knowledge there are no central areas for the city and lie on very steep slopes. At a more local scale the integration measurement does a reasonably good job in locating the main areas of integration, or ‘to’ space, demonstrating how the cable-car has helped to improve the integration of neighbourhoods. This is most potent for the first cable-car line, whereas with the second the integrational impact is minimal. It is therefore reasonable to say with this case that integration is accurate when examining local scales, but less so at a global scale.

When this analysis looks at the measurement of ‘Choice’, at a global scale all of the main ‘through’ spaces are picked up, such as highways and bus routes. Yet, unlike ‘Integration’, when the cable-car is introduced there is very little, if any, affect on the overall network. This is the result of a well-established network not being affected by the introduction of two new lines. When these measurements are examined more closely in the individual neighbourhoods, it becomes apparent that the analysis does not pick up elements that may hinder movement, such as steepness and road conditions, since some of the important routes indicated are difficult to navigate on foot. Therefore what we see here with ‘Choice’ is that unlike ‘Integration’ the impact of local factors affects the results at a neighbourhood scale.

These failings become apparent when looking at the topology of Medellin, as this unmistakably shows the city located in a very steep valley, with much of the urban fabric situated on the steep, hence the necessity for a cable-car. It is these local conditions that a 2d analysis is unable to pick (figure 2). This has resulted in the city-scale analysis of ‘to’ spaces and the

The next part of the analysis examines the speed of movement, by investigating the results of the speed map that represents the average speed of each segment within the city. What is instantly clear from this is the areas located on steep slopes have the slowest speed and the area on the flat the fastest and whilst this is expected it does confirm that the methodology works (figure 3). Also, in the areas with the slowest speed is the largest concentration of urban poverty and almost matches a map of city's informal settlements. Therefore, it is clear that this map represents a simple and accurate image of movement speeds across the city. When it is examined more closely around the local neighbourhoods, the roads that run perpendicular to the cable-car along flatter and faster areas, often form high-streets, with a hive of commer-
cial and pedestrian activities. Whereas the roads that run down the steep slopes have less commercial activities, but a variety of irregular and informal shops.

Whilst the speed map shows some basic urban information about the city, it would be difficult to say this demonstrates anything that is not obvious to the general observer. Yet, it represents an opportunity to weight these dynamic results against more standard space syntax measurements, in an effort to create a more accurate image of the city. This is done using depthmap (Varoudis 2012), a Space Syntax analysis software, and using the standard weighting function within when analysing the system.

When this analysis is run to include the weighted value of speed for 'Integration' there is a change in the global scale map, with the hotspot in the city centre appearing to be smaller with less integration to the east and north of the city. This suggests that 'speed' provides a more accurate account of the whole city (figure 4). At the local scale the integration values remaining roughly the same. When this is used with 'Choice', there is very little impact to the overall network of 'through' spaces at the global scale, however when the results are looked more closely at walkable scales, the 'through' space network becomes clearer. Hence, at scales between 1250 and 3000 the main walking routes become more apparent, demonstrating the steepness of the topology is having an impact on the results (figure 5).

In these results, the two main forms of analysis in Space Syntax are affected differently. With 'Integration' it is at the global scale that speed is most affective, allowing the central hotspots to be more accurate, while at the local scale there is very little difference. Whereas with 'Choice' the global impact of speed is minimal, yet at the local scale its introduction creates a clearer representation of 'through' space. Therefore, the introduction of speed as a weighted element starts to demonstrate how a city like Medellin can be represented more accurately in spatial analysis and opens up the possibility for dynamic measurements.

Figure 4
Normalised Integration (NAIN) weighted 'without' (left) and 'with' (right) speed.
Local choice results surrounding the first cable-car line. 'Without' (left) and 'With' (right) speed calculations.

With this said, it is important to test these results against the actual movement patterns obtained by counting the movement of people around the cable-car stations. These observations show that the majority of movement is perpendicular to each station, with people moving to and from the station. At the stations along the first cable-car line, movement is mostly perpendicular along the flatter main roads, which are generally the main 'through' spaces and are generally high streets and areas of high pedestrian activity and commercial land-use. The observed movement patterns are less clear around the second cable-car, since the stations are located on less well-established urban grids, making the relationship with movement hard to observe. These observations of both lines show that where there are extremely steep paths, there is less movement and with this less commerce and pedestrian activities.

These results start to demonstrate the role of speed in understanding the spatial connections of a non-standard city and how speed as a measurement can help us interpret the role cable-cars have played in transforming informal settlements within Medellin.

**FINDINGS**

In order to test the results, certain correlations between the varied results are needed. In Space Syntax, a standard method to test the intelligibility of a city is to measure the correlation between 'Connectivity' and 'Global Integration', the higher the correlation the more intelligible. This provides a method to test the speed weighting. When this correlation is tested with the standard space syntax spatial model (not weighted with speed) the result is $0.11r^2$ for standard connectivity and $0.05r^2$ for angular connectivity. When the same intelligibility test is measured against the model weighted with speed, the correlation is slightly higher, at $0.15r^2$ for standard connectivity and $0.07r^2$ for angular connectivity, suggesting this provides a slightly higher level of intelligibility (figure 6). However, both intelligibility results are very low. Then potentially, the most relevant correlation test is the connection between the results of 'Choice' and onsite movement surveys. This showed a reasonable correlation between movement and 'Choice' without speed, at a local scale above 5000m and when the same test is performed with the speed-weighted model, there is very little difference (figure 7).

From these statistical values it would suggest that nothing conclusive has resulted from the introduction of speed. These failings could be a result of many individual segments creating a conflict between positive 'speed' and a negative 'integration' values. However, it is hard to ignore the visual changes to the overall map of the city when speed is introduced and by intuitively understanding the city, these maps ap-
pear to reflect a clearly picture of 'to' and 'though' spaces. So whilst the standard methods for testing correlations do not add up, the visual results are enough to suggest that this weighted measurement could be of value.

Figure 7
Correlation with movement and speed weighted maps.

Whilst these results show the spatial maps representing a closer image of the city, the statistical results do not correspond. Therefore, it is worthwhile reflecting on some of the elements that need refined for improving accuracy.

The only transport system to be included in the speed analysis was the metro-train and cable-car, which are fully integrated, yet, the most popular form of public transport in Medellin is the micro-buses. Therefore, whilst this form of transport is hard to map, it is still important to include this in some form in any further studies. It is also worth noting that the speed of the public transport represented at average speed for the whole line (600 metres a minute for the metro train and 300 metres a minute for the cable-car), but this does not include the time it take to get on and off or the waiting times, whereas walking speeds were calculated exactly. For consistency, these exact values should be added into the speed map. Another potential failing is the movement survey. The speed weighted maps show clearly walking paths at a local scale and by tested this against the onsite observations these results can be verified, yet in this article the movement survey was limited to 16 main junctions within 500m radius of the cable-car station (due to limited resources). So to improve accuracy, the movement survey should cover a larger area.

Whilst 'speed' improved the visual representation of the city's overall integration, there was a high level of disparity with the statistical values, indicating that the roughness of the values are hidden at a large scale. One of the main reasons for this is the large number of high 'speed' values found on small segments in poorly integrated zones, sharply contrasting the low integration values. Also, the use of a standard intelligibility test should be adjusted to represent 'speed' more accurately, since the standard connectivity value used is not altered for speed. In general the methods and equations used to formulate the spatial connectivity of the city needs to be fully evaluated, to determine if they are fully appropriate for this type of analysis, since the two types of results often conflict.

It is clear from the visual results that the weighted measurement of 'speed' has merits and could provide a better opportunity to understand the spatial impact new urban connections. This is especially important when using a methodology that is designed for 2-dimensions, as by using a standard variable like speed, the 3-dimensional elements of landscape and dynamic connections of transport can be better incorporated into the analysis process.

CONCLUSIONS
As this research strives to understand the impact of urban cable-cars, it is important to understand and evaluate the role that space has played in reconnecting isolated areas. One of the most reliable methods for doing this is Space Syntax. It has an established and trusted association with measuring the impact of spatial interventions and in the past has been used to discuss the transformation process of informal settlements. Yet with the case of Medellin, its steep sloping valleys force people to move differently, making the use of Space Syntax questionable, since it does not traditionally pick up these local factors due to its analysis being grounded in a 2-dimensional method.

It is for these reasons this article has explored the worthiness of 'speed' in spatial analysis. It provides a pure value for the connection between different spaces and can represent the way individuals move along routes, whether steep or flat and accurately represents different forms of transport. This article demonstrates an accurate method for calculating the walking speeds and discusses how its weighting with a standard Space Syntax model can start
to visually represent spatial connectivity more accurately. Yet, whilst it has to be acknowledged that this does not fully prove that 'speed' is a valuable addition, it does suggest how it maybe included in the future, providing a potential dynamic variable that can be altered for the individual. Therefore, by accepting that space is something more dynamic that simple linear connections, this provides an opportunity to explore how it can be perceived in different locations and through different mechanism that connect us from one space to another. This provides the opportunity to better understand the transformation process of complex urban fabrics, like Medellin's.

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