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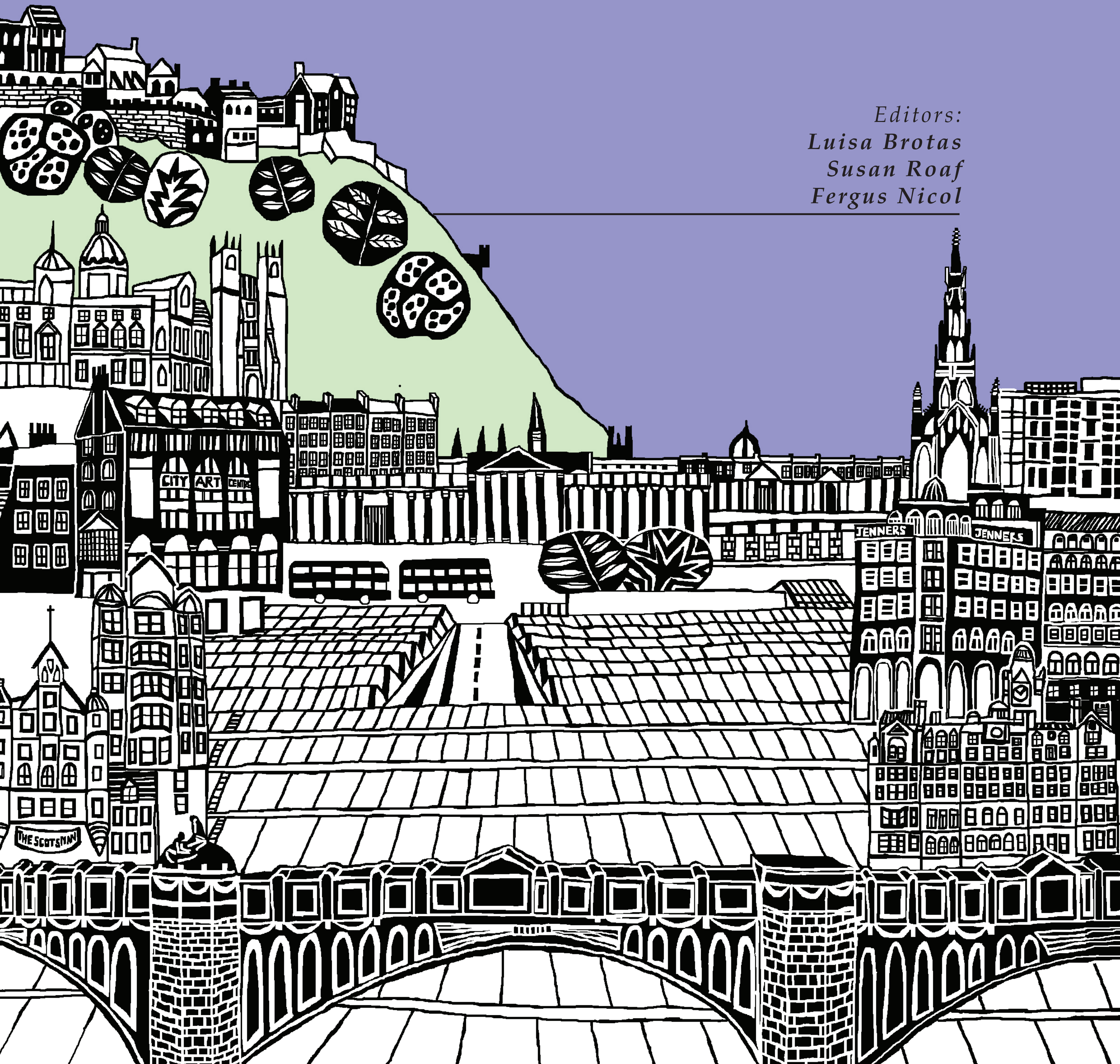

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Design to Thrive

Resilience in Latin America: exploring flooding mitigation in Bogotá (Colombia)

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Abstract: This paper is concerned with the implications of flooding in Bogotá (Colombia) by focusing on a specific typology of flooding -surface water flooding- resulting from excess of surface water runoff as it occurs in the Colombian capita. In particular, the paper considers some of the main alternative strategies that can be used to reduce the risk of surface water flooding and pays specific attention to the benefits of Sustainable Urban Drainages (SUDS). The suitability of SUDS in the urban context is tested through an approach focusing on the city block scale and its surfaces' characteristics. Technical and social elements of SUDS are critically analysed and accordingly, a comparative analysis is performed to test different adaptive strategies scenarios for a case study in quartier Carimagua in the inner urban area of Bogotá. Carimagua barrio has been found to be able to effectively mitigate the excess of surface water runoff, and by so to meet some of the challenges associated with climate change. On this basis, it is defended that the city block can cope with not only its own surface water runoff but also to compensate as active catchment for other parts of the city where adaptation might not be feasible.

Keywords: climate change, flooding mitigation, urban resilience, permeability, sustainable urban drainages.

Introduction

This paper will focus on the drainage capacity of neighbourhoods of Bogotá to give some answers to the risk of flooding caused by climate change phenomenon. For this reason, this paper engages with future climate change and specifically with predicted increased risk of flooding, with specific focus to test flooding mitigation techniques in the increasing urbanised land of Colombia, and Latin America in general.

From 2010 to 2011 La Niña phenomenon affected Colombia and caused economic losses caused by flooding, related to the destruction of infrastructure and urban areas. A paradigm shift in water management is recognized as a necessary step for adaptation to climate change and crucial for furthering the sustainability agenda in Bogotá. On this regards, research conducted (Hoyos et al; 2013) emphasized the importance of both the spatial context as well as the variables related to hazard exposure and social vulnerability (figure 1). Melgarejo et al. (2014) stress this point in view that extreme weather events are becoming disaster management systems in the city.

Effects of climate change in Colombia have been modelled (IDEAM et al; 2015) and a generic change in temperature and rainfall is expected to increase the climatic variability effects of El Niño and La Niña, which have an exacerbated impact in Colombia and Latin America in general. In the Cundinamarca region, where Bogotá is located, it has been predicted an increase in average temperatures by 2100 to up to 2.3°C against today values.

Also it has been predicted a change in the precipitation patterns: an increase in rainfall to up to 30% in the province of Bogotá North, with values between 10% and 30% compared to today's values (IDEAM et al; 2015). Some of the effects of such changes are expected to affect the farming sector due to both changes in temperatures as well as infestation associated with increased rainfall. Also, infrastructural sector (transport and energy) are expected to fail (IDEAM et al; 2015) with potentially devastating effects on population (when this is associated with population security).

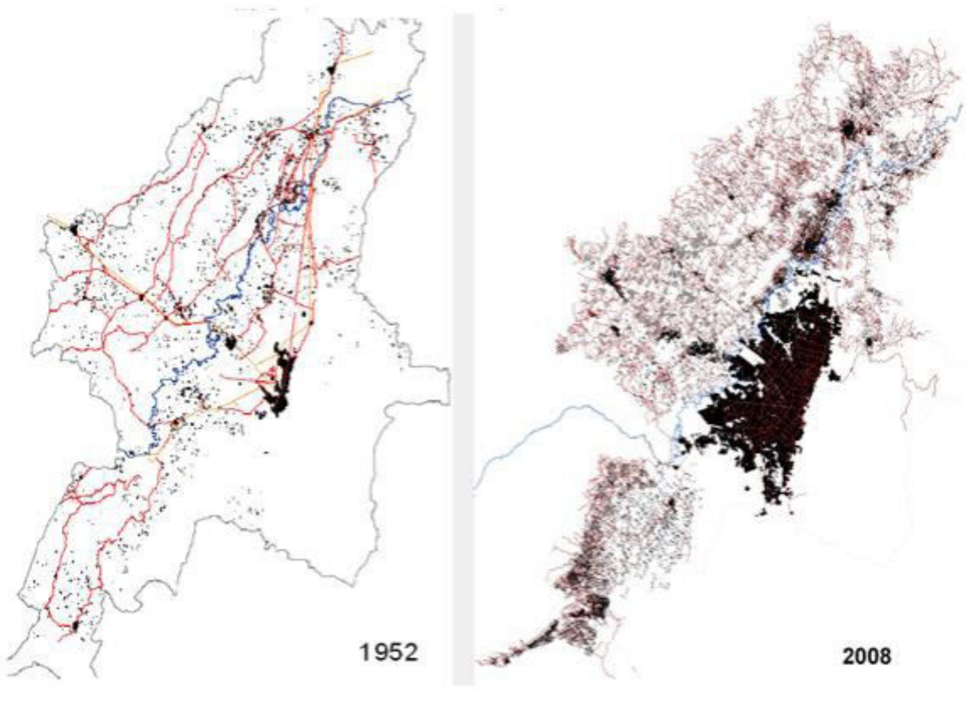

Figure 1. Land urbanisation and density evolution of Bogotá (Niño, 2012).

The Colombian disaster risk management ministry (UNGRD), in cooperation with other international organisations, are implementing the project "Strengthening the risk management capacity of Floods" in order to create directives to cope with excess rainfall and the necessary standards to control this kind of events, by means of identifying four flooding risk scenarios: (a) first, ponding water, (b) second, flooding, (c) third, electrical storms (d) tree-falling. These scenarios are connected to three climate phenomena, i.e. hailstorm, landslides and gales (INDIGER, 2016).

To mitigate these changes, and specifically with the predicted increase rainfall, an adaptation technique is required. Techniques available to mitigate with the excess water runoff are the sustainable urban drainage systems (SUDS), which are non-piped drainage systems that minimise the impact of surface water runoff (rainfall that cannot infiltrate the soil). According to Toledo (2012), SUDS that are most sustainable and suitable to urban environment are green roofs and pervious surfaces. Pervious surfaces effectively reduce surface water runoff and pollution to a significant extent.

On the other hand, green roofs represent a cheap, relatively good option to reduce surface water runoff. In fact, they reduce surface water runoff to a more limited extent when compared to previous surfaces, but they can add benefits not only regarding pollution reduction, but also regarding biodiversity, wildlife, amenity, health, reduction of urban heat island effect.

Related, green roofs increase the life of roofing materials, reduce the urban heat-island effect (Ritchie & Thomas, 2013) and reduce the energy demand (GLA, 2011). This paper aims at contributing to the development of an adaptation strategy within Bogotá by producing a strategic test of adaptation to flooding strategy that effectively mitigates with the predicted increase of rainfall in the Province of Bogotá.

Methods

To analyse closely this phenomenon as it occurs, it has been selected an urban area in Bogotá, the Carimagua neighbourhood. This quartier was founded in 1967 and was an example of social housing in Bogotá composed of 1108 single-family homes.

Figure 2. Carimagua neighbourhood: analysed portion evidenced.

Currently, the houses are transformed according to the needs of the inhabitants; however, the urban structure is maintained (figures 3 and 4). On the other hand, Carimagua neighbourhood is in a middle-high flooding risk area, and this paper intends to respond to the following question: is the urban barrio of Carimagua able to mitigate the predicted 30% rainfall increase?

Figure 3. Carimagua neighbourhood in 1967 (left) and today (right).

Figure 4. Carimagua neighbourhood, examples of adaptive initiatives.

To respond to such question, a critical analysis of flooding mitigation strategies to retain rainfall is performed in order to identify which devices are the most suitable ones in terms of costs and benefits (i.e. cost, maintenance, land-take, peak flow reduction and volume reduction) and in terms of extra benefits (i.e. pollution reduction, landscape/wildlife/amenity benefit), as shown in figure 5.

Secondly, an analysis of the case study city block has been carried out. In this context, it is being performed a comparison of the effects of water runoff mitigation of the city block by reducing the degree of impermeability of the surfaces according the use of different finishing surfaces' permeability, as proposed on a recent publication by Ritchie & Thomas (2013), see figure 6, with the value 1.00 being completely impermeable and 0.00 being completely permeable and hence desirable. This city block calculation is aimed at assessing SUDS-based strategies that can be followed to reduce the surface water runoff (i.e. to increase their permeable degree and reduce their impermeable degree).

		investment & benefits					extra benefits		
					surface water runoff reduction				
	techniques	capital cost	maintenance	land-take	peak flow reduction	volume reduction	pollution reduction	landscape, wildlife, amenity	
SUDS	GREENROOFS	low-high	medium	none	medium	medium	√	√	▲ most sustainable
SUDS	BIORETENTION	low	medium	high	medium	medium to high	√	√	
SUDS	DETENTION BASINS	low	low	medium	good	low	√	√	
SUDS	PONDS	medium-high	medium	high	good	low	√	√	
SUDS	STORMWATER WETLANDS	high	medium-low	high	good	low	√	√	
SUDS	FILTER STRIPS	low	low	high	low	low	√	√	
SUDS	SWALES	low	medium	high	medium	medium	√	√	
SUDS	INFILTRATION BASINS	low	low	high	good	good	√	√	
SUDS	INFILTRATION TRENCHES	low-medium	medium	low	medium	low	√	√	
SUDS	SOAKAWAYS	low	low	low	good	good	√	√	
SUDS	PERVIOUS SURFACES	low-medium	low	none	good	good	√		
SUDS	SAND FILTERS	low	high	low	low	low	√		
SUDS	GEOCELLULAR MODULAR SYSTEMS	low	low	low	good	low			
SUDS	RAINWATER HARVESTING: water butts	low	low	none	low	low			
SUDS	RAINWATER HARVESTING: big tanks	high	medium	none	high	high			
traditional	TRADITIONAL PIPED SEWER	high	high	none	low	high			least sustainable ▼

Figure 5. SUDS analysis of suitability to mitigate surface water runoff in urban areas.

Accordingly, it has been performed an inventory of surfaces materials within a selected area of Barrio Carimagua (figure 2) to then proceed to calculate the overall degree of permeability based on the degree of permeability of each material. This step required to quantify the area of all the surfaces within the city block (such as roofs, pavements, backyards, etc.) and multiply them by the degree of impermeability of the characterising material, as listed in figure 6. This provided a numerical result that is the *overall degree of impermeability*, which for the selected case study is 0.9.

Pitched roof	1.00
Asphalt, concrete, paving with mortar joints	1.00
Flat gravel roofs	0.80
Paving on sand bed (tight joint)	0.80
Large paving with large joints	0.70
Mosaic paving with large joints	0.60
Bound gravel	0.50–0.40
Grasscrete paving	0.30
Planted roofs	0.30
Lawn	0.25
Planted area (general planting)	0.10–0.00

Figure 6. Degree of impermeability of different materials (Ritchie & Thomas, 2013)

Hypothesising the need to cope with 30% increase rainfall, a strategy to reduce such degree of impermeability by the 30%, a new goal of *overall degree of impermeability* to 0.6 for the selected case study is been pursued. This *new* degree of permeability of the city block will be calculated by changing materials to the surfaces an applying new degrees of permeability as listed in guidance for sustainable urban design (Ritchie & Thomas 2013).

To evaluate the efficiency and feasibility that the proposed devices (green roofs and pervious surfaces) have in reducing the surface water runoff, a selection of strategies were conducted to deliver a new value of impermeability after the surface-materials were substituted by green roofs and pervious surfaces.

Finally, by building on the results achieved in the previous steps, it is presented a critical discussion of the advantages and disadvantages of this adaptation strategy within the city of Bogotá.

Results

Adaptation of the city block with sustainable urban drainages has been performed, and three possible adaptation scenarios were explored to achieve the aspiring 30% permeability increase to cope with predicted excess rainfall (see Table 1 below).

The first scenario (strategy A) modifies the degree of permeability of the publicly owned areas (streets and parking) by replacement of the (impermeable) cement and asphalt to a permeable parking and permeable asphalt. This strategy achieved the desired *overall degree of impermeability* of 0.6 (see first shaded column in table 1).

The second scenario (strategy B) modifies the degree of permeability of the privately-owned areas (within the plots) by retrofitting roofs to green roofs and by adding planted areas in the front gardens. This strategy also achieved the desired *overall degree of impermeability* of 0.6 (see second shaded column in table 1).

The third scenario (strategy C) combines both the previous strategies, and it has shown that an outstanding 52% increased permeability, equal to an overall degree of impermeability of 0.3 (see last shaded column in table 1).

Table 1. Calculation of improved permeability in Carimagua city block.

Existing situation (Carimagua city block)					need for adaptation (imperviousness reduced by 30%) strategy A: public		strategy B: private		strategy C: both	
	area (m2)	% of total area	degree of imperm.	degree of imperm. (*surface)	degree of imperm.	degree of imperm. (*surface)	degree of imperm.	degree of imperm. (*surface)	degree of imperm.	degree of imperm. (*surface)
Streets and Parkings (asphalt)	12324	32%	1	12324	0.3	3697	1	12324	0.3	3697
flat roofs (Fibre cement)	9792	26%	1	9792	1	9792	0.3	2938	0.3	2938
Green areas (lawn)	7380	19%	0.25	1845	0.25	1845	0.25	1845	0.25	1845
Backyard (concrete)	5760	15%	1	5760	1	5760	1	5760	0.6	3456
front gardens (concrete)	2880	8%	1	2880	1	2880	0.3	864	0.3	864
overall degree of impermeability			**0.9**		**0.6**		**0.6**		**0.3**	
					23%		23%		52%	
					more permeable		more permeable		more permeable	

Discussion

From the physical realm point of view, the results proposed show that effective adaptation strategies to cope to increase rainfall are feasible, in different ways and in different degrees. However, inhabited built environments are known to present different levels of organisations, so it is recognise that while numerically adaptation is feasible, shortcomings should be expected when implementing these in a real project.

With specific regards to Barrio Carimagua, since its construction, this quartier has embedded continuous modifications and transformative processes, because of the nature of this type of social housing in Colombia (Cubillos, 2006). These processes are expected to facilitate adaptive strategies. In fact, in Barrio Carimagua is has been found feasible some different strategies of flooding adaptation, according to the owners' preferences; i.e. some owners might opt for green roofs and benefit also from the improved thermal comfort with the homes; some might opt for an internal garden). Where no action is preferred, the government can still opt to adapt communal spaces such as parking spaces.

Strategies deployed to increase permeability increase are successful. With the strategies used, the percentage of permeability is increased by 23 percent. It has been possible to increase the total permeable area by 52 percent combined different strategies.

In the parking area it is suggested to change the soil cement by a semipermeable material that improves the permeability percentage but maintains the mechanical properties similar to those of the current cement. And to the extent possible, it is proposed to recover the original garden of the facade to recover the green areas and increase the area of permeability.

Conclusion

This study identifies the importance of satisfying the need for permeable urban areas today in Bogotá, and consequently, the results propose to implement a model that can respond to such a need, and to implement and optimise life conditions of an urban habitat.

Green roofs constitute an adequate and economical strategy that substantially contributes to increasing the percentage of permeable area in Bogotá and Carimagua neighbourhood is a good example of this adaptability. Also, it could be used as an urban vegetable garden where some vegetables, water retention plants and aromatic plants could be planted.

In Carimagua neighbourhood is evident the demand for habitable soil, because residents tend to occupy all the open spaces available within the plots by physically building on front garden and backyard, with a change use of the plot area, different than the one initially designed. This is a general phenomenon in Bogotá and also other Latin American cities.

It is recognised the limits of this research: while it is used a 30% increase in rainfall is considered over a year, the time factor is not be considered. More research is needed to evaluate the rainfall as it occurs in a short amount of time and test the validity of the present research with the effect of a storm. This could lead to a combined strategy in the outskirts of the urban areas to apply other integrative strategies such as large water reservoirs. However, the ultimate aim of this research is to propose a starting point of adaptive strategies in Latin American urbanised contexts in a moment when heavy urbanisation is occurring and recommendations and guidelines being produced.

Further research is oriented at proposing a factorial model in the study regarding the degree of relationship between variables and factors contributing to increasing resilience to flooding. In this model, variables such as permeability, porosity, percentage of drainage, percentage of runoff and humidity will be interrelated.

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