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Designing water infrastructure and context-responsive housing: A case study in the Sabana de Bogotá.

The flood prone areas and agricultural soils along the Bogotá River in Colombia face a continuously increasing conflict between urban development, amongst others by low-cost housing projects, and environmental needs. This research investigates how current contested relations between water, settlement patterns, and productive landscapes can be turned into a constructive interplay. This paper presents a water urbanism research project, which uses interpretative mapping and research by design to critically understand the evolution of the relationship between water and settlements in the peri-urban areas of Funza and Mosquera. The project landscape typologies for adaptation and mitigation in view of climate change and to address demands of urbanization in the Bogotá River floodplain. The paper demonstrates how designing *with* water can re-qualify the peripheral areas of Bogotá, solving both qualitative and quantitative water issues, delivering a framework for new housing fabrics, and creating new sustainable relations between different water uses.

Keywords' water urbanism, landscape urbanism, sustainable water management, research by design, low income housing, Bogotá.

Introduction: Context.

The rapid urban development in the Sabana de Bogotá has led to an exhaustion of the carrying capacity of the Bogotá River watershed. To cope with the growing demand for fresh water, fragile ecosystems such as páramos and aquifers are being harvested in an unsustainable way. Urbanization has also resulted in a drastic transformation of the water system: the encroachment of floodplains and water bodies, disappearance of wetlands, expansion of impermeable surfaces and urbanization of the fertile agricultural soils. The Sabana de Bogotá geographically it coincides with a plateau located in the middle basin of the Bogotá River at an average altitude of 2600 m above sea level. The landscape changes have contributed to a significant decrease of landscape resilience. In this research, resilience is understood as the capacity of an ecological system to absorb the changes induced by climatic and geophysical processes. When the accumulation of incremental changes exceeds the capacity of the ecosystems to adapt to such changes resilience is lost (Holling and Goldberg, 1971). The incomplete waste water infrastructure, need of expansion of sewer interceptors and limited capacity of the Waste Water Treatment Plant (WWTP), result in heavy pollution and loss of biodiversity, adding more challenges to the critical socio-ecological situation (CAR, 2006).

Population growth in the Sabana de Bogotá has slowed, however, there remains a significant housing deficit. In 2018 the quantitative housing deficit for the Bogotá Region[1] was calculated as 110,926 dwelling units, and population projections predict that the region will need an average of 74,822 new units annually (Triana and Cristancho, 2018). Low-income housing would comprise a large percentage of this deficit, which is also partly driven by the needs of displaced population[2]. In Bogotá, as in other cities of the Global South, the formal market has failed to provide sufficient and affordable housing solutions, resulting in new urban inhabitants relying on self-construction on land provided by the informal market (Torres, 2011). Soil quality, risk exposure and accessibility to infrastructure and services determine land prices and also explain the informal occupation of flood-prone and landslide risk areas.

During the past decades, different policies and programs have been created at national and local level to address the low-income housing demands; nevertheless, a

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[1] The Bogotá Region is the first administrative, economic and population centre of Colombia, however it is not defined in legal or administrative terms.

[2] Between 1985 and 2008, around 10% of Bogotá's population growth corresponded to a displaced population (CODHES, 2008).

sustainable approach to the management of natural resources is seen to be lacking in these projects. National and local government have responded to the housing crisis by three means: (1) the creation of the public land bank agency *Metrovivienda* in 1999, (2) the development of Macroprojects of National Social Interest (Macroproyecto de Interés Social Nacional' (MISN), (3) the consolidation of housing subsidy programs as well as the promotion of policies for free housing. The projects built through these instruments indeed contributed towards reducing the housing deficit, but also resulted in the occupation of flood risk areas, and the expansion of the urban frontier onto agricultural land. Furthermore, many projects showed a lack of connectivity to job opportunities and social infrastructure. For instance, to provide cheap urban land to private developers, *Metrovivienda* bought large plots of land located in floodrisk areas in the locality of Bosa, and developed two large-scale housing projects for 22,500 dwellings: El Recreo and El Porvenir (Gilbert, 2009; Metrovivienda, 2011). Another example is the MISN Ciudad Verde project for 49.500 dwellings, built between 2009-2018, and developed entirely by the private market, located on rural land in the municipality of Soacha. These projects consolidated the occupation of the floodplain and rely on hard engineering solutions and mechanical systems to control flood risk. The floods of 2011 in El Recreo and El Porvenir due to a failure of a pump system, affected 50,000 inhabitants, demonstrating the shortcomings of this approach.

Climate change projections confirm the extremely urgent need to integrate adaptation measures that reduce the stress on fragile ecosystems (Figure 1). Estimations[3] show that, between 2041 and 2070, rainfall could increase around 10% to

[3] The possible impacts of climate change in the Sabana de Bogotá were evaluated for three periods (2011-2040, 2041-2070 and 2071-2100) by the Climate Change Regional Plan PRICC (Plan Regional Integral de Cambio Climático de Bogotá – Cundinamarca).

30% in the central part of the plateau[4] and decrease around 10% to 20% especially in the mountains where water sources are located. These changes will increase flood risks along the Bogotá River during the rainy season and threaten water supply during the dry season. In addition, temperature may reach increases of 2-4 °C by the end of the century, affecting the Páramo, a high Andean ecosystem which provides more than 80% of the water supply[5] (IDEAM et al., 2014). The El Niño and La Niña anomalies make the situation even more challenging, since these phenomena aggravate extreme conditions, causing droughts and floods to be more severe.

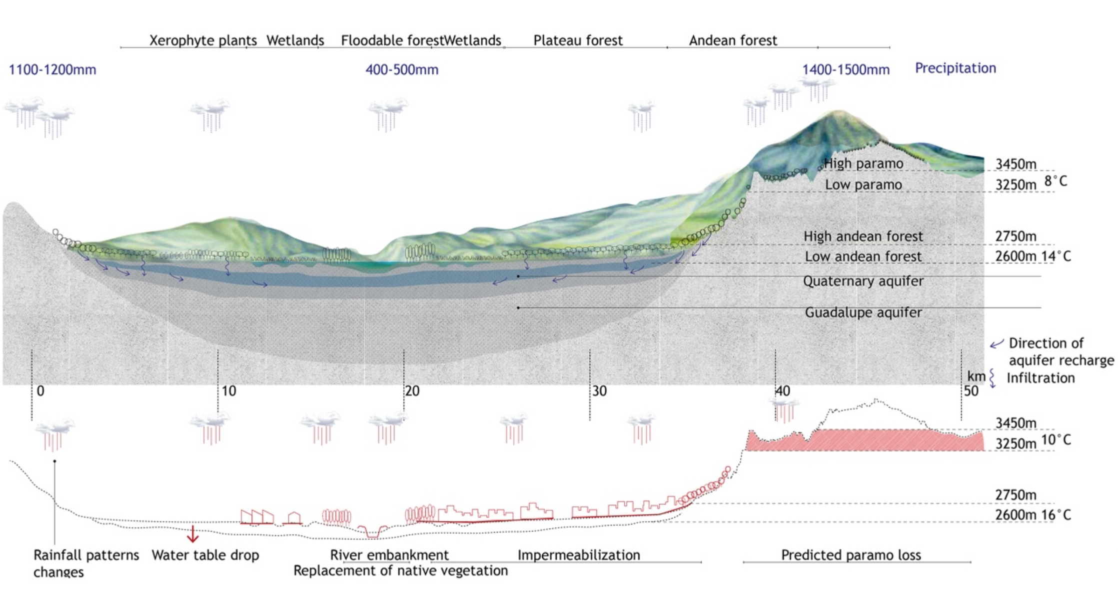

Figure 1. Schematic sections comparing the conditions of the Bogotá plateau before and after urbanization. The sections illustrate the natural water cycle and the possible

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[4] Current rainfall patterns from the north east to the south west vary from 1000 to 500 millimetres (CAR 2006; Veloza 2013).

[5] Around 1.45 million m3 (16,8m3/s), 83% of the water consumed in Bogotá and nine surrounding municipalities comes from the Chingaza Páramo, in the Orinoco watershed and 10% from the Sumapaz Páramo. The water storage capacity of the Páramos depends on the absorptive properties of its unique vegetation and soils types.

impacts of climate change. Based on: Van der Hammen (1998); IDEAM, et al. (2014); Google Earth, (2015).

Research question and aims

In response to the aforementioned issues, this research proposes to 'settle' the conflicts between urban development and environmental needs through the transformation of water infrastructure. The research aims to investigate how water infrastructure can be designed to protect fragile ecosystems and provide structure to settlements. This study is aligned with the discourse of 'water urbanism', and combines historical analysis about the transformation of the settlements and water infrastructure from the pre-Hispanic period to the present (research for design), to create a new cartography of the territory, and the development of new landscape typologies (research through design).

The paper contributes to the 'soft' engineering approach to water infrastructure (Kozlovsky and Grobman, 2016), adopting the notion of 'settling' in response to the current environmental and urban challenges. 'Settling' is understood from a number of perspectives: as 'establishing a permanent place', 'reaching an agreement', or 'dealing with'. Two design strategies were tested, firstly, a re-engagement with the ground, and secondly, the design of new landscape typologies organized through the water cycle. The first strategy reinterprets the system of ridged fields, an indigenous landscape archetype on which the manipulation of the land creates an infrastructure to 'live with' the waters. The second explores functional arrangements to 'deal with' waters by organizing urban uses along the water infrastructure while responding to local economies and the contemporary urban processes.

Water Urbanism as framework for inquiry

In recent decades, landscape design as an approach capable of dealing with current environmental challenges has taken a central role in urban design, planning and architecture. Landscape urbanism began as a term in the United States, it challenged the traditional concept of the city periphery formed by an inevitable sprawl and sought to include post-industrial landscapes more explicitly in urbanism; it was primarily concerned with the remediation of brownfields. Principles from ecology - particularly the notion of feedback loop disturbance and natural processes evolving over time - were taken and used as design strategies (Hight, 2014; Mostafvi, 2003; Waldheim, 2006, 2016).

Landscape urbanism can also be understood as the re-interpretation of ancient practices of settlements structured according hydrological regimes and slight topographical variations. For the still urbanizing world, it was developed as a lens from which to structure new settlement in relation to natural systems, 'working with, rather than against, the forces of nature'. It focuses on where to build as much as where to not build (De Meulder and Shannon, 2010; Shannon, 2004) and provides context-responsive solutions grounded in local knowledge.

Water urbanism emerged as a specific domain within landscape urbanism. It is based on the hypothesis that, historically, water networks provided the structure for entire territories and that this intelligence can be revived in contemporary urbanism (Shannon, De Meulder, D'Auria, & Gosseye, 2008). Water urbanism is aligned with a paradigm shift in the management and design of water infrastructure that arose from the failure of modern standardized practices of pipe engineering.. This shift appeals for the construction of 'polytechnic infrastructure' using 'soft engineered' strategies that address multiple purposes, for instance, flood control conveyance, aquatic biota, ecological biodiversity, and recreation (Mumford, 2010; Novotny, 2008; Shannon, 2013). Concepts such as 'sustainable urban drainage systems (SUDS)' or 'water sensitive urban design (WSUD)' as well as 'nature based solutions' (NBS) all address this shift.

Water Urbanism in Bogotá and Latin America

To date studies that investigate the integration of water infrastructure and social housing from a spatial perspective and provide solutions for both issues in the context of Latin America are lacking. To address this gap, this research extends the notion of water urbanism to the specific issues of low-cost housing in Bogotá, Colombia and adds to ongoing research on water infrastructure and public spaces as a measure for climate change adaptation in Latin America (Stokman, 2017; Urbanisten and Deltares, 2016)[6] [7].

The research innovation lies in the integration of fragmented knowledge from different disciplines: urban design, hydraulic engineering, and architecture, through interpretative mapping and design. In Bogotá, research on hydraulic engineering has focussed on sustainable water management tools at the city-scale without, however, addressing its spatial integration with the urban tissue (Díaz-Granados and Camacho, 2012; Rodriguez et al., 2008). There has been fragmented historical research on the urban history of Bogotá's rivers (with a focus on the Tunjuelo River) and the history of Bogotá's water company (Osorio, 2008; Salazar, 2008; Zambrano, 2004). Social housing has been explored extensively, specifically focusing on either architectonics or policy issues, (Angel Samper and O'Byrne, 2012; Escallón, 2011; Saldarriaga, 1996; Tarchópulos and Ceballos, 2005; Torres, 2011), however its relation with water infrastructure remains unexplored.

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[6] German-Peruvian research project LiWa : Sustainable water and waste water management in urban growth centres coping with climate change. University of Stuttgart.

[7] Water Sensitive Mexico City. Designed by De Urbanisten and Deltares, and commissioned by the government of Mexico City CDMX.

Designing with water: Interpretative Mapping and Research by Design

This paper is informed by 'research by design' using Funza and Mosquera as a case study (Figure 2). Two steps can be identified in the research process using the already classical categorization of research into/through/for art and design introduced by Frayling in 1993 (Prominski, 2016). Firstly, an 'interpretative mapping'(Corner, 1999; Shannon, 2008) exploration that corresponds with a 'research for design' process combining multidisciplinary knowledge to later substantiate the design work. During this step we collected spatial data and cartographic material from different sources[8]. The data covered multiple themes and was assembled in illustrator a vector graphic design software, creating a system of layers that was later used to re-combine information and produce new cartographies. Secondly, a 'research through design' process that consisted in the design of landscape typologies was adopted. We used sketches, 3d models and urban plans to develop the design. These typologies tested the application of concepts of 'soft engineered' infrastructure while responding to the specific conditions of the context.

[8] Cartographical archives, technical reports, literature review and fieldwork.

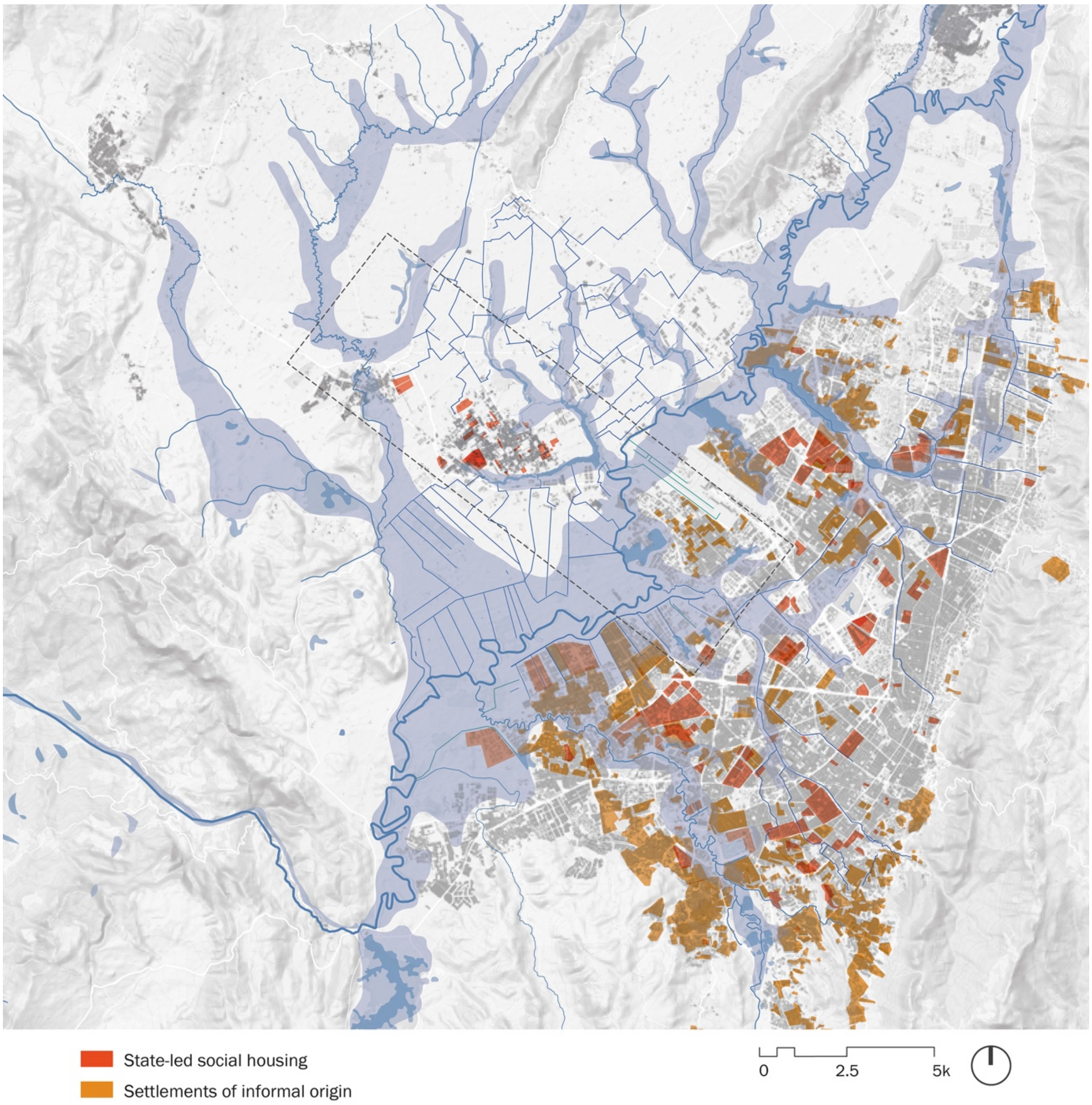

Figure 2. Location of the case-study of 22.5 km x 7.5 km. The municipalities of Funza and Mosquera are surrounded by the El Gualí-Tres Esquinas wetland.

Multiple scales and frames were defined to carry out the ‘interpretative mapping’ exploration, exploring socio-cultural relations between people and landscape and the physical transformation of landscape and infrastructure. On a regional scale the maps cover the central area of the Sabana de Bogotá (40 km2 x 40km2), and the context of the case-study of 22.5 km x 7.5 km. The maps in plan view were complemented with sectional drawings. ‘Research through design’ was carried out in areas of 4 x 4 km for two case studies: Vereda Siete Trojes and Vereda El Hato (Figure 3). The research by design process consisted in drawing alterations on the water infrastructure and landscape layers. These alterations operate as 'material research' (Frayling, 1993) exploring how interventions on physical structures based on re-directing existing processes can rebalance the relationship between water and settlement. The two case studies are located in areas of conflict between the ongoing low-income housing production and fragile environments, these areas have different flood risks, providing a ground to test different adaptation strategies.

Funza and Mosquera

Water infrastructure & settlement. Historical interplay

In the municipalities of Funza and Mosquera, the traditional agricultural landscape is undergoing a fast process of transformation characterized by the juxtaposition of industrial activities, flower farming, low-cost housing, and traditional patterns of small scale agriculture (Figure 3) (Rojas Bernal, 2018). The identity of the municipality as a rural and agricultural enclave persist in the practices of its urban inhabitants (Figure 4). Some of them preserve the tradition of having small orchards with vegetables, tubers, cereals and herbs, in their plots, though their income depends on working in the industrial or service sector (Otálora, 2014). Other small scale economic practices take advantage of the natural resources of the wetland, such as the harvesting of flowers (Zantedeschia aethiopica) carried out on the banks by a few inhabitants (Biocolombia and CAR, 2004). In contrast, industrial flower farming appeared after 1970s, motivated by access to underground water, cheap labor and proximity to the airport as well as large scale industrial platforms after 1990s driven by land availability and road infrastructure (McQuaid, 2011; Montañez, Arcila, & Pacheco, 1992).

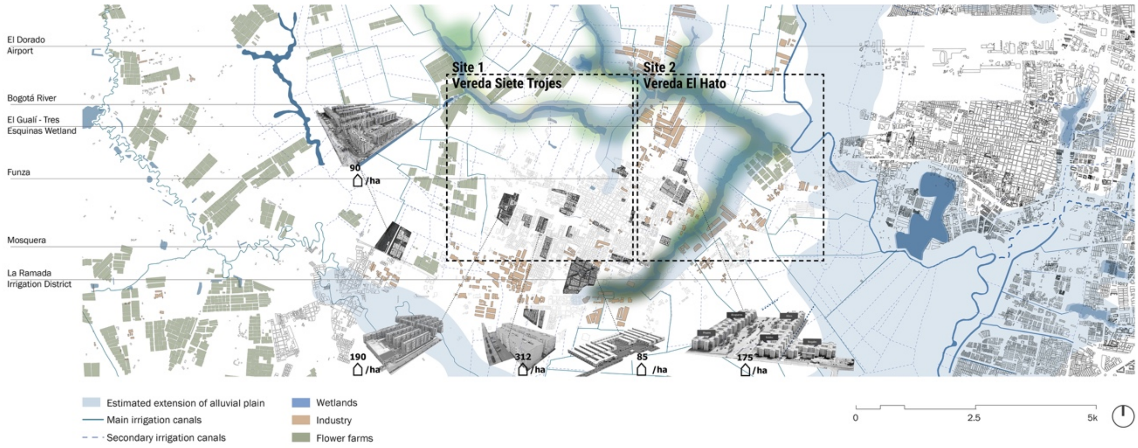

Figure 3. Map of the case-study area Funza and Mosquera showing the juxtaposition of urban uses on the fragile Gualí-Tres Esquinas wetland. The map highlights the projects for low-cost housing built between 2000-2016. The size of projects varies from small blocks of 33 dwellings to complexes with more than 3,000 units. Usually the perimeter is fenced, which leads to mono-functional urban enclaves. Based on: Alcaldía de Funza (2013); Municipio de Mosquera (2013).

Figure 4. Small patches of agriculture persist within the self-built housing tissue.

Funza and Mosquera are independent in administrative terms, but they are part of an urban conurbation, of which boundaries are merely a legal formality. These municipalities extend across 177 km2 with a population of 225.000 inhabitants (DANE, 2020). Over the last decades the population of this area has grown faster than that of Bogotá . For instance, between 1993 and 2005, the annual growth rate was 8.1% in Mosquera, 2.92% in Funza and 1.95% in Bogotá (SDP, 2009). An important part of this growth corresponds to the construction of social housing, which was facilitated by faster and easier legal procedures as well lower land prices for developers. However, the urban plans never envisaged this growth (Escallón and Quiñones, 2010). Official city population projections estimate the need to construct 58,000 new housing units by 2030 (DANE, 2006). Nevertheless, these projections ignore regional and national population dynamics, especially the displacement of population from Bogotá.

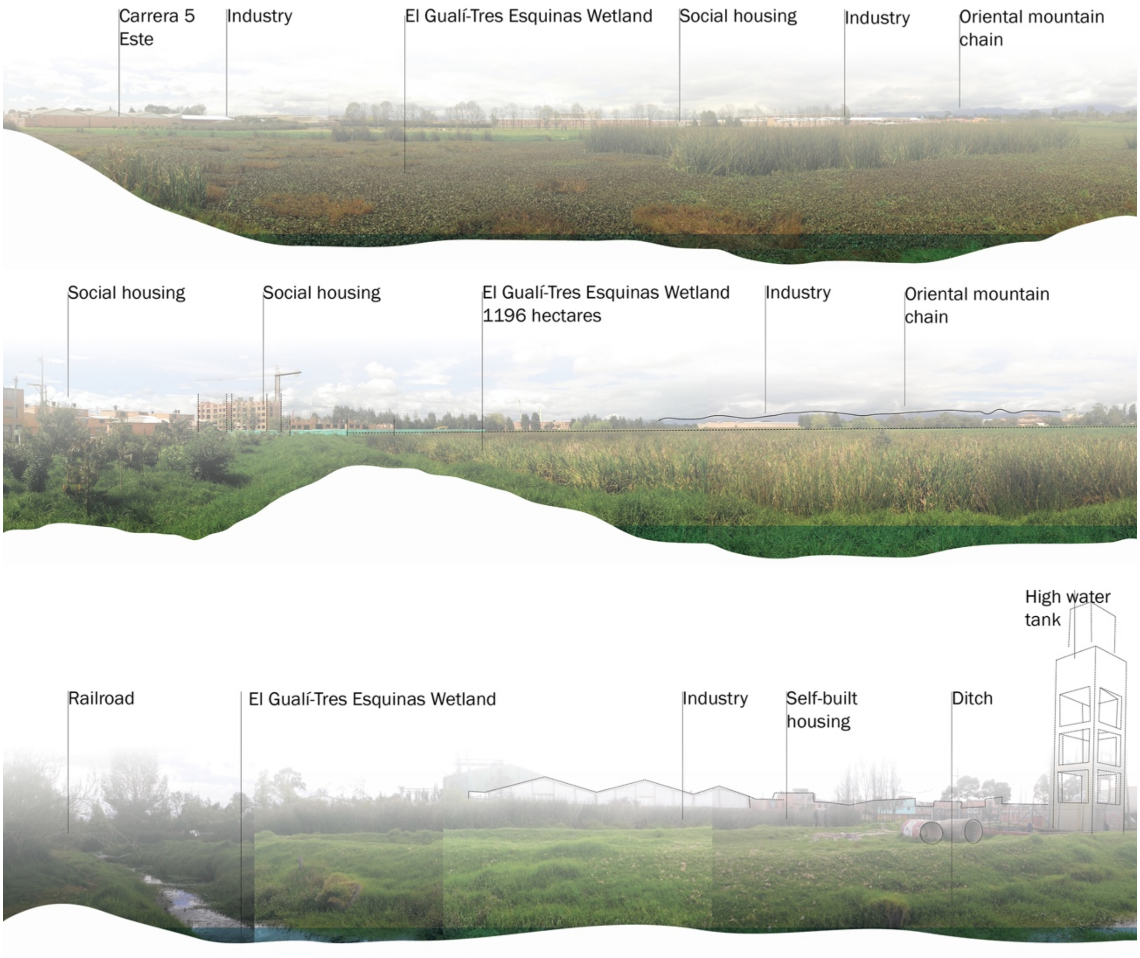

Figure 5. Schematic sections of the surroundings of Gualí-Tres Esquinas wetland.

Funza and Mosquera’s main landscape assets are: (1) the Gualí-Tres Esquinas wetland, (2) the Ramada irrigation district and (3) the high fertility of the soils. The wetland is part of the remains of the original wetland ecosystem that covered the lower areas of the Sabana de Bogotá before being drained for urbanisation and agricultural purposes (Van der Hammen, 1998). This wetland preserves hydrological and ecological values that are critical to guarantee resilience against flood risk, and is a unique habitat for endangered species (Figure 5) (CAR 2004). In addition, the El Guali-Tres Esquinas wetland functions as a reservoir for the La Ramada irrigation district. The irrigation district was built after the 1920s, partly re-using the old irrigation network built progressively from the seventeenth century onwards (Condori, 2006). Today La Ramada district covers an area of 6,500 hectares of which approximately 70% corresponds to the river floodplain. It was declared as ‘Regional District of Integrated Management’ (Distrito Regional de Manejo Integrado) because of its environmental, cultural and productive values. Its preservation is critical to guarantee food security for the region, nevertheless it is threatened by the expansion of urbanization and the worsening of water quality and soils fertility (Figure 6).

Figure 6. Low-cost housing project built along an agricultural canal.

Archeological material suggests that the largest Muisca settlement was located in Funza at the arrival of the Spanish colonizers (Broadbent, 1974). Nevertheless, human occupation in the area dated back to the Early Herrera Period (300BC and 200 AD). In this period, small clusters of houses were located along the wetland. During the Late Herrera Period (AD 200-1000), there was a substantial population growth concentrated in the area of the Vereda el Hato and La Ramada and separated by the Gualí wetland. During the Muisca period (AD 1000-1600), the population continued to increase. At the arrival of the Spanish colonizers the area was the capital of the 'zipazgo'[9] and the place

[9] The Muisca territory was divided in two political units: the 'zipazgo' in the south, and the 'zacazgo' in the north.

of residence or ‘cercado’ of the regional ‘cacique’[10] known as Hunza (Correa, 2004).

The population growth during the pre-Hispanic era, and the development of ‘cazicagos’, a complex social political institution that organizes settlement and social relations, was linked to the development of a ‘landscape urbanism archetype’: the ridged fields (Rojas Bernal, Shannon, & De Meulder, 2015). Ridged fields served to manage extremely wet soils, they improved drainage and soil conditions, controlled temperature differences and provided an appropriate space for fish farming (Bernal, 1990). The ridged fields took advantage of the natural overflows of and the sediments of the Bogotá River (Figure 7 and 8). The extension of the system and its need for periodic maintenance suggests that its construction took several centuries and depended upon a strong social collaboration that implied robust leadership (Correa, 2004).

[10] The political and religious power in the Muisca society was in the hands of the ‘caciques,’ they were considered direct descendants of the sun or the moon, and stood at the top of the hierarchical organization.

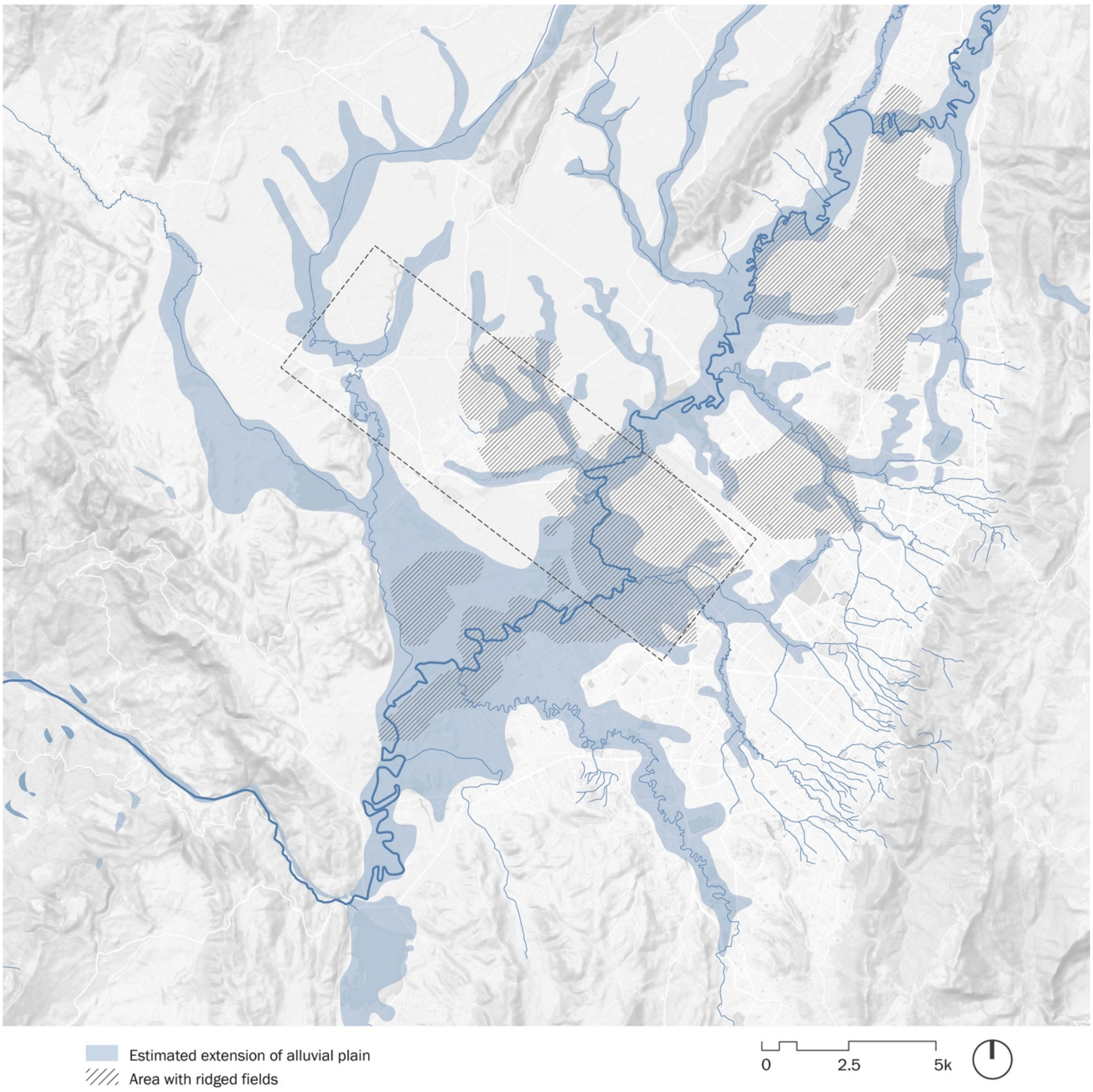

Figure 7. Areas with archaeological remnants of pre-Hispanic ridged fields. Based on: Boada (2006); Etayo (2002).

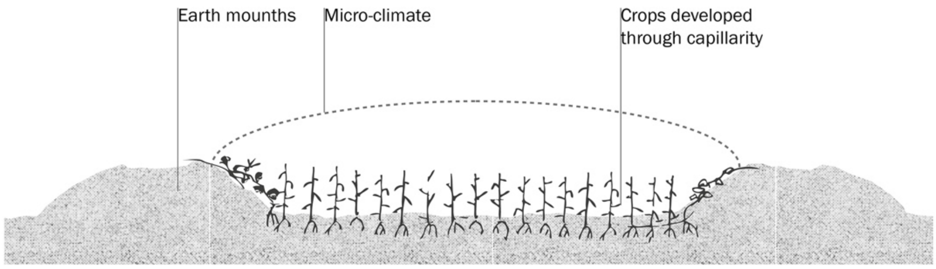

Figure 8. Schematic section of pre-Hispanic ridged field. Based on: Bernal (1990).

The urban structure imposed by the Spanish was based on the pre-Hispanic network of roads and the re-distribution of population for labor purposes, but disregarded the ancient system of ridged fields (Figure 9). In 1600, Spanish colonizers founded Bacatá, an Indian town at the center of the Gualí-Tres Esquinas wetland. This name was preserved until approximately 1825, the date of the first registers with the name Funza. The Indian town was surrounded by an Indian 'resguardo'[11] and located in proximity to the cross-roads between the path that connects the Sabana de Bogotá with Honda, a port city on the Magdalena River, and the path that connects the settlements on the west bank of the Bogotá River.

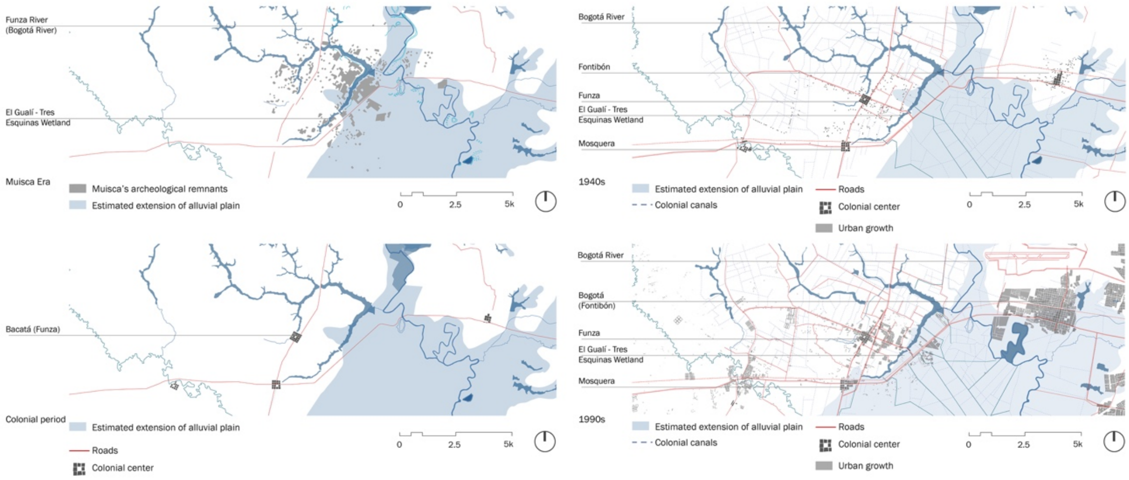

Figure 9. Transformation of water infrastructure and settlement patters in Funza and Mosquera: Muisca Era, Colonial Period, 1940s and 1990s. Based on: Cuéllar Sánchez and Mejía (2007); Talleres del Estado Mayor General (1930); Instituto Geógrafico Militar y Catastral (1942); IGAC (1978); Alcaldía de Funza (2013); Municipio de Mosquera (2013); CAR (2013); IDECA (2013); and Google Earth (2015).

Peri-urban landscapes: Vereda Siete Trojes and Vereda El Hato

The sites for the design investigation: Vereda Siete Trojes and Vereda El Hato (4x4km) were chosen due to their strategic position as transitional spaces between the wetland and the urban tissue (Figure 3). These neglected spaces are the result of the fragmented

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[11] A *resguardo* is a socio-political legal institution, which assigned ownership for territory to an indigenous community.

development, they have low accessibility, weak connection with the urban tissue and are surrounded by fences, blank walls or dikes. The lack of visual and physical connection restrain the engagement of community in the protection of the wetland and the general awareness about its landscape features. This landscape is probably not part of the public imaginary, during our field visits and informal conversations with inhabitants, the wetland was never mentioned as part of what they consider public or recreational spaces.

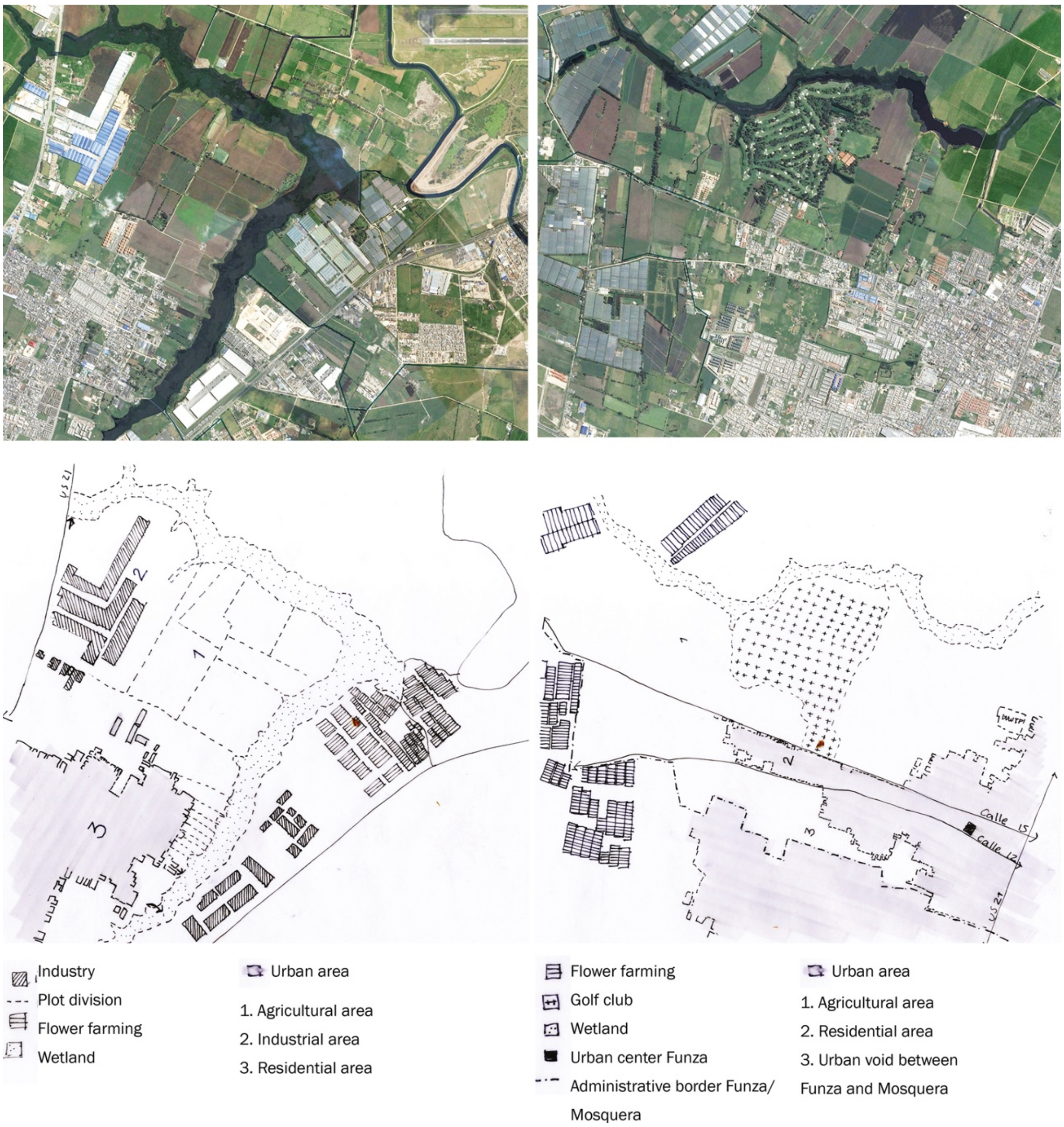

Figure 10. Aerial images of Vereda Siete Trojes (right) and Vereda El Hato (left). Google Earth (2015).

Vereda Siete Trojes is located in the northern part of Funza and Mosquera, here the disappearance of agricultural activity is related to the development of industrial parks, flower growing and new housing projects (Figure 10). This development has transformed the water system, filling in irrigation canals and large areas of the wetland. There is also a golf club in the area that restricts access to the wetland. During the 1960s, families engaged in medium-scale agriculture inhabited the area. Some of these medium-scale farms retained their agricultural vocation until the late 1980s. Today few farm families are still present. The weakening of peasant social networks and the construction of a modern aqueduct have also contributed to the lack of maintenance of water infrastructure (Otálora, 2014). The average elevation is 2550 meters, though existing topography is higher in the central area along the road Calle 15 and decreases towards the wetland. This road connects the area with the colonial center of Funza, which still functions as the urban center of the town.

Vereda El Hato is located in the eastern part of Funza, it is a large agricultural land amidst the wetland, industrial platforms and middle-scale housing projects (Figure 10). The land was used almost exclusively for agriculture until the 1970s when self-built housing began to develop. At the beginning of the 2000s the first industries were built along the US 21 regional road. The area is at an average elevation of 2530 meters above sea level, however the slope descends slightly towards the wetland. In the lower zone there is a low risk of flooding.

Informed by the historical mapping of the water infrastructure and settlement development, the research tested a series of landscape interventions aiming at providing solutions for housing needs and increasing resilience against climate change. Hence, the design investigation has focused on rationalizing the existing processes (topographical manipulation, agricultural production, and housing construction) in order to requalify the existing water infrastructure to structure new settlement patterns.

Re-engagement with the ground

This strategy reinterprets the sophisticated system of pre-Hispanic ridged fields built before the Spanish conquest, to adapt to changing natural cycles through the construction of artificial earth mounds, which improved productivity and protected settlements from floods (Rojas, De Meulder, and Shannon 2015). Field visits also evidence that the ongoing process of urbanization, mostly for industrial projects and gated communities, is built by raising land 1 to 1.5 meters. There is also a dike surrounding some of the housing projects of about 2 meters.

Drawing on the process of topographical manipulation and on the pre-Hispanic system of ridged fields, a series of new platforms for urban uses were projected taking advantage of the natural topography (Figure 11). In the Vereda Siete Trojes, the platforms are aligned with the extension of the irrigation network. In the Vereda El Hato they cluster towards the existing infrastructure, allotting more space for the preservation of the wetland. This configuration also responds to the flood risk which is higher in the latter. The manipulation of the land through ‘cut and fill’ operations, not only creates ‘safe land’ for urban uses but also gives more space to water, creating spaces to retain, circulate, clean or recycle water. The sectional manipulation of the land also creates variable conditions that depend on the fluctuating water levees which increase biodiversity.

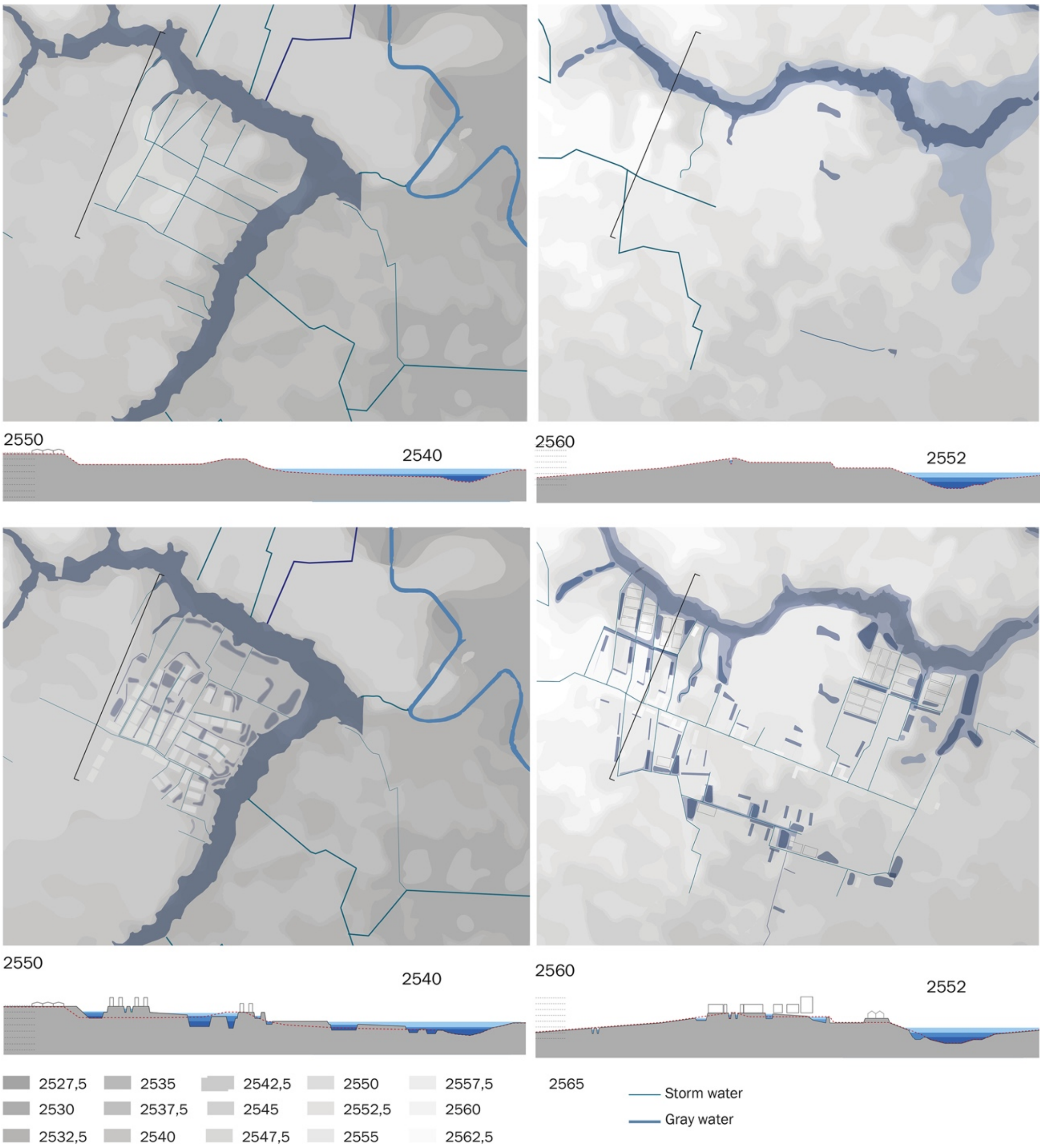

Figure 11. The strategy of topographical manipulation applied to Vereda Siete Trojes (right) and Vereda El Hato (left).

Landscape typologies

Making use of existing landscape assets, such as the irrigation network, the fertile soils and local rainfall and the existing productive activities, the design investigation aims to organize the different uses along a water infrastructure.

The decentralization of water management guides the design of gray and storm water infrastructure. Through the design of decentralized water management units, the uses are organized to take advantage of the reclamation of water, the 600mm of annual rainfall, and recreation and environmental values of the ‘soft engineered’ infrastructure. In the Vereta Siete Trojes, the irrigation network is extended, re-activating old canals and reclaiming filled sections of the wetland (Figure 12). The new infrastructure defines an independent system of gray water collection and treatment. This is composed by constructed linear wetlands that progressively clean the domestic gray water. The treated water is re-used in flower farming, reclaimed for domestic use (toilet flushing or clothes washing) or diverted towards the wetland to be re-circulated in the irrigation network. In the Vereda El Hato, the design follows the same logic, defining decentralized units with a central swale that allows for the reclamation of the water or its diversion towards the wetland (Figure 13). Here the constructed wetlands are larger, giving more space for the fluctuations associated with flood risk, and creating a filter that lessens the impact of recreational activities on the ecologically fragile areas of the wetland. The water system is transformed from a linear structure into a hybrid water infrastructure that combines linear elements and surfaces defined by the new topography. These landscapes are reinforced through afforestation and revegetation strategies. The restored and extended wetland can provide space for growing flowers that can be harvested by organized local flower collectors. Communities have the potential to recompense for this right by protecting the ecosystems through the development of projects for environmental education, as has already been identified in the wetland management plan (Biocolombia and CAR, 2004).

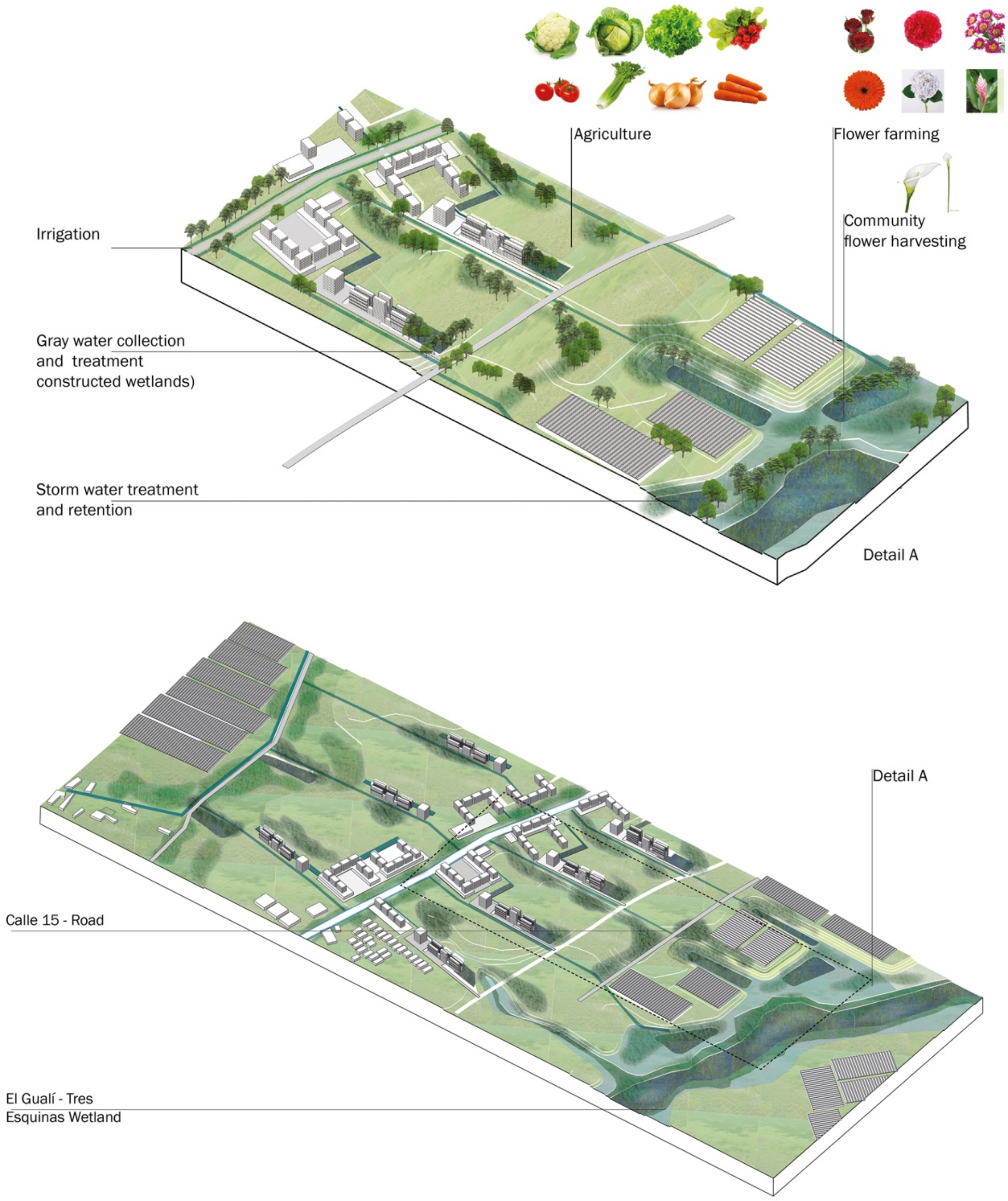

Figure 12. Proposed sectional typology in Vereda Siete Trojes 750 x 1250 meters and detail.

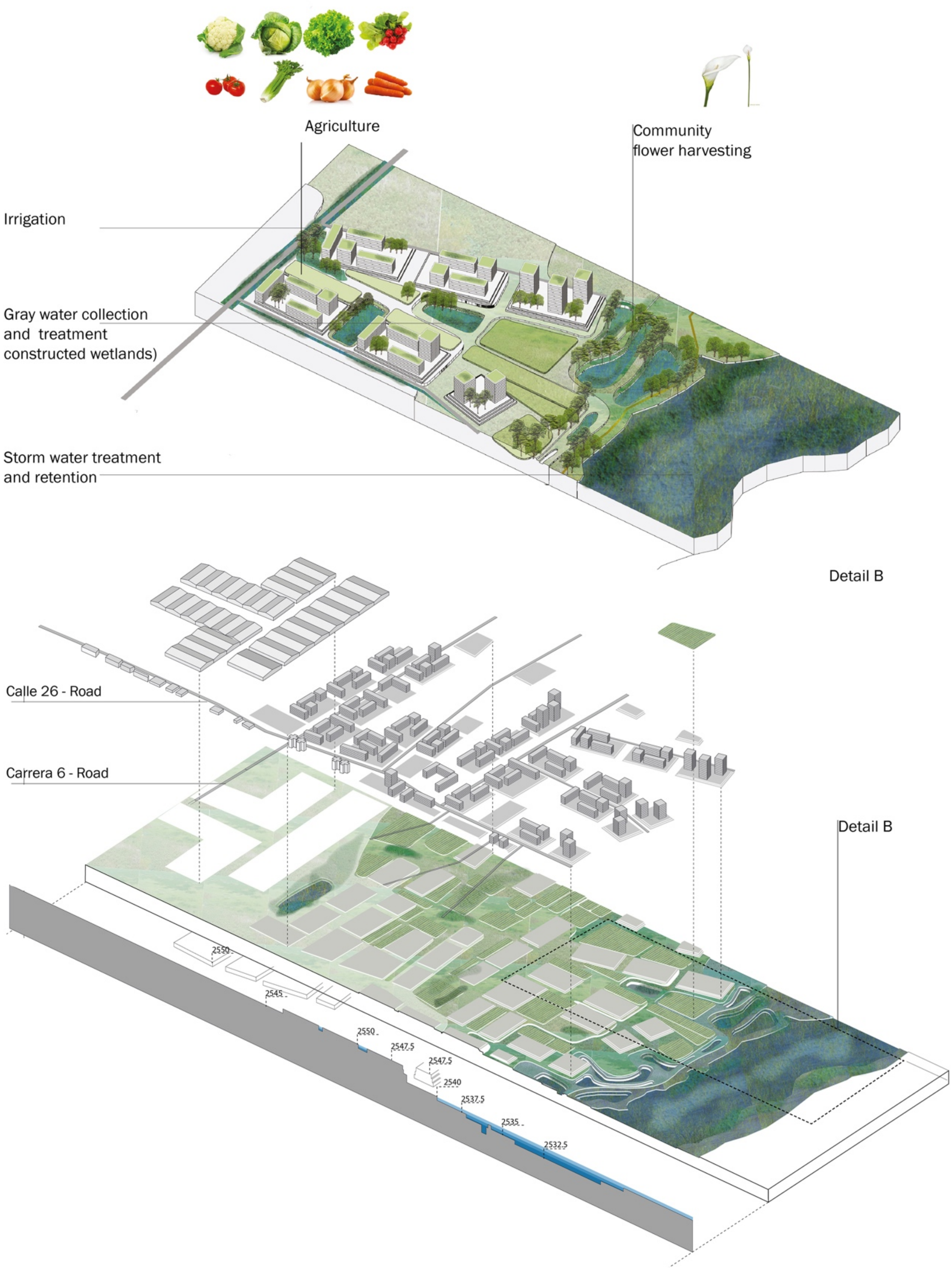

Figure 13. Proposed sectional typology in Vereda Siete Trojes 750 x 1250 meters and detail.

The organization of uses also responded to the specific characteristics of the urban structure. An increased public connectivity and accessibility is provided through the extended irrigation network. This infrastructure guarantees the water inflow to the wetland and works as an organizing element for the new housing projects. The water infrastructure is extended to preserve the most fertile soils that still have agricultural uses. In addition, it adds a new social dimension to the landscape providing ecosystem services.

In Vereda Siete Trojes, the modified topography defines three areas, the higher area, along Calle 15, works as a civic armature and is mainly dedicated to mid-rise - high-density housing, urban services, and small-scale agriculture; an intermediate zone that combines high density housing with agriculture; and a lower area for the extension and preservation of the wetland in which flower farming is combined with ponds for rainwater collection (Figure 12). In Vereda El Hato, the urban tissue is anchored to the existing fabric through the prolongation of the roads Calle 27 and Carrera 6 (Figure 13). These roads create an armature that contains commercial functions and services. The occupation of the land and the road infrastructure is restricted towards the wetland, giving more space to water and environmental restoration. Urban density increases in this area, taking advantage of the views over the natural surroundings.

Local communities and environmental organizations in Bogotá have played an active role in the protection of different water ecosystems. Two examples that illustrate the role of the community's drive in the protection of ecosystems are the restoration of La Vieja creek and Cordoba wetland. The first is a project that has been promoted by the local community of La Vieja creek since 1984 to recover the ecosystem as a public space. Thanks to its success, the project became the model for the recent program for creek restoration promoted by Bogotá's government. The program aims to restore upstream creeks through re-naturalization strategies and the active participation of the community (Bejarano, 2014; Jimenez, 2013). The second example corresponds to a resistance process promoted by the local community of Cordoba wetland to prevent the implementation of a hard engineering intervention that intended to create concrete pathways and hard surfaces in the wetland surroundings. The community formed an organization that continues to have an active role in any decision-making process for the wetland (Sandoval, 2012). These approaches demonstrate that despite the high degree of environmental deterioration, communities are aware of the importance of preserving and restoring fragile landscapes. This potential can be drawn upon to support any design strategy.

Essentially, the design investigations shown through three dimensional drawings, are reinterpretations of the water infrastructure that supported the pre-Hispanic settlements, combining water management, productive uses and cultural values, into a contemporary context-responsive water infrastructure that gives structure to housing and preserves economic activities such as flower farming and agriculture.

Discussion

Revealing landscape structures to accommodate development needs

This 'research by design' investigation demonstrates that the production of housing can serve as a means to implement the latest paradigm in water management in peri-urban areas of Latin American cities. In most of these cities, peri-urban areas and traditional agricultural lands are under development pressure and need solutions that can reconcile development and environmental needs. Irrigation systems in peri-urban areas, are the result of long processes of negotiation between people and landscape. This infrastructure should be considered as an asset to re-structure settlement patters and provide solutions to climate change challenges.

The methodology presented in this paper can be adapted to other contexts that face similar questions. It proposes a systematic reading of the socio-cultural and ecological process of the site using 'interpretative mapping' and the development of landscape typologies through 'research by design'. This approach is not only a necessary step to produce context-responsive solutions, but also to produce situated knowledge that derives from the identity of the local landscapes (Muir, 1998). Such understanding of landscape urbanism requires integrating local expertise from different disciplines (ecology, anthropology, hydraulic engineer, urban history, amongst others). An interdisciplinary approach has the potential to strengthen the identity of local landscapes and their cultural values, offering resistance against the equalizing practices of neo-liberal urban development. This approach also calls for a critical implementation of foreign city models and best-practices that make abstractions of landscape variations, without considering the specificity of the environment and its inhabitants.

The terrain as infrastructure

The design investigations presented in this paper illustrate the capacity of landscape design to develop spatial structures that work with the water cycle. These structures are three-dimensional, therefore the design in section proves to be a valuable tool, it enables the re-engagement with ground conditions and develops new modes of settling in the landscape. Topographical manipulation also enables the testing of the implementation of the latest shift towards a sustainable water management paradigm, which goes hand-in-hand with a shift towards a polytechnical infrastructure. The manipulation of topography can transform the land into an infrastructure for settlement and ecologies.

Possible limitations of the case studies presented in this paper derive from the need to create financial and planning models that could support the implementation of these systems. This is necessary considering the land property and the institutional fragmentation of urban management in the Sabana de Bogotá. Further studies could calculate the economic benefits and disadvantages of the implementation of these systems and create economic models that allow a distribution of benefits and cost amongst stakeholders. In addition, further collaboration with other disciplines, for instance, hydraulic modeling, ecology and bio-engineering, are needed to refine and resolve technical issues.

Shared narratives for common values

In Bogotá, the transformation of the water system from a dynamic living ecosystem into a linear monofunctional infrastructure went hand in hand with the loss of ecological and cultural values. This is partly due to the replacement of the word 'river' by the word 'canal' as rivers were transformed into mono-functional flood control canals (Carreira, 2007). This semantic change also expresses a detachment between people and landscape which is consistent with the modern (and deteriorating) relations between nature and society, in which water is to a large extent de-symbolized (Shannon, 2013). The proposed design of water infrastructure is intended to bring back water to the public sphere. This should be considered to be a first step towards a cultural engagement with water.

Furthermore, by creating a new set of interpretative maps that highlight ecological values and re-interpret indigenous landscape urbanism, this research aims to make visible the role of the arts and humanities in climate research. The creation of new visual narratives can serve as tools for engaging different actors in the construction of common values and potentially trigger changes in behavior. The proposed design strategies could be tested by further action research steps while engaging with community agencies and local government. Local communities in Bogotá have created innovative approaches for the restoration and management of water ecosystems. These approaches are a solid base to stimulate behavioral changes in society that need to be intertwined with design strategies.

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