DESIGNING RESILIENCE: TRANSFORMING RESIDUAL SPACES WITHIN INFORMAL SETTLEMENTS /

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Abstract. Informal settlements emerge in contexts of rapid urbanisation, rural-to-urban migration, socioeconomic inequality, and environmental and political vulnerabilities and are characterised by spatial segregation, inadequate infrastructure, and limited access to services. Addressing these challenges requires innovative approaches that go beyond conventional urban planning, emphasising strategies that integrate ecological, social, and cultural dimensions of the built environment. This paper explores regenerative design strategies for built environments and urban voids within informal settlements, with a particular attention to contexts marked by high social and ecological vulnerability. Drawing on a case study conducted in a hillside informal settlement in Cali, Colombia, the research examines how residual and interstitial spaces—often overlooked or underutilised—can become catalysts for urban transformation. The case study, developed by two graduate students under the co-supervision of the authors, investigates the fragmented urban structure of a settlement that has been systematically excluded from strategic municipal projects, resulting in limited access to basic services, infrastructure, and urban opportunities. Through field analysis and design exploration, the study identifies vacant and residual spaces within the dense informal settlement as viable locations for intervention, proposing a series of integrated strategies that address multiple dimensions of sustainability. These potential project spaces include community-managed urban gardens, decentralised water collection and treatment systems, modular sanitation infrastructure, and mobility solutions adapted to difficult topographies. Beyond physical infrastructure, the proposed interventions aim to strengthen the social fabric, foster collective appropriation of public space, and enhance emergency response capacity in a context exposed to landslides, flooding, and climate-related risks. The paper argues that residual spaces in informal settlements are latent opportunities for transformative interventions through regenerative design approaches. It further suggests that such strategies can simultaneously meet immediate material needs while fostering long-term inclusion, environmental restoration, and community empowerment, offering replicable insights for similar contexts.

Introduction. In recent decades, rapid and often unregulated urbanisation has profoundly reshaped the territorial structure of major cities worldwide, leaving lasting marks on their physical fabric and giving rise to informal settlements characterised not only by disorder and inequality but also by deep socio-spatial segregation (Carvalho & Netto, 2023). These settlements often face environmental vulnerabilities (Hussainzad & Gou, 2024) and are situated far from main urban corridors, collective infrastructure, basic services, and the opportunities provided by the planned city (UN, 2025). Moreover, the phenomenon of informal urban sprawl is far from uncommon or temporary (Atkinson, 2024), especially in Global South contexts (Dovey et al., 2020). In Latin America, for instance, this form of urbanisation is expected to become the predominant living environment for the urban population and the principal mode of city expansion in the coming years (Gouverneur, 2015; Baratta et al., 2016; Tessari, 2020). However, viewing informal settlements solely through the lens of deficit and pathology overlooks their latent potentiality, one *"that can become resources"* (Max-Neef et al, 1986, p.34). In this sense, they may be interpreted as "not yet" territories, spaces charged with "on the one hand, capacity (potency) and, on the other, possibility (potentiality)" (De Sousa Santos, 2010, p. 25).

As Perriccioli further notes, these marginalised areas:

> (...) *have become areas of exclusion, of minorities, poverty and immigration, but also of refuge and expectation where hopes and projects can be cultivated. In these "grey areas" where citizens constitute the masses but do not become communities, the social groups excluded from the immediate exercise of power begin to acquire self-awareness and design skills, creating community spaces* (...) (2017, *p. 26*).

The challenge of improving informal settlements requires moving beyond simplistic and limited upgrading programs focused on social housing construction, which converts inhabitants into *"mere dwelling consumers"* (Muñoz Veloza, 2022, p. 100). On the contrary, a holistic analytical framework is required to consider all the project spheres—environmental, social, economic, and cultural—as well as the *"kinetic"* nature (Mehrotra, 2010) and capacity for continuous adaptation and transformation of informal settlements. This understanding shifts the focus from an imposing tabula rasa approach (Certeau, 1984) to a context-sensitive one, based on strategies that *"prioritise social networks, pedestrian accessibility, and the capacity for incremental adaptation"* (Nezhadmasoum & Vehbi, 2025, p.10) Considering the points outlined above, this paper argues that residual and interstitial spaces within these settlements—often overlooked or underutilised—can become catalysts for urban transformation. when approached through regenerative design strategies. It focuses on a case study developed by two graduate students under the co-supervision of the authors. The case study is situated in a hillside area of Cali, Colombia, which faces significant physical, environmental, and social challenges. The research question guiding the regenerative design strategies was: *"How to transform the public space with the aim of meeting satisfied basic needs in order to contribute to the improvement of the quality of life in informal settlements?"* (Montero Correa & Roldán Becerra, 2024, p. 13). Based on field documentation and the analysis of several best practices, the proposed interventions are embedded within a broader vision that recognises the "social aesthetics" (Arango Escobar, 2004) of informal settlements, their capacity for collective action, spatial flexibility, and community self-organisation.

Context. Santiago de Cali (Cali), Colombia's third-largest city, exemplifies the challenges and contradictions of rapid urbanisation in Latin America. The city has been profoundly affected by informal urban sprawl, driven by internal migration resulting from armed conflict and rural displacement (Domínguez, 2021). In response, the Municipality of Cali adopted the Mi Hábitat Public Policy in 2017 as a framework for the comprehensive improvement of urban settlements in precarious conditions. Subsequently, in 2018, the Mayor's Office published the Plan de Acción de la Política Pública de Mejoramiento Integral del Hábitat 2018-2030 (PAPMIH) (Action Plan for the Public Policy on Comprehensive Habitat Improvement 2018–2030), which provides clarity for the development of improvement processes. However, despite significant legislative and research progress, the current challenge remains moving to practical action, as the implementation of the programs and projects designed to reduce the city's social inequalities is still limited (Saa Tafur et al., 2023).

District 1, one of the 22 districts of Cali, located on the northwestern hillside of the city, exemplifies these social and economic disparities. The area is characterised by stark contrasts, where high-income housing developments sit adjacent to informal settlements inhabited by lower-income populations. These proximities create visible boundaries, while also highlighting the lack of urban infrastructure and public spaces in the most disadvantaged areas. Approximately 15 informal settlements are dispersed throughout Commune 1, with the majority concentrated in specific zones, including Puente Azul-Bajo Aguacatal (DANE, 2018), which face multiple vulnerabilities, as shown in Figure 1. Many of these settlements accommodate a significant portion of the population displaced by Colombia's armed conflict, while some are also exposed to natural hazards, such as the risk of mass movement.

Case study. Puente Azul-Bajo Aguacatal (Figure 2) was selected as the case study area due to its strategic location and the presence of notable infrastructural deficiencies. The settlement's proximity to the riverbank, a sportive area including soccer fields, and the city's transport infrastructure underscores its potential for enhanced urban integration. However, its positioning on steep terrain significantly constrains accessibility, as inadequate pedestrian pathways impede residents from the upper sections of the settlement from effectively reaching these lower-lying urban facilities. Other deficiencies present in the settlements include issues related to insufficient sanitation services, a lack of public spaces, and poor infrastructural maintenance. Environmental risks further compound these challenges, particularly impacts on river basins caused by deforestation, pollution, and inadequate wastewater management. Field documentation revealed critical physical conditions and significant topographic constraints, such as unpaved pedestrian pathways and deteriorated stairs, the latter being essential for transverse connections to access the upper parts of the hill (Montero Correa & Roldan Becerra, 2024). However, positive community practices were also identified, "*including the presence of a small-scale community vegetable garden and the use of soccer fields by young people*" (p. 101).

Regenerative Design Strategies. The proposed interventions for Puente Azul-Bajo Aguacatal are grounded on a need/performance-based approach, which "*takes up the challenge of coping with methodological, sociological, economic, and scientific aspects, beyond technical ones*" (Daglio & Gambaro, 2017, p.120). According to the identified needs, the design strategies address five primary requirements: food security, clean water and sanitation, waste management, accessibility, and community life/community services. Each requirement is met through specific tactical interventions. Table 1 presents the identified needs and requirements, along with the proposed strategies.

Moreover, the analysis identified two main categories of residual spaces with potential for intervention as exemplified in Figure 3: i) spaces embedded within the internal courtyards formed by clusters of dwellings, more appropriate for small-scale, locally managed solutions, including organic waste composting points, micro-gardens, and rooftop rainwater harvesting systems; and ii) areas located along the primary access roads, suitable for interventions of a broader scale, such as multifunctional community centers integrating sanitation services and collective urban gardens.

Food Security. For food security, the proposal combines two main small-scale strategies: the creation of community vegetable gardens in areas with favourable solar exposure and the introduction of cooking modules equipped with wood-burning ovens, placed at locations that maximise their collective use. Both components are incorporated into community centres, which are conceived to support collective-led food practices. The community centres are thought to be integrated into a broader urban agriculture network grounded in circular-economy principles, including shared kitchens, communal gardens, and composting systems.

Clean water and sanitation. For clean water and sanitation, the proposal outlines a set of four complementary strategies that operate at both large and small scales. These include: i) rainwater harvesting systems designed for non-potable uses such as irrigation and cleaning, equipped with collection, storage, and distribution elements; ii) sanitary modules incorporating portable storage tanks to improve access to clean water; iii) upgraded drainage infrastructure to form a functional sewage network supported by a decentralised wastewater treatment system consisting of septic tanks, a grease trap, and an infiltration field; and iv) the integration of natural drainage solutions, particularly phytoremediation plantings along the riverbank, to mitigate pollution and contribute to ecological restoration.

Waste collection. For waste management, the proposal adopts two ecological strategies applicable at both large and small scales. The first involves dry composting toilet systems, which separate liquid and solid waste and stabilise it with dry organic materials—such as sawdust or leaves—to produce compost suitable for non-edible vegetation. The second consists of designated composting areas for organic household waste, placed in semi-shaded and well-ventilated locations, where waste is processed in containers of adequate capacity with alternating layers of materials. The resulting compost can then be reused to enrich the soil of community vegetable gardens.

Accessibility. For accessibility, the proposal addresses the steep topography by enhancing the existing circulation network and expanding it where

necessary. This includes the rehabilitation of deteriorated stairways and pathways, as well as the introduction of new routes to strengthen transversal connections across the slope. A key component is the installation of a monorail system aligned with the main stair axis, featuring five stations that interface with the proposed community centres. This solution offers an efficient and minimally invasive alternative to more complex mechanical infrastructure, enhancing mobility for residents while respecting the hillside context.

Community life/community services. To strengthen community life and local services, the proposal introduces two types of community centres that serve as key social infrastructures. i) The large-scale typology is conceived as an open and adaptable facility capable of hosting a broad spectrum of collective activities, such as educational programmes, local fairs, health-related initiatives, and community workshops. Its flexible spatial organisation enables it to respond to changing needs and promotes social interaction. ii) The small-scale typology focuses specifically on food-related community practices, including gathering spaces, a kitchen, and storage areas, complemented by an adjoining sanitation module equipped with handwashing facilities, a sink, and a toilet. Water storage tanks positioned above the module help address the settlement's limited access to a reliable water supply. Across both typologies, the architectural strategy prioritises adaptability and community involvement by using lightweight and easy-to-handle materials—such as drywall, OSB panels, and polycarbonate—to allow construction by local workers and to facilitate modularity, scalability, and future replication of the centres.

Figure 4 shows an overview of the proposed interventions.

Discussion. This research recognises the robust "social form" (Lefebvre, 1974), community networks, and collective sense of belonging inherent in informal settlements, advocating not only for the provision of infrastructure and technical solutions but also for the creation of spaces that enable what Certeau described as the "*'tactics' articulated in the details of everyday life*" (1984, p. XIV). The Puente Azul-Bajo Aguacatal case study illustrates how regenerative design strategies can transform urban voids in informal settlements into catalysts for comprehensive improvement, positioning public space as an active component of social infrastructure.

Despite their apparent deficiencies, informal built environments embody valuable local knowledge and practices. Successful regenerative interventions, therefore, require moving beyond *"the limits that the determinants of the object set on its utilisation"* (Certeau, 1984, p. 98). By fostering community bonds and supporting collective self-management, maintenance becomes more feasible, contributing to long-term sustainability. The intervention strategies were developed as a flexible framework to address recurring challenges across the settlement, integrating multiple facilities while preserving adaptability. The use of lightweight, easily handled materials facilitates scalability and replication, ensuring that these solutions can be effectively applied in other informal contexts.

Conclusions. This paper has explored regenerative design strategies for urban voids and the built environment in informal settlements through a case study in Cali, Colombia. The research focused on residual and interstitial spaces within informal settlements, often overlooked or underutilised as catalysts for urban transformation. The intervention proposal for Puente Azul-Bajo Aguacatal addresses multiple dimensions of sustainability through integrated strategies: community-managed urban gardens, decentralised water systems, ecological waste management, adapted mobility infrastructure, and community centres conceived as social infrastructure. The case study illustrates how residual spaces in informal settlements are places still in formation, where unexpressed possibilities offer the basis for imagining and constructing different futures through collective practices. Moreover, the proposed strategies seek to address both immediate material needs and longer-term processes of inclusion, environmental regeneration, and community empowerment. In doing so, they seek to recognise and build upon the collaborative dynamics and transformative capacities already embedded within informal settlements across the Global South. Once again, architectural design, especially when practised within contexts that allow a critical distance from dominant cultural and market-driven logics, demonstrates its exploratory and prefigurative potential, capable of fuelling innovative visions and strategies for inclusive, low-environmental-impact transformative actions. In this vision, the academic world represents a subject that can contribute effectively, through the tool of design, to accompanying and supporting public initiatives such as the one described above (Crotti & Salvia, 2023, p. 168).

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Figures.

FIGURE 1 – Minor architecture in Porto. Foto: Rodica Crișan, 2022. Personal archive.
FIGURE 2 – Refurbished minor architecture in Porto. Foto: Rodica Crișan, 2022. Personal archive.
FIGURE 3 – Minor architecture in Bucharest. Foto: Rodica Crișan, 2018. Personal archive.
FIGURE 4 – Destroyed historic building in Bucharest. Foto: Rodica Crișan, 2006, 2007, 2023. Personal archive.
FIGURE 5 – Facadism in historic Bucharest. Foto: Rodica Crișan, 2020. Personal archive.
FIGURE 6 – New architecture in historic protected areas in Bucharest. Foto: Rodica Crișan, 2023. Personal archive.

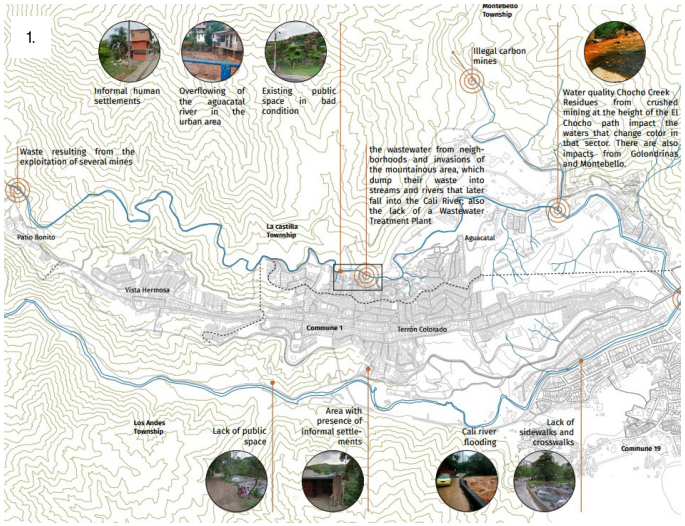
Tabels.

TABLE 1 - Identified needs and requirements, and proposed strategies. Source: Elaborated by the authors based on Montero Correa & Roldán Becerra, 2024, pp.127-129

Table 1 - Identified needs and requirements, and proposed strategies.

Needs	Requirements	Strategies
Basic services of first necessity	Food security	Community vegetable garden
		Cooking module with wood-burning oven
	Clean water and sanitation	Rain harvesting for the irrigation of non-food plants and cleaning
		Sanitary module for food washing and preparation
		Drainage system
		Complementary natural drainage system
	Waste management	Dry compost toilet system
		Organic waste composting points
	Accessibility	Transversal and longitudinal connections in hillside areas
		Road safety
Complementary services	Community life/community services	Medical assistance services
		Educational services
		Metting points
		Sportive area
		Children's entertainment and didactic areas
		Vegetation areas

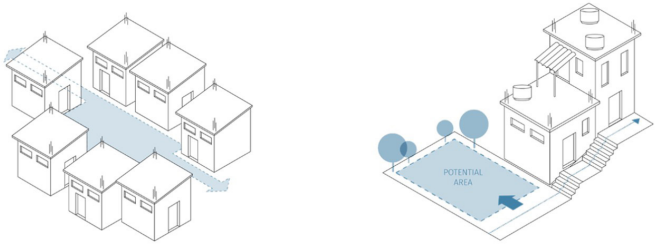
1.


Informal human settlements
Overflowing of the aguacatal river in the urban area
Existing public space in bad condition
Illegal carbon mines
Water quality Chocho Creek
Residues from crushed mining at the height of the El Chocho path impact the waters that change color in that sector. There are also impacts from Colonitrinas and Montebello.
Waste resulting from the exploitation of several mines
the wastewater from neighborhoods and invasions of the mountainous area, which dump their waste into streams and rivers that later fall into the Cali River, also the lack of a Wastewater Treatment Plant
Montebello Township
La castilla Township
Aguacatal
Pance
Vista Hermosa
Commune 1
Terrón Colorado
Los Andes Township
Lack of public space
Area with presence of informal settlements
Cali river flooding
Lack of sidewalks and crosswalks
Commune 19

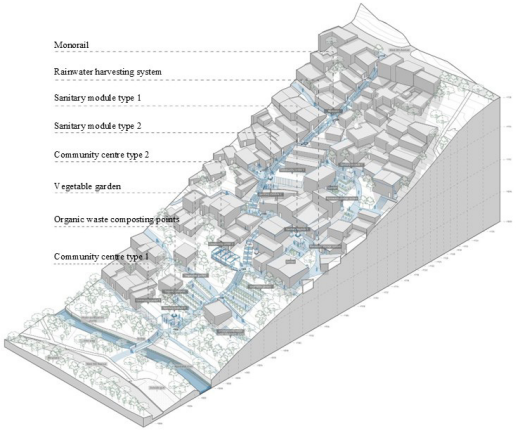
2.



3.


POTENTIAL AREA

4.


Monorail
Rainwater harvesting system
Sanitary module type 1
Sanitary module type 2
Community centre type 2
Vegetable garden
Organic waste composting points
Community centre type 1

INTEGRATION AND USAGE OF ARTIFICIAL INTELLIGENCE SYSTEMS IN PARAMETRIC GENERATION / AN EXPERIMENT/

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Abstract. This article presents the development process of a parametric application for design and architecture, designed to generate customizable three-dimensional structures through a modular, spiral, and deformable logic. The software tool enables the creation of complex spatial forms by controlling geometric parameters and applying spatial transformations within an intuitive graphical interface.

The application was developed in Python [1], using essential open-source libraries: PyQt5 for the graphical interface, Trimesh for geometry generation, and Open3d for real-time interactive visualization. The project began with the procedural generation of spiral-stacked cubic modules and gradually evolved to include various geometric primitives, advanced deformation techniques, and scaling in real physical units. Additional features, such as wireframe visualization and .OBJ export, ensure compatibility with external 3D design workflows [2] (e.g., Blender, Rhino).

This experimental project, with an applied research component, demonstrates how parametric thinking and accessible computational tools can be integrated into a unique generative framework, enabling real-time exploration of architectural form and beyond. The resulting application provides both pedagogical value and professional applicability in the field of computational design and digital prototyping, up to a physical development stage including 3D printing.

The experiment illustrates the applicability of artificial intelligence programs and thus becomes a potential starting point for integrating and using these new technologies in future applications that can generate or analyze structures from the conceptualization process of forms.

Introduction. In recent years, procedural generation of three-dimensional forms has gained increased interest in architecture, engineering, product design and the visual arts. Software applications that enable parametric modeling of structures offer high levels of flexibility, efficiency and creativity, being essential for rapid prototyping, form studies, spatial simulations and computer-aided manufacturing. These tools are no longer just a technical support, but become co-authors of the design process, allowing fast exploration of variants and alternative scenarios (Jaechang Ko, John Ajibefun, Wei Yan, 2025, Generative AI-powered parametric modeling and BIM for architectural design and visualization).

The present project aims to develop a parametric 3D application dedicated to generating deformable spiral structures and, in a more advanced stage, volumetric fractal networks that grow along the same trajectory. The user controls the real physical dimensions of the modules (width, height, depth), deformation (twist and noise), global curvature (bend on the X and Z axes), the level of fractal branching and the base geometric form. The application exports models in .OBJ format [3], compatible with external software such as Blender, 3ds Max or Unity, opening possibilities of integration into complex workflows including rendering, simulation or virtual reality.

The following sections describe the methodology, the software architecture, the implemented functionalities and the obtained results, as well as future development directions.

Project Objectives. The main objectives were initially formulated around the idea of parametric generation of a spiral building and were later expanded to include advanced deformations and fractal developments. Thus, the project aims to:

- develop an intuitive graphical interface, based on PyQt5, that allows direct control of the main parameters of the generated 3D form through sliders, numeric fields and dropdown selections;

- generate spiral structures procedurally by interpolating position and rotation parameters for each individual module, with the possibility to control the number of floors and the characteristics of the helical trajectory;

- implement modular deformation using twist and noise effects for obtaining more organic forms, and add a progressive bend on the X and Z axes that gradually curves the structure with height;

- control the physical dimensions of spiral modules via numerical inputs (QDoubleSpinBox) for width, height and depth, expressed in real units (millimetres, centimetres, metres), with interpolation between the base and top dimensions;

- introduce an extended set of geometric primitives (cube, sphere, torus, cylinder, tube, pyramid, frustum pyramid, cone, frustum cone), which can be used as base modules of the building or of the volumetric network;

- implement real-time manual rotation of the generated model through mouse manipulation, including a quick "Reset View" button and zoom via mouse scroll;

- implement a fractal component that allows the generation of volumetric branches at each module, controlled by parameters such as fractal depth, branch scale and number of branches per module;

- provide export of the generated models in .OBJ format through a "Save As" function that offers control over file name and location;

- prepare the application for distribution and use on other computers by generating a standalone executable with PyInstaller, eliminating the need for a manually installed Python environment.

Methodology. *Software architecture.* The application was developed in Python 3.x, using PyQt5 for the graphical interface and PyOpenGL for rendering the 3D forms. The architecture is structured into two main components:

– GLWidget: a component derived from QGLWidget, responsible for initializing the OpenGL context, drawing the 3D forms, applying