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URBAN PATTERNS AND DISASTER RISK:
The informal city on the hills

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Abstract

The magnitude of disasters depends on the natural hazard and the physical and socio-economical fragility to which a human settlement is exposed. While hazard indicators refer to the natural conditions of a place (precipitation, soil conditions, etc), indicators of vulnerability derive from the interaction nature-human activities, i.e. urbanization patterns.

Having this as our initial assumption, this work explores urban configuration as a potential vulnerability indicator of landslides in the hills of Mexico City, which from the second half of the 20th century, have been gradually and informally settled. Although some efforts have been made to develop socio-economical vulnerability indicators (population density, income, dwelling materials, etc.), conditions related to the urban morphology of these territories under threat, remain unexplored.

This research focused on two of the most representative cases in Mexico City where material and human losses took place as a result of hydro-meteorological disasters related to flooding and landslides. This type of disasters are expected to increase in this environment of continuous informal growth and climate change.

Taking the Space Syntax Theory as interpretative basis, the results helped us conclude that the occurrence, location and magnitude of landslides are not solely related to the socio-economical vulnerability of these places, but also to the urban layout. Hence, the findings of this research open the doors for architects and urban planners to get more involved in new risk and vulnerability analyses, founded on different viewpoints.

Keywords: *urban patterns, disaster risk, informal city, landslides, Mexico City.*

Theme: *Urban Space and Social, Economic and Cultural Phenomena*

1. Introduction: urban morphology and disaster risks in Mexico City

Mexico City is constituted by several cities: "*the historical city"*, "*the modern city"* and "the *informal city"*, currently overlap each other. Each of these "cities" has features of their own that lead to the study of risks in different directions.

In the historical city, -a seismic risk area-, three types of loss are likely to occur: human, material and heritage loss. Heritage loss would imply the destruction of the historical vestiges, a disruption of the sense of history and a radical change of the urban landscape.

When considering "the modern city", and the loss of property associated to it, we are talking about housing complexes where urban design paradigms pose an enormous risk in this highly-populated zone.

Included within this category of the city, we should take into account the large housing blocks built in the second half of the twentieth century, of which we might use as representative cases the "Nonoalco-Tlatelolco Housing Project"[1], which is subject to seismic risk, and the large housing projects in Iztapalapa[2], subjected as they are to subsurface fracture risks.

Equally important is the "informal city", which originated from the process of industrialization and the rural-urban migration in Mexico. I refer here to the concentration of dwellings which were built in no compliance with the official regulations or urban planning. This phenomenon of self-help building (or "building without architects) has occurred in a large scale. It is estimated today that between 50% and 60% of the total dwellings in Mexico City - around 10 million inhabitants- have an irregular origin (Kunz 2005, 58-59).

These settlements in many cases were constructed on land unsuitable for urban development, such as steep terrains or land subject to flooding, where building is difficult and infrastructure is unavailable. Due to these conditions, these settlements have become in the last decades, the unfortunate setting of disasters, such as floods and landslides with their respective material and human losses.

In 1994 Legorreta (1994, 52) estimated that at least 30% of the areas occupied by informal settlers are located on steep slopes and far from any supply of equipment and infrastructure, which means that they lacked drinking water, drainage, paving, schools, hospitals or amenities of any kind. Four years later, in 1998, approximately 11,512 households were calculated to be located on such slopes (Audefroy 2008, 71). In recent years, natural phenomena such as "El Niño" have triggered more events and revealed the degree of vulnerability of human settlements located in canyon areas. In 1998, for instance, a series of torrential downpours led to floods and landslides which overflowed rivers and collapsed precarious housing (Audefroy and Aceves 2003, 228).

[1] Nonoalco-Tlatelolco is a large housing complex located near the historical city of Mexico City. It is composed of 15,000 housing apartments and 1,000 inhabitants per hectare. During the 1985 Mexico City earthquake, many buildings were destroyed or severely damaged. After the earthquake, some buildings were demolished or their height was partially reduced.

[2] After the 1985 earthquake, many families left the center of Mexico City and moved to the east of the city, where new and relatively cheap, highly densified housing projects were offered. Today, these housing units are characteristic of Iztapalapa, one of the 16 boroughs in Mexico City and one of the most populated. An overexploitation of underground water is one of the causes of the subsurface fracture risk in the area.

2. Informal urbanization on hills: the two sides of the same coin

One of the main characteristics of informal settlements is the lack of adaptation to the environment and hence the chaotic consequences in the long run. This land transformation from an agricultural to an urban configuration basically obeys to greedy reasons, with no prior official authorization or environmental impact subdivisions, and involves a high social cost due to the lack of services, equipment and infra-structure (Bazant 2004, 191).

As opposed to "formal" urbanization, which begins with an urban plan, a legal delimitation of property, infrastructure and the services necessary to complete the constructions, informal urbanization begins with none of this considered. Informal settlers first build their houses, then bring in the infrastructure and finally define their ownership.

According to Legorreta (1994, 52) the layout of new illegal settlements in Mexico City typically corresponds to the American model that prevailed in the founding of new US cities since the late eighteenth century: grid-based rectangular blocks without administrative and religious buildings located around a square or center. Planning the streets perpendicular to the contour lines is the most common case in informal settlements, regardless of the slope these streets have. Usually the informal land dealers want to avoid costly cuts on the road (Bazant 2004, 193). A building block has normally 30 to 60 plots, with sizes that may vary from 150 to 200 square meters.

On the other hand, in spite of the negative circumstances in which informal settlements grow, they are seen by other authors as laboratories which bear witness to urban and social processes which are different to those of the contemporary formal city. A city cell that preserves the human scale of urban space and the use of the street as a social space, something which can contribute to the definition of new urban tools and sustainability (Saez 2010, 1-14).

In line with this ideas, it has been said that the relation between informal settlements and landscape is very important because spontaneous (informal) settlements are often built on land that no one else wants, including extremely steep slopes; and the way in which builders cope with these relationships are most striking and enlightening (Rapoport 1998, 67).

The author further argues that "the solutions to difficult sites one can find among spontaneous settlements far surpass the simplistic approaches of professional designers" (Rapoport 1988, 67). From this standpoint, "if vernacular design is defined properly, spontaneous settlements can be shown to be its closest contemporary equivalent" (Rapoport 1988, 53). If this assumption is right, Informal settlements can be considered as a cultural landscape. That is to say, these settlements are the physical and social result of repeated and collective decisions made by many individuals over a long period of time. Hence, these "multilayered" cultural landscapes could be considered as a whole and as an apprehensible object with its own analytical framework. So Kellet (2011: 2-12) explores the interface and overlap between traditional vernacular and contemporary popular processes, and demonstrates that far from inhabiting separate universes there are many points of commonality.

Oliver (2003, 226-227) reinforces this idea, stating that "with the accumulated knowledge and experience gained in some settlements by two or three generations over a period of fifty years, there are indications of the emergence of new vernacular traditions".

All in all, both authors warn about the "real danger of romanticizing spontaneous settlements" (Rapoport 1988, 74), reminding that there are extremely unsuccessful and environmentally disastrous spontaneous settlements as well, but finally the point of Rapoport is that there are proportionately more successes among spontaneous settlements than among professionally

designed environments.

Bringing the informal settlements discussion to the field of urban design is not new, however. The way to evaluate their quality of design or even to demonstrate their good or bad relation to the landscape remains somehow without an answer. And therefore the questions which the present work intends to answer are:

- Would be **Space Syntax Theory** a useful tool to evaluate the "**qualities of design**" of informal settlements at urban scale? If it is so,

- Is the adaptation of informal settlements to the natural landscape susceptible for evaluation?

3. Space Syntax and disaster risk

In the last years the Space Syntax theory has been increasingly used to analyze, understand, explain and predict some of the social phenomena related to different kinds and phases of disasters (see Table 1). The works written focus mainly on natural risks (whether geological or hydrological), but also take into account "man-made" disasters like blazes. From the examples of Table 1 at least two broad tendencies can be identified.

On the one hand, a first group of studies has been developed at a local scale focusing on the relationship between the constructions and pedestrians. These studies particularly explore the interaction between the spatial layout of buildings or settlements and the possible movement of people in case of emergencies. That is to say, how the constructions enable or prevent free movement or evacuation from: a) hospitals (Alper ¨Unlü et al. 2005), b) from high-standing buildings (Choi et al. 2007), or c) from specific scenarios of risk such as earthquakes or tsunamis (see Firat and Kubat 2012 and Fakhrurrazi and van Nes 2012).

On the other hand, another group of works has been concerned with the urban or regional scale, focusing on the analysis of the street network and its role on the accessibility to emergency shelters (Dou and Zhan 2011). Other studies focus on the indirect impact of floods in the city; so, for example, Gil and Steinbach (2008), measure the number of urban areas that have become isolated as a consequence of a flood, which may be: a) an island without land access to the surroundings; b) a peninsula with a single connection which can become a critical route for emergency access; c) a peripheral area that has a more difficult access than before; or d) sites that might become more accessible and that would play a more central role than before.

The occurrence of some of the most striking disasters in the decade, - such as the tsunami that hit the coast of Indonesia in 2004 or the Hurricane Katrina in the U.S.- has no doubt influenced an increase of the research in this field. At the same time, the theoretical development of the field itself and the change of paradigms are important to consider, i. e., the International Decade for the Reduction of Natural Disasters (IDRD) that ended paradoxically with the conclusion that disasters are by no means "natural", but rather socially constructed.

Disasters research focus also on the phases of disaster as well. That means the temporal component of the disaster: a risk mitigation phase, an emergency phase, and a recovery phase that some authors also call the resilience phase, which has to do with reconstruction after disaster, as shown by Carpenter, in the analysis of interactions between recovery works and the role of the physical space in New Orleans and Mississippi (Carpenter 2012).

Perhaps the most important aspect is to confirm that the impact of natural hazards, does not

exclude less or more developed regions. This is a condition that reinforces the need to confront both, risk management strategies of different contexts and cultures, as well as academic inquiries and possibilities to share techniques and methodologies of morphological analysis.

Table 1 Some examples on the links between the Space Syntax Theory and the Disasters Risk Reduction research. Source: Own elaboration based on the cited references

Type of disaster	Phase of disaster			Topic	Author (s)	Study Area
	Mitigation	Emergency	Recovery			
Non specified		X		Evacuation of Hospitals	Alper ¨Unlü et al, 2005.	Istanbul, Turkey
Eventual fires on high-rise buildings		X		Evacuation	Choi, et al, 2007.	Seoul, Korea
Flood	X	X		Street network and flood risk	Gil, J and P. Steinbach, 2008.	London, United Kingdom
Non specified		X		Accessibility of Urban Emergency Shelters	Dou, Kaili, and Quingming Zhan, 2011.	Wuhan, China
Earthquake		X		Evacuation	Sari, Firat and Ayşe Sema Kubat, 2012.	Istanbul, Turkey
Tsunami	X	X		Evacuation	Fakhrurrazi and Akkelies van Nes, 2012.	Banda Aceh, Indonesia
Hurricane			X	Built environment and disaster recovery	Carpenter, Ann, 2012.	New Orleans and Mississippi, United States

4. Contoured landform in Space Syntax

Contoured landform is one of the most important features related to landslides as it provides a snapshot of the induced risk implied in a steep slope. However, just a few works have been conducted in the Space Syntax field to explore the role of contoured landform in the "reading" of the spatial configuration.

Preliminary studies concerning the relationship between spatial integration and socio-spatial interactions of the topography of urban areas on contoured landform are provided by Ramadanta and Darjosanjoto (2012). However, regarding concrete examples and the use of traditional Space Syntax indicators, Cutini (2012) analyses a sample set of Italian historic towns characterized by their strong steepness and provides evidence that slope and integration are significantly correlated. On the other hand, Asami (et. al, 2002 and 2003) introduced the third dimension on space syntax and proposed an extended version of the axial lines named "extended axial curves" since the extended version of axial line is typically a curve along the road surface. Since in the usual space syntax no distinction is made for axial lines intersecting with different angles, the authors developed a new method by introducing weights determined by the intersecting angles of two line segments.

In our case, assuming that the "informal city" on the hill after some time becomes an urban unit with its own centrality and own spatial structure, we explore here the space syntax indicators considering the hill as a "concentric city". In other words, if the informal occupation pattern of the hills is gradual and it starts at the basement of the hill, our main assumption was that the higher the settlement grows, the more difficult the morphological adaptation is. So it was

expected that the longer the distance to the center, the "better" the statistical adjustment of the morphological indicators.

To test the hypothesis, we run the space syntax model for two of the most representative cases of informally urbanized hills in Mexico City and considered the distance between each axial line and the highest point of the hill.

To simplify the analysis, several axis were drawn from the highest point of the hills and space syntax indicators were correlated to the distance (see Figure 2). Below, the main characteristics of the case studies and results are described.

4.1 Case study 1: Chiquihuite Hill[3]

It has a height of 2,730 meters above sea level and is the second highest elevation in the mountains. Geologically speaking, it is an exogenous volcanic dome, which is associated with potential mechanisms of slope movements (Garcia 2012, 125). Hence, it presents soils with moderate limitations in their use, so the recommendation for it is the conservation due to their steep slopes, its territory is not optimal for agricultural use or for urban settlements.

In the early twentieth century the lands of the hill were common lands called "ejidos"[4]. However, from the 1940s until 2000 many hectares of common land were expropriated. This caused that the territory was radically altered and an inevitable process of urbanization began. By 1940, industrial development had developed at a rapid rate, causing the installation of large factories in the current municipality. At that stage, the common land owners still worked their land. However, the subdivision and sale of land were a more profitable activity, so that they started selling the land that others needed. Thus, practically the whole place was subdivided and became irregular settlements on common land. In other cases the land was just invaded. By 1967 mainly the northeastern slope of the hill was urbanized and by 1984 most of the area had been urbanized (Garcia 2012, 136).

The Chiquihuite hill territory is divided into two regions: the eastern one, in the municipality of Tlalnepantla, State of Mexico, and the western part, corresponding to the Municipality (*delegación)* Gustavo A. Madero in Mexico.

The area occupied by informal settlements on the slopes of Chiquihuite Hill is divided into 18 neighborhoods (30,419 dwellings) that house 135.649 inhabitants (Garcia 2012, 157).

The uncontrolled urbanization that took place on the slopes of the hill of Chiquihuite further produced flooding problems both in the upper as well as in the lower areas of the mountain. Over time, more than ten landslides have occurred and many neighborhoods are flooded each year.

4.2 Case study 2: Chimalhuacán[5] Hill

According to Cerecedo (2006), Three units comprise the territory morphogenetic Chimalhuacan: a) volcanic structures b) a transition zone between plains and relief hills and c) lacustrine plains (Cerecedo 2006, 28).

The upper limit of foothills is among the 2,265 m, while the lowest point in contact with the plain is set in the 2,240 meters, approximate data. The terrain is 6 degrees uneven, and it is

[3] In the náhuatl language it means "reed basket without handles".
[4] Common property land for agricultural purposes.
[5] In Nahuatl language it means "place of the shields".

related to ephemeral steps alternating with convex surfaces. The terrain inclination varies between 1.5 and and 6 degrees.

The origins of the place are rooted to the pre-Hispanic time; however, the rapid urbanization period goes back to the middle of the last century. This municipality follows the same pattern as the other one and is urbanized in the decade of 1950 onwards by means of an irregular market.

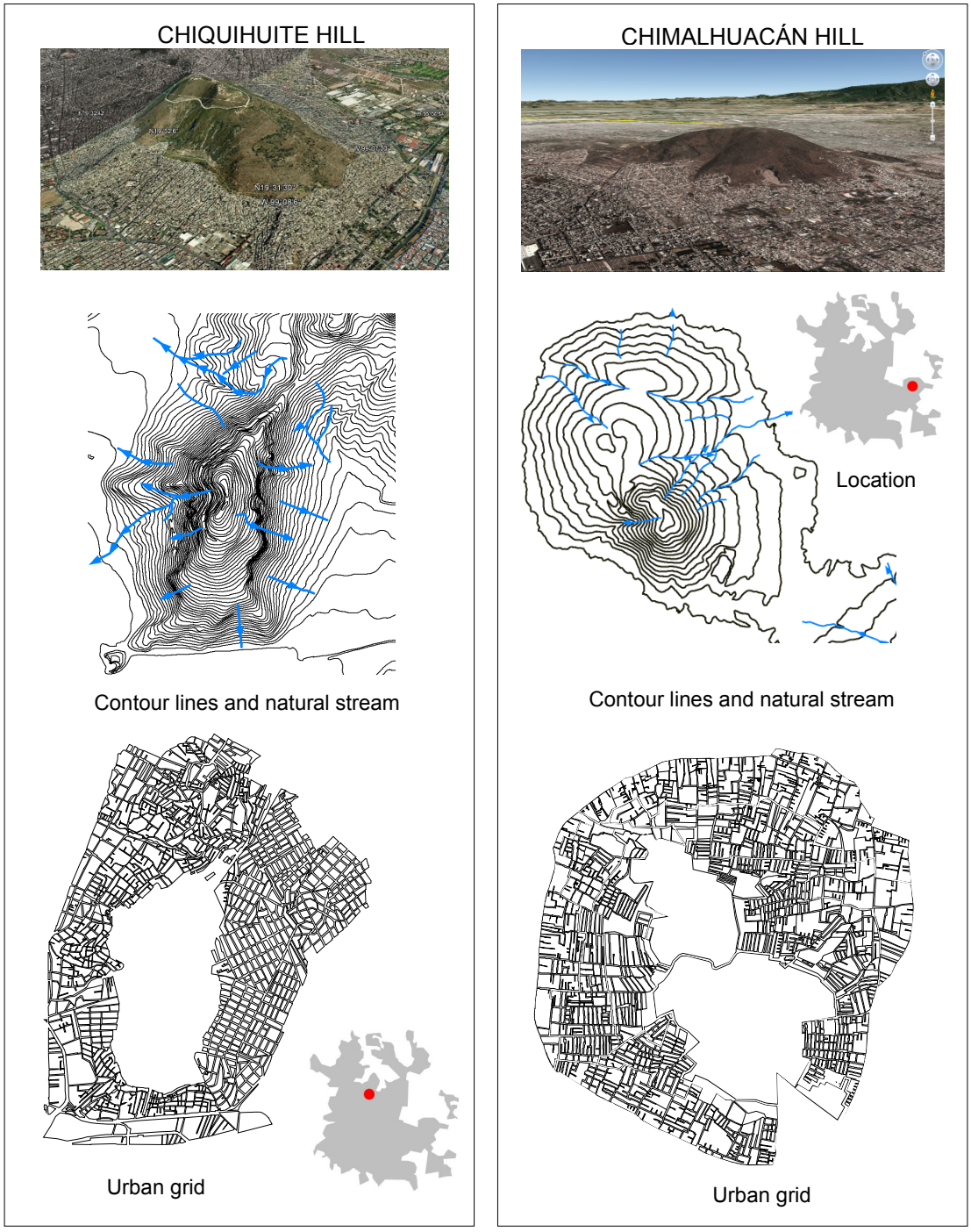


Figure 1. Case studies

The young families which came to the place had as origin rural zones of Mexico, but also the Federal District and the neighboring municipalities as well. By 1990 it was almost saturated and the population of Chimalhuacan increased from almost 20,000 inhabitants 1970, to more than 600,000 inhabitants 2010 (Sedesol 2011, 38)[6]. The density in the oldest parts of the municipality varies between 100 and 150 inhabitants per hectare.

The urban areas of the plain surface have no trees or arboreal surfaces, mainly due to the poor soil conditions. Green areas are restricted to small isolated areas and in the transition belt between the hill and the lacustrine plain, which coincides with the line of the main road. As a consequence, there are no natural barriers to stop natural debris in case of flash floods. June 2010, due to a mudslide a house was razed, and a baby died. As a consequence, 14 houses were resettled.

5. Results

Contoured landform and urban grid

At a first glance the typology of urban grids is not even for all the cases. In case 1 (Chiquihuite Hill) urban grid is composed of two different typologies. To the east it seems to be more regular and homogeneous than the west part, which also is more irregular in its landform. For the second case (Chimalhuacan Hill) urban grid is more irregular but this irregularity is at the same time homogenous for the whole area. These regularities have a correspondence to the connectivity values.

Connectivity and distance to the highest point

For both cases connectivity increases as the settlement gets farther from the top of the hill (see Figures 2 and 3). This is more evident for the first case. However, after the first 1000 meters, this trend seems to have no regular pattern and connectivity shows higher and lower values in the lowest part of the hill (2000-2500 meters from the highest point). Its clear that some other parameters must be taken into consideration, so as to give a finer explanation to this unexpected statistical dispersion.

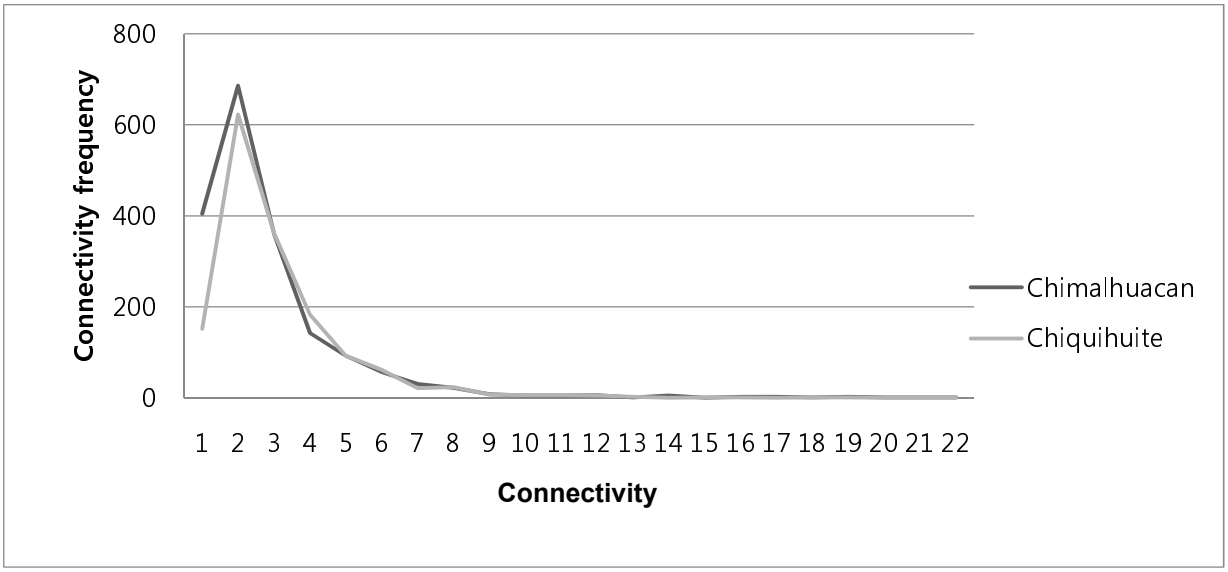
Integration and total depth

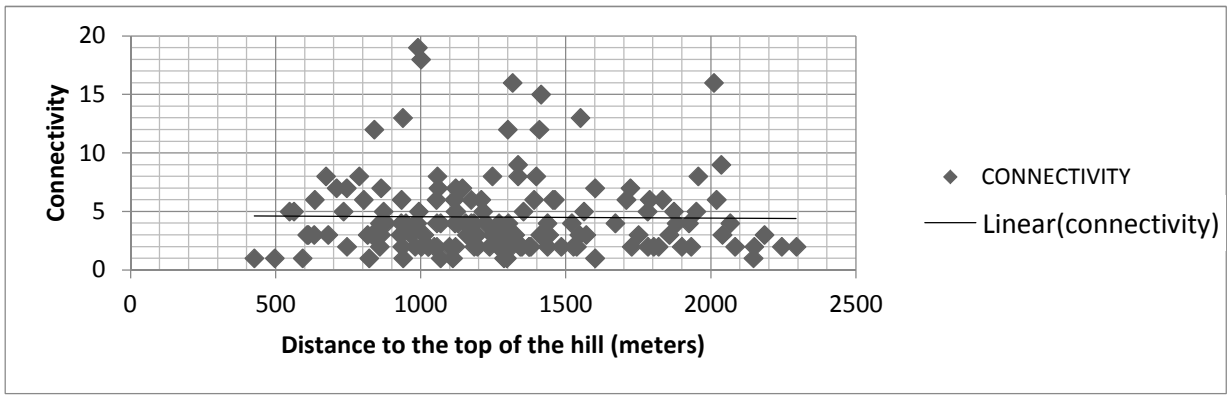
In spite of the fact that connectivity correlation is weak for Chimalhuacan, integration decreases gradually from the highest point, while such correlation does not exist at all for the other case. Similarly to the above consideration, total depth values in Chimalhuacan increase as axial lines get farther from the highest point, while no correlation at all is evident at Chiquihuite Hill.

Syntactic indicators and landslides

Landslides occurrence depend on many factors and urban morphology is just one of the too many variables. However, from the analysis it is evident that the highest values of the syntactic factors do not correspond to the direction of the natural stream flows. In spite of the higher values of connectivity, more landslides have been occurring in Chiquihuite Hill, where integration is rather low. This lack of integration to the natural landscape, has no doubt to do with the fact that such settlements develop without a general urban plan, but rather, they grow more in a scattered pattern.

[6] For this study just a part of the municipality is considered, approximately a fifth of the same.





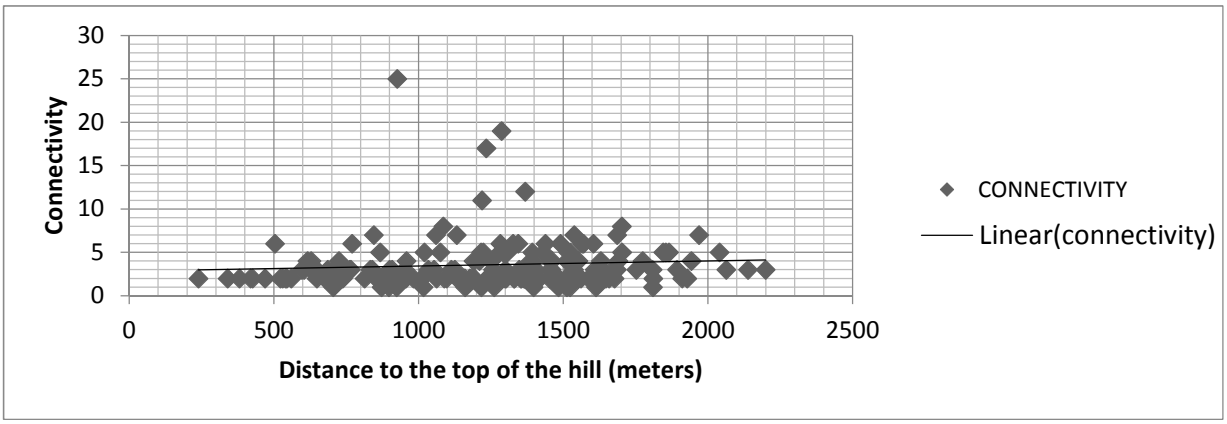
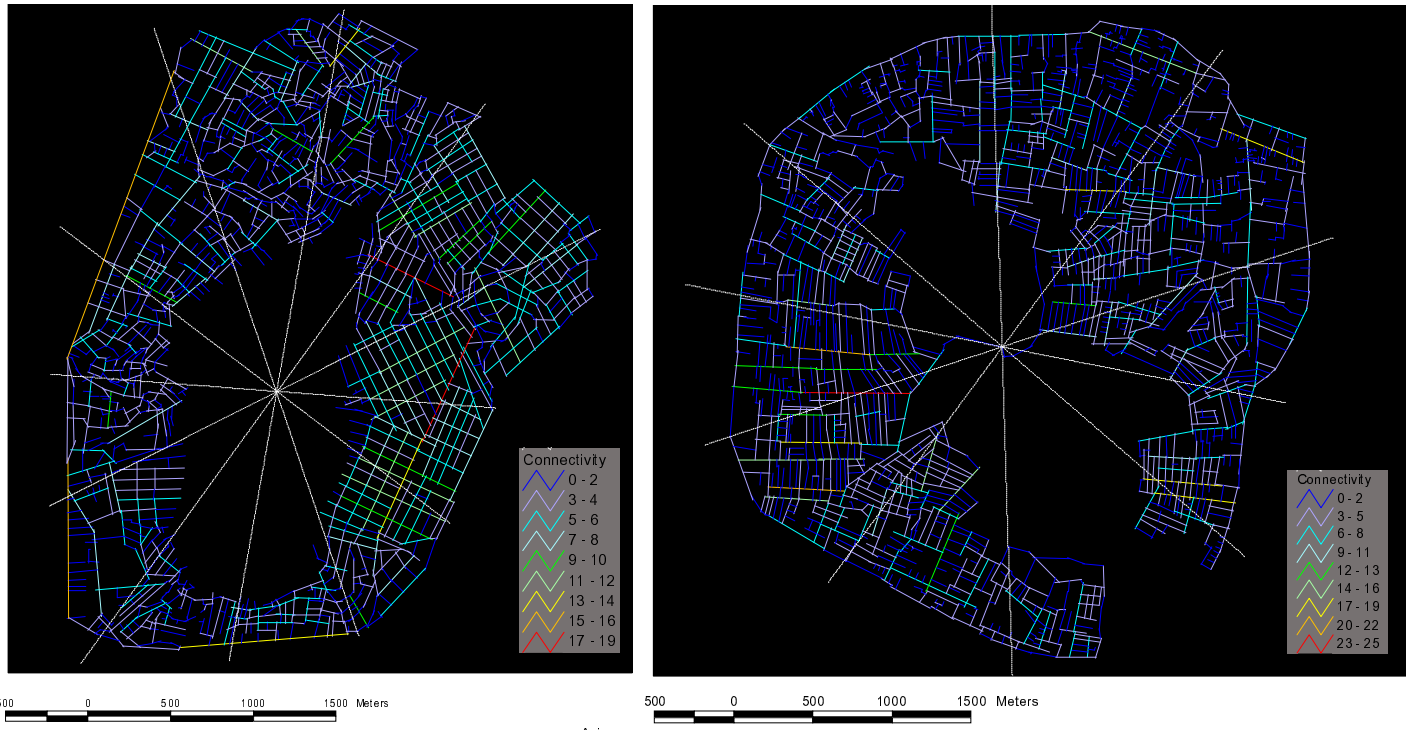
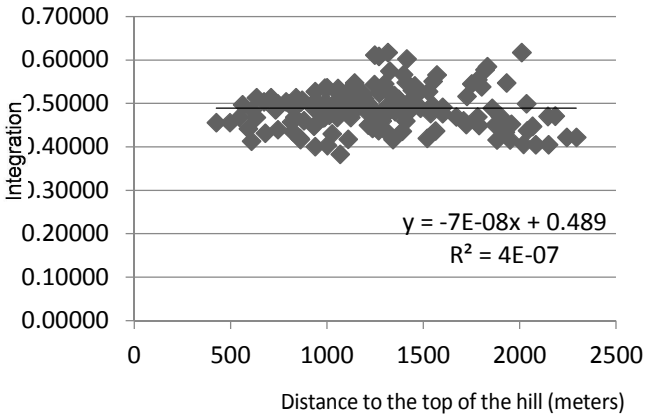
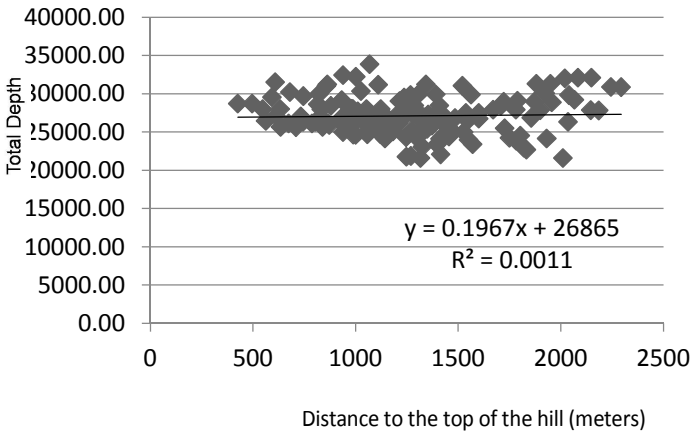


Figure 2 Correlation analysis of study areas.

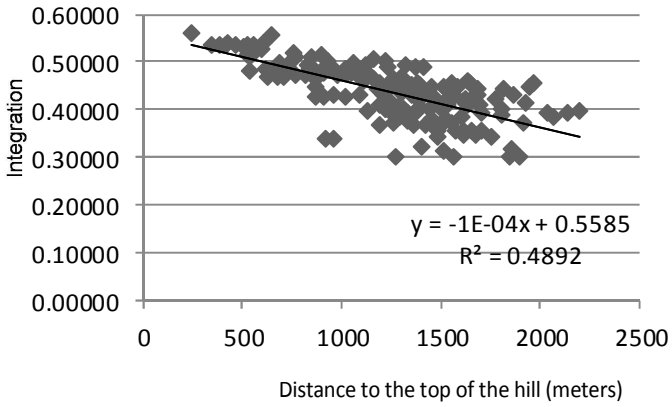


CHIQUIHUITE HILL





CHIMALHUACÁN HILL



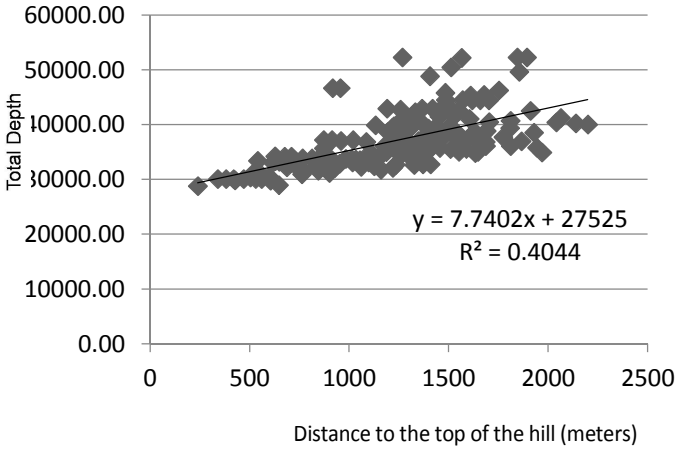


Figure 3 Space Syntax Analysis of the case studies

6. Summary

Informal urbanization of hills follows a quite different pattern in comparison to planned towns constructed on hills, e.g. the European medieval towns. The main explanation of this is that informal urban growth on hills depends on the decisions of informal land dealers, and not on a formal urban planning. This radical difference consequently influences patterns regarding configuration and steepness adaptation, which can be summarized below:

- The informal urban subdivision of plots clearly follows an economic profit, which prevents any urban design intention on the side of the informal land dealers to promote landscape adaptation and risk reduction.

- Informal urban growth on hills follows merely a "patched pattern", which turns up to be the opposite of what we could call a planned road structure, which in turn distorts a clear integration pattern. Therefore, a spatial analysis of partial areas could be methodologically more suitable than a concentric city analysis.

- In spite of a "patched urban growth", statistical distribution of connectivity seems to be almost the same for both cases: informal urbanization on the hills consists of a similar number of segments for both cases and the frequency distribution of connectivity is quite similar for both hills.

- Steeped paths have not been an obstacle for informal urbanization to go on and a "social sense of acceptance of risk" seems to justify further informal urban growth on the hills.

- Landslides risk is an issue that will hardly disappear. However, Space Syntax techniques can contribute to a better comprehension of the built environmental vulnerability and such elements could be part of future vulnerability maps. Such studies could very well consider that:

- As informal settlements grow gradually, population density is also heterogeneous. Therefore, analyzing adaptation to landscape should consider housing typologies and their corresponding building adaptation to the slope.

- Hydraulic behavior of urban streets becomes critical to understand flooding and landslides on informally urbanized hills. Further analysis should consider then, direction of natural stream flows, and Space Syntax factors, as road network interactions intensify and influence rain flows and landslides risk.

- Finally, interpretation of the data must consider jurisdictional factors. Risk reduction actions in Chiquihuite Hill shall be politically more difficult to achieve because Chiquihuite Hill belongs to different municipalities. However, Chimalhuacan Hill is a municipality on its own, and this advantage can be taken into account in future planning decisions.

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