Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 134 (2017) 356–365

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Conference on Sustainability in Energy and Buildings, SEB-17, 5-7 July 2017, Chania, Crete, Greece

Environmental Performance and Social Inclusion: a Project for the Rocinha Favela in Rio de Janeiro

Andrea Arcidiacono[a], Francesco Causone[b], Mario Grosso[c], Gabriele Masera[d], Massimo Tadi[d]* Hadi Mohammad Zadeh[d]

[a] Department of Architecture and Urban Studies, Politecnico di Milano, Via Bonardi 2, 20133 Milano, Italy.
[b] Department of Energy, Politecnico di Milano, Via Lambruschini 4, 20156 Milano, Italy.
[c] Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy.
[d] Department of Architecture Built Environment and Construction Engineering, Politecnico di Milano, Via Ponzio 31, 20133 Milano, Italy.

Abstract

Rocinha, located in the city of Rio de Janeiro, is one the largest favela of Latin-America. Founded in the early 1930's it is now home of more than 160000 inhabitants, and it is characterized by low water quality, poor housing, lack of drainage and sanitation systems, and of green and public spaces. This paper presents the preliminary results of a joint research project between the Politecnico di Milano and the Federal University of Rio de Janeiro (UFRJ) for the improvement of the urban quality, health, livability and inclusiveness of Rocinha, that moves from an upgrading process of the environmental performance of the existing built environment. The project, in the frame the social responsibility program of Politecnico di Milano (Polisocial), is based on a multidisciplinary and integrated design methodology named IMM (Integrated Modification Methodology). The research aims to demonstrate that in a planet where the informal settlements are exponentially growing, strategies to improve the quality of life of their inhabitants are possible, and preliminary results, mostly achieved in the diagnostic phase of the process, are presented. Rocinha is seen as a complex system that has been investigated in its own morphological structure and the related environmental performance, focusing on: climate and energy, ecosystem services, waste management and their relation with urban morphology. This phase opens up to the next phases, specifically the intervention and retrofitting, that intend to select intervention areas and priorities and then to objectively size the implementation in Rocinha.

Peer-review under responsibility of KES International.

Keywords: Energy efficiency; Sustainable urban design; Slums upgrading; Environmetal performances; Complex Adaptive System

* Corresponding author. Tel.: +39 02 2399 5744; fax: +39.02.2399.6237.
E-mail address: massimo.tadi@polimi.it

1876-6102
Peer-review under responsibility of KES International.
10.1016/j.egypro.2017.09.546

1. Introduction

By 2050, 75% of the world's population is projected to be living in cities [1] and 60% of it will be living in informal settlements or slums. In these areas, 60 % of the necessary infrastructure is yet to be built [2].

In a planet where favelas/slums growth continues, the aims to optimize their environmental impact together with the improvement of the quality of life of their inhabitants become crucial [3]. This paper aims to highlight the unexpected qualities inherent to informal settlements, in particular the consolidated ones such as in the case of Rio de Janeiro [4], and the potential lessons they can offer for a sustainable urbanization. Rio de Janeiro, the second largest city in Brazil and the third largest metropolitan area in South America, with over 6.3 million inhabitants, approximately 22 % of whom live in favelas, is an interesting case study to investigate urban upgrading [5]. The paper will focus, in particular, on the case study of Rocinha, the biggest favela in South America.

Following the Integrated Modification Methodology (IMM) [6], Rocinha is considered as a specific urban complex adaptive system (CAS). The paper moves from an objective evaluation of its morphological organization and environmental performance, in terms of ecosystem services provision, toward the optimization of its unexpressed full-potential. In Rocinha many families live in extreme poverty, with needs related to livability and sustainability of their environment, such as internal mobility, drainage, sanitation, housing, public spaces, green and open spaces. In order to properly deal with "the issue of favelas" it is necessary to understand that favelas are not just an urban aberration, but rather a specific morphological organization, characterized by self-organized arrangement and weak connection with the other parts of the city [7]. The idea that favelas, as systems based on self-construction, must be simply defined as "urban chaos", does not permit to go beyond the attempts of their eradication or, on opposite, to assimilate them in the "formal" city. On the contrary, the work presented in this paper focuses on the upgrading processes in some of the basic services of Rocinha, unveiling its unique and proper potential [8]. The analysis reported in this paper resume the initial outcomes of a project developed by the Politecnico di Milano in partnership with the Federal University of Rio de Janeiro and "Il Sorriso dei Miei Bimbi" a non-profit organization engaged with the community of Rocinha to support actions for the education and the culture for children and youth. The project aims to contribute to the improvement of the urban and environmental infrastructure of Rocinha, identifying intervention priorities and actions rooted in a strong community engagement and defined by a full understanding of the peculiar morphological organization, characteristics and performance of the favela. The research offers also a fresh new contribution to the actual debate on the possible actions, policies methodologies and design strategies necessary to upgrade worldwide informal settlement [9].

2. Context to literature

Over the course of its conceptual evolution, sustainability has been portrayed as an edifice supported by the three pillars of economic growth, environmental protection, and social progress [10]. It is commonly accepted that the goals of the sustainable development are manifested in the convergence of the above-mentioned areas of knowledge [11]. The interconnectedness of the development challenges within and in-between the three pillars showed the importance of an interdisciplinary approach for the sustainability research on new urgencies [12,13]. Nevertheless, many studies carried out in the field of sustainability resulted as significant institutional and structural obstacles to what an interdisciplinary study is supposed to pursue [14,15]. By solely focusing on the performance of individual buildings, sustainable architecture is trapped in the mono-disciplinarily of the environmental methodologies which, regardless of their wide audience, are not really making connections across the pillars of knowledge [16]. In recent years, it has been proven that concentrating on green engineering alone is not sufficient to achieve sustainability, since non-integrated efficient subsystems might obstacle the capacity of the entire system to be sustainable, and they may lead to socially unacceptable outcomes [17]. Therefore, sustainability must be quested in systemic and multi-scalar manners, integrating all the built environment's subsystems.

Considering the above mentioned methodological gaps, the Integrated Modification Methodology (IMM) offers a systemic procedure for analysing and modify urban morphology by addressing the various subsystems of the built environment. IMM's main element of approach is the consideration of the built environment as a complex adaptive system (CAS). Complex systems are recognized to be decomposable in their parts and arranged in diverse levels, with a profound mutual relationship between their subsets [12]. The IMM is structured around dismantling and re-fusing the urban subsystems and studying the relationships between them. This requires an effective interdisciplinary approach, able to brace the different functioning elements and to work on the reciprocal relationships between different subsets.

3. Method

The paper, following the IMM considers favelas as a CAS, and it moves from an objective evaluation of its morphological organization and environmental performance to a comparison with proposed alternatives, in order to evaluate and then improve their unexpressed full potential. IMM is an analysis and design methodology based on a nonlinear phasing process. With a holistic approach, the main aim of IMM is to deliver a new understanding of the city's behaviour by decomposing it into its parts and studying the structure of its subsystems [18]. Unlike most of the current theories and methods, which, through simplifications, are inclined to offer generic and commandment-like principles for urban sustainability, IMM proposes a systemic inquiry into the local structure of the built environment and it tends to include the sources of its complexity. In IMM local changes in system's parts produce a chain reaction that ultimately will change the system globally. Relying on this principle, IMM tries to envision the indirect effects of the limited interventions beyond the local scale/subsystem, and explain how a collection of slight changes can produce considerable performance improvements in energy efficiency, environmental protection, and social wellbeing in our cities.

The core of the methodology is an iterative process made of four main phases: Investigation, Assumption, Transformation and Optimisation. *Investigation,* being the first phase, consists basically in the creation of a model out of the urban system. Just like any other system, built environment is characterized by including parts and subsystems connected by complex relationships; during the investigation phase, the system is, thus, broken into its parts. Morphologically speaking, these parts for the cities are: *urban volume, urban void, links,* and *urban function*.

After analyzing the four subsystems individually, the analysis proceeds by investigating the relationships among them. Hence, the subsystems are fused with each other, one by one. As the outcome of a conceptual chemical reaction, the result of fusing is more than overlapping the basic layers. In this step, six performing attributes of the built environment are studied. They are called Key Categories and are namely: *porosity, proximity, diversity, interface, accessibility,* and *effectiveness* (Fig. 1).

Assumption is the second phase of IMM, and it includes the identification of malfunctioning in subsystems. It, moreover, takes the role of the transformation catalyst. It means that any intervention with the purpose of improving the entire system should start by upgrading the subsystem that showed to be the weaker. Only through the catalyst the scope of the transformation is actually defined. In this way, design principles for any project are locally defined according to its very particular situation.

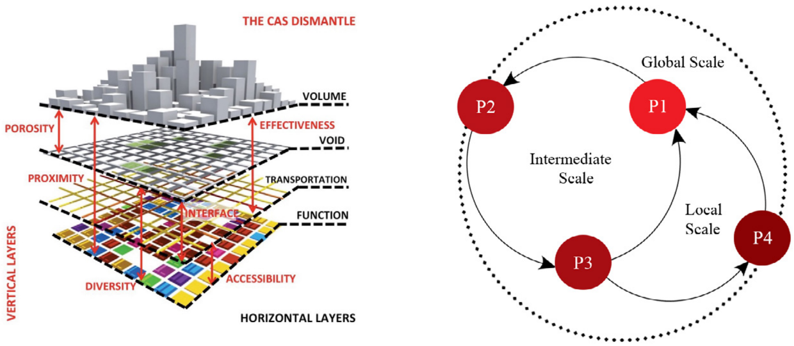

Fig. 1. (a) The disassembling process of the CAS's Horizontal components and Vertical ligands; (b) IMM a no-linear phasing process. P1, P2, P3 and P4 stand for IMM Phases 1 to 4 which are Investigation, Assumption, Transformation and Optimization respectively.

Transformation is the third phase; here various modification scenarios are tested into the project by means of the same modelling mechanism used in the investigation phase. Compared to the actual situation, these scenarios are evaluated and tested over and over until an acceptable modification scenario results.

Optimization is the fourth phase of the IMM, during which the outcome of the previous phase is subjected to retrofitting process. At this point the system is expected to perform much better than it does in the actual situation.

4. Analysis results

IMM applied in Rocinha allowed to identify the areas where the potential of the context is yet unexpressed, and where major resources does exist. Considering the large scale of Rocinha, and the hidden diversity in its rather organic shape, it is necessary a holistic approach for viewing the morphology of the area in a systemic perspective.

This view should reveal the morphological subsystems, and more importantly, the complex mechanism, which connects them and subsequently rules the functioning of the whole system.

The goal is to understand where and how the limited local modification can influence the entire system and lead to tangible global improvement.

4.1. Climate and Energy

The Köppen Climate Classification subtype for the climate of Rio de Janeiro (and of Rocinha) is “Aw”, i.e. Tropical Savanna Climate [19]. The warmest month, on average, is February with an average temperature of 26.9°C, whereas the coolest month is July, with an average temperature 20.8 °C. However, the temperature fluctuations along the year are limited and the same is true for night-to-day temperature shifts. The yearly minimum and maximum temperature are, on the basis of the weather data set adopted [20], 12.4 °C in August, and 37.0 °C in January respectively. The yearly average temperature is 24.0 °C. Since Rio shows a tropical climate, the relative humidity is quite high, varying in a range between 34 % and 100 %, with an average yearly value of 78 %. Only 1 % of the yearly hourly relative humidity values is lower than, or equal to 50 %. Monthly sifts between maximum and minimum values are not relevant. Weather data for Rio de Janeiro are summarized in Fig. 2.

The average amount of precipitation for the year in Rio de Janeiro is 1172 mm. The month with the most precipitation on average is December, whereas the month with the least precipitation is July.

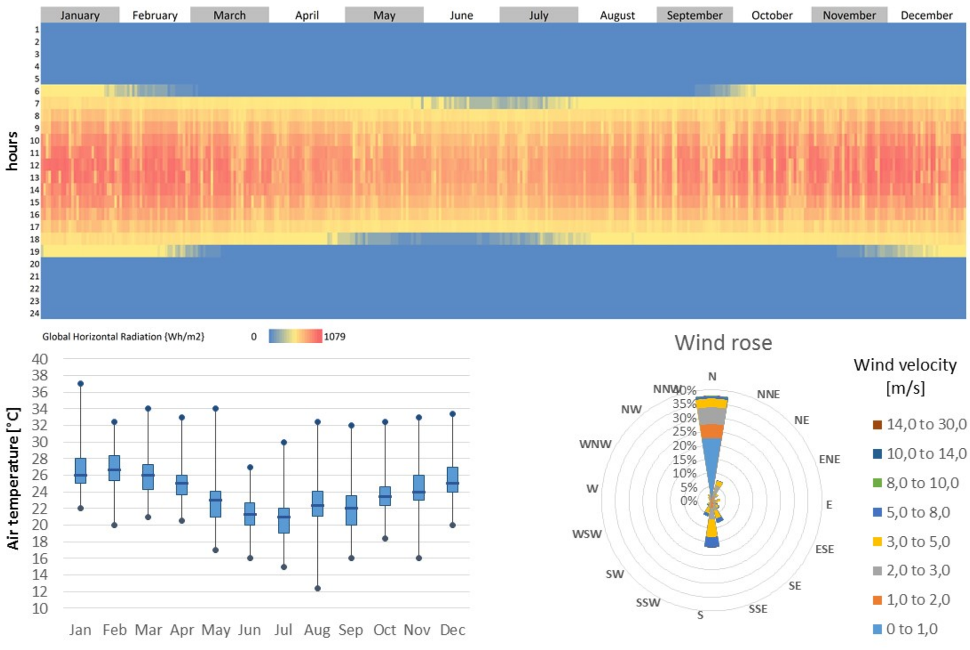

Fig. 2. Rio de Janeiro climate analysis: on the top the yearly hourly global radiation, on the bottom left the monthly interquartile analysis for hourly temperature, on the bottom right the wind direction and velocity analysis.

Solar radiation is quite high and sky cover low, it means that there is abundance of solar radiation at the ground level and especially on rooftops, where shadows are limited. The sky cover index is for the 43 % of the year between 0 and 40, i.e. clear sky, for the 21 % between 40 and 80, i.e. partially overcast sky, and for the 36% of the time between 80 and 100, i.e. overcast sky. The average monthly solar irradiance on the horizontal plane at ground level is equal to 197 kWh/m^2; 68 % of it is due to direct beam radiation and 32 % to diffuse radiation. It is a quite stable value, varying from a maximum of 236 kWh/m^2 in January to a minimum of 162 kWh/m^2 in June.

The wind direction is quite stable too, blowing mostly from North to South (38 % of the values) or from South to North (17 % of the values). The wind velocity may reach values higher than 14 m/s; however, the majority of values are included in the range between 0 and 5 m/s.

Data on average energy consumption for the favela of Rocinha are very difficult to be found; we will therefore refer to data for Brazil and for Rio de Janeiro as summarized in Table 1. The average yearly consumption of electrical energy in Rio de Janeiro is in line with the national data, and equal to 2481 kWh/inhab, i.e. 207 kWh/inhab circa, per month [25, 26]. The figures for Rocinha are probably slightly lower, since the favela is mostly composed of low-income households. A study available in the literature for Rio, reports reference values for low-income households ranging from 190 to 250 kWh/month per household [24], another study referred to 2002 data, reports an average value of 103.19 kWh/month per household [25]. Electrical energy represent the principal energy carrier in Rocinha, since natural gas is used typically for cooking only; moreover, a study referred to the city of São Paulo, shows that electricity consumption may be a reliable predictor of household income [26].

This data, if compared to the average monthly solar irradiance on the horizontal plane at ground level, reported in the climate analysis, i.e. 197 kWh/m^2, shows that solar energy may be effectively exploited to balance a substantial part of the households' energy consumption in Rocinha. Early results for a solar map potential, referred to a focus area in Rocinha, shows, in fact, a large amount of solar energy potentially convertible into electrical energy by means of low-cost photovoltaic panels, or into thermal energy by means of solar thermal panels (Fig. 3).

Table 1. Energy data for Brazil and Rio de Janeiro for year 2015

Energy indicator (year 2015)	Quantity	Rate from renewable
Brazil total yearly energy consumption per capita	1.27 toe/inhab	41.2 %
Brazil yearly electrical energy consumption per capita	2547 kWh/inhab	75. 5 %
Rio de Janeiro yearly electrical energy consumption per capita	2481 kWh/inhab	n.a.

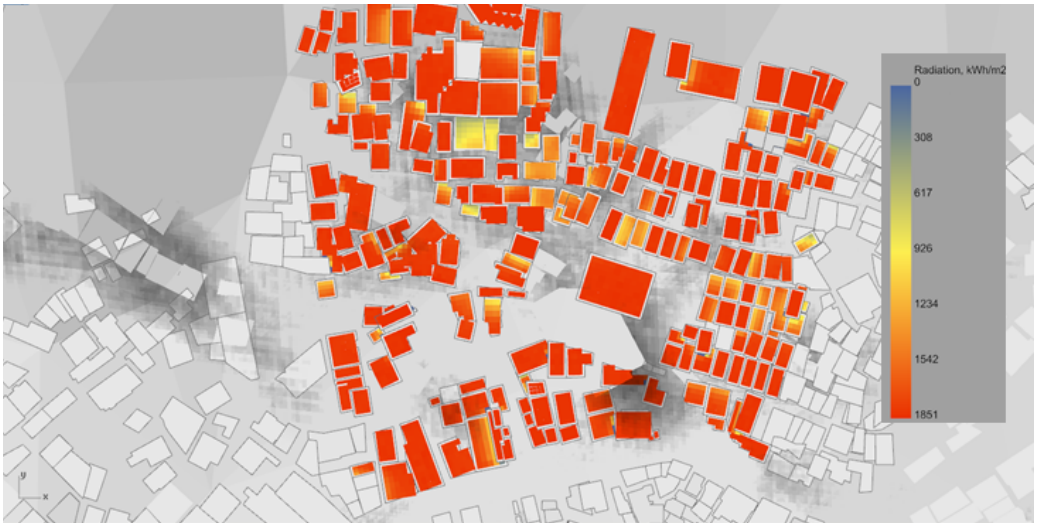

Fig. 3. Early study of solar potential map for Rocinha; the plotting reports the yearly solar energy impinging on the roof surface of buildings.

4.2. Ecosystem services assessment: a multi-scale approach for natural resources management

The rapid urbanization process occurred in the last decades in Rio de Janeiro has involved more than 1.4 million people that nowadays live mostly in dense favelas, informal urban settlements [27] characterized by a consolidated built environment, morphologically recognizable, and by strong social identity and “sense of belonging” [28, 29].

As several favelas, Rocinha is characterized by a dense, continuous built environment, with a high degree of impervious surfaces, result of an intense and spontaneous development. Rocinha presents a low level of environmental and ecological performance, without a regular sewage system, with high density housing condition, reduced distances and narrow spaces between buildings, rare public spaces for social use, and the absence of urban green areas rather than any other type of open spaces that traditionally characterize the physical structure of a “planned” urban environment. Nonetheless, the character of urbanity is rather relevant even without a compulsory land use planning regulation. Rocinha has the social and physical features of a formal city, although the socio-economic and environmental conditions are particularly complex and critical. Considering the ecological characterization, the urbanization of Rocinha and other favelas of Rio de Janeiro region have radically modified the ecological features and the provision capacity of Ecosystem Services (ES) in the metropolitan area.

ES are commonly defined as “the benefits that humans obtain from Ecosystem functions [30,31], or as direct and indirect contributions from Ecosystems to Human Well-being” [32]. At least, ES are the set of processes and conditions that make possible the existence of human life in Natural Ecosystems. The capacity of an ecosystem to provide services strictly depends on the Land Use and Land Cover (LULC) quality and on their biophysical conditions [33]. The ES potentially provided by the LULC are acknowledged as a key condition for linking human and natural systems for environmental management [34,35] and for spatial planning process aimed at increasing sustainability. The impact assessment of intensive ecological transformation of Rocinha area and its surroundings, and related ES degradation, is one of the main challenges to the process of urban revitalization. The high dense and compact urbanization process determines: habitat quality decrease caused by the sealing and fragmentation as well as the loss of natural green areas; the alteration of the water cycle; the depletion of landscape value and the instability of the climate regulation concerning heat island and water filtering condition.

Considering the multidisciplinary approach of the project, the IMM methodology has been integrated with the assessment of the ES “state and trend” to support decision-making processes aimed at defining strategies and design priorities for natural resources management to retrofit ES in a future scenario. The assessment of ES in Rocinha requires the adoption of a multiscale approach that combines the local scale investigation (which has been applied to the analysis of other research units), with a broader/large scale suitable for ES evaluation.

The ES considered are: Habitat quality, Carbon sequestration, Nutrient retention and Sediment retention. The mapping and assessment process has been settled using InVEST system (Integrated Valuation of Ecosystem Services and Tradeoffs), free software developed by the Natural Capital Project. InVEST is a tool for geographic, economic and ecological accounting on ES, designed to support territorial and urban planning in the decision-making process concerning the restoration and conservation of the natural capacity of soil to provide ES [36].

The decision to use InVEST as a software for ES mapping offers the possibility to have a comprehensive set of models including the possibility to add eventually an economic evaluation, to use a multi-layer analysis and to compare different scenario (current and future). Considering the ES selected and the geomorphological condition of Rocinha and its surrounding areas (the favela is placed on a steep mountain slope in the Tijuca National Park bordering it to the north [37], the scale of analysis considers a wider area of interest (AOI) which includes the sorrounding sites of Rocinha that should be included as an ES supplier. Therefore, two scales of analysis has been used for the IMM analysis: the urban ones, focused on Rocinha, and the ecological ones, considering the overall ES supply areas. The adoption of the ecological scale for ES assessment allow interactions between the urban analysis of Rocinha with the overall framework for ES capacity. Such approach recognizes the institutional dimension as the perimeter where services are generated, valued and managed. Moreover, it allows to partially solve the mismatches between the governance and management dimension of ES and their supply which traditionally affected the spatial representation and implementation of decision-making process [38]. Considering the ecological scale, the AOI selected was the Metropolitan area of Rio de Janeiro with a territorial extension of 10,257.12 km^2.

The mapping and assessment of ES requested an inputs dataset construction, which has been related to LULC information. Notably, each ES model is based on LULC and the geometric resolution and data precision are crucial for a reliable output. The construction of the land use dataset was the fundamental step required to harmonise the land cover classification system of Rio de Janeiro's area and design a suitable layer for all the IMM analysis.

Considering the above-mentioned institutional dimension where Rochinha is placed, the LULC has been settled with the highes geometrical resolution and a detailed land use classification. Such methodological step was of great importance to highlight the clustering differences among the continuous urban pattern such as the presence of permeable surfaces, rather than the existence of fragmented subgroups and sub-locations with a less dense urban pattern. Three main databases were used for the construction of the LULC layer, as illustrated in the Fig. 4:

- Land use maps of Rio de Janeiro provided in 2004 by the Instituto Municipal de Urbanismo Pereira Passos;
- Land use maps of Brasil elaborated in 2014 by Ministério do planejamento, Desenvolvimento e gestão;
- Mapa de Cobertura;
- OpenStreetMaps – OSM, as a project aimed at collecting geolocated information from volunteers to expedite and facilitate the process of LULC mapping providing training samples and accessing the accuracy of classification's output. The available layer used were roads, buildings and waterways, natural and land use features, The OSM data has been downloaded from the official data provider Geofabrik in February 2017.

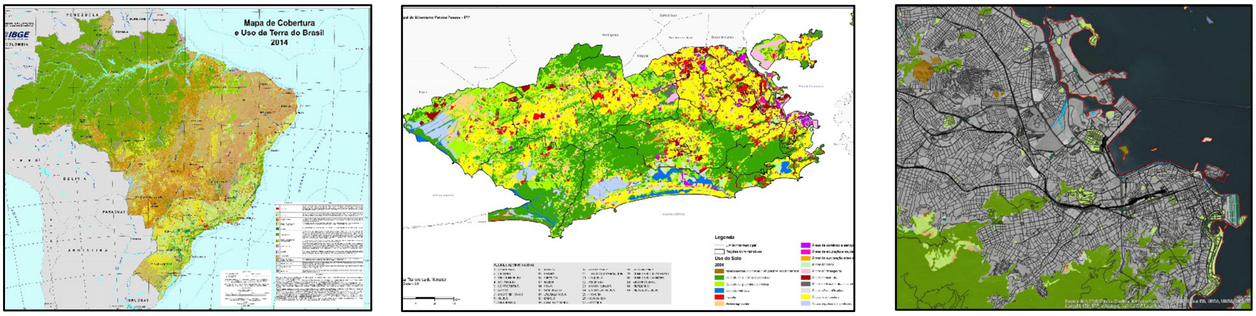

Fig. 4. (a) The Land use maps of Rio de Janeiro, (b) Land use maps of Brazil, (c) the detailed information of OSM.

The integration of different sources required a harmonisation of LULC classification system to achieve a homogeneous legend/nomenclature that fits each land units. The legend has been settled according to the Corinne Land Cover (CLC) classes - Copernicus, an inventory set up in 1985, composed by 44 land cover classes, promoted by European Commission. The LULC maps (Fig. 5) were then integrated with the building survey of Rocinha elaborated by the local research group. The integration of the analysis allows gathering details of urban morphologies and achieving an ES distribution also in dense urbanized areas. The output database will be the primary layer used for ES mapping and assessment required by InVEST. The next steps of the project will be mainly related on the ES mapping starting from the LULC database created with the methodology proposed above and considering the LULC as the core elements for running all the InVEST models. The ES mapping will be used for estimating the possible project actions to consider according with ES provision.

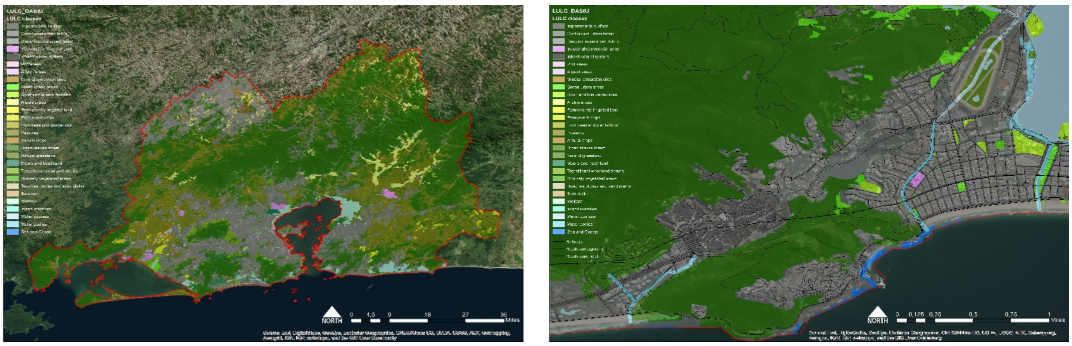

Fig. 5. The achieved LULC maps.

4.3. Waste management

Underlining the importance of a proper Solid Waste Management (SWM) is worthy, as residues can generate pollution and contamination of water, and their environmental impacts can affect seriously public health, becoming a source of diseases. Other tangible consequences of improper management concern landscape degradation, which influences not only the appearance, but also wellbeing and liveability. On the other side, waste can become a resource, in terms of material and energy, if properly managed.

A SWM is based on several steps, such as collection, treatment and final disposal of waste. Collection can absorb up to 70-80 % of the entire budget, especially in low-income countries. Besides economical sustainability, other concerns for SWM in developing countries are equity in service provision and excessive reliance on imported or not appropriate technologies [39]. Brazil cannot be considered a developing country; nonetheless, a really high level of inequity characterizes it, of which favelas are the evidence. These issues are likely to affect Rocinha, due to its social and urban characteristics. A first step to deal with SWM is to understand the regulation framework in force, necessary to identify the actors of the waste management systems and the existing strategies (if any).

Laws on environment and waste management exist over three administrative levels. The state of Rio de Janeiro approved in 2003 a Policy for Solid Waste, which foreruns the National Policy for Solid Waste, a federal law established in 2010. Relevant legislation for the Municipality of Rio de Janeiro include the PMGIRS, a municipal plan for integrated solid waste management, published for the first time in 2008, and several laws on public health and sustainable development. Moreover, Rocinha became officially a neighbourhood of Rio de Janeiro since 1995, when it was identified as the Administrative Region XXVII. A consequence of this acknowledgement is the inclusion inside public programs such as Programs for Acceleration of Growth (PAC). The project "Rocinha PAC-2", carried out by the public company Empresa de Municipal Obras Públicas (EMOP), was focused on sanitation, with the purpose of improving drainage and sewage networks and waste collection. Compactors and underground storage were suggested to solve illegal dumping, together with collection points and cleaning campaign.

A study [40] performed under the umbrella of "Rocinha PAC-2" described the situation inside the favela: due to a discontinuous collection service, waste were spread everywhere, occupying the sidewalk and impeding pedestrian mobility. Main problems were related to waste accumulation and presence of animals, with consequent possibility of pest spreading, and the simultaneous use of the existing channels network for drainage, sewage and waste disposal, causing floods during rainy periods. Interventions on the inadequate waste management were consequently addressed as urgent, due to the high health risk.

Thus, the lack of policies and regulations does not seem to be a major problem, and public authorities are aware of the situation. Interventions on SWM in the favela were expected, and it is necessary to assess their success and efficacy. Meanwhile, providing a description of the overall SWM system and its weakness is possible.

Waste management in Rocinha is performed by Comlurb, a public company charged with the collection, treatment and disposal of municipal solid waste in the whole Municipality of Rio de Janeiro. Waste collected in Rocinha is transferred to the Transfer Station (ETR) of Caju, and moved to the controlled landfill of CTR-Rio Seropédica, in which treatment of leachate and landfill gas burning are performed. Besides, particular waste streams, such as organic or construction and demolition wastes, are already addressed, at least on a pilot scale.

Inside the boundaries of Rocinha, waste collection phase is the most relevant, as consequences on public health can derive from service continuity, coverage of the area and scaling of the system. According to some field information, collection is performed on a daily basis, and containers are mainly located on the street (Estrada da Gavea) which crosses Rocinha, leaving wide areas of the neighbourhood totally uncovered.

Concerning waste production, official data on collected domestic and public waste are available on the behalf of Comlurb. An increasing trend is observed on the whole area of Rio de Janeiro since 1990, reaching 3 millions of tons in 2014. In the same year, 35329 tons of domestic and public waste were collected in Rocinha [41].

Further evaluation on waste production in Rocinha should take into account the existence of streams, which are not included in this value, since they are not collected by Comlurb. Coverage of waste collection range from 58 % [42] to 98 %. Estimations are usually done also in terms of average per capita production, but in the case of an informal settlement, the lack of reliable information on population would affect the data. However, the investigation commissioned for "Rocinha PAC-2" provides some approximate values, assessing the daily waste production at 97 t/d, varying from winter (80-90 t/d) to summer (100-130 t/d) and the production per capita at 0.67 kg/inhab/d of domestic waste and 0.33 kg/inhab/d of public waste (e.g. deriving from street sweeping). Besides waste generation, it is important to assess also the composition of waste produced. Data for Rocinha are available for a single year and are based on a sampling campaign performed by Comlurb on informal settlements [43]. During this campaign, 21 favelas were analysed. Results are illustrating an abundance of organic matter, followed by plastic and paper or cardboard. This composition should be taken into account for further evaluation.

5. Discussion

The literature shows that a very strictly sectorial approach in sustainable urban design could result in neglecting mutual interdependencies between the different parts of the urban environment. Conversely, in this paper some research findings, mostly from the diagnostic phase of the process, have been presented to demonstrate how a fully integrated approach that focuses on the interdependencies between climate and energy, ecosystem services, waste management and urban morphology, can better address the research questions. Moreover, the literature shows a gap in the actual practice on favelas' upgrading process that mostly concentrates on social problems and on assimilating favelas to the "formal" city. Our research tries to fill the methodological gap in knowledge and practises about "Favelas Upgrading" processes [44] by considering that they are not just an urban aberration, but rather a specific morphological organization made of self-organized subsystems. Hence, Rocinha, seen as Complex Adaptive System, has been investigated in its own morphological structure and the related environmental performance, providing a promising result in terms of the analysis approach and the consequent practical applications.

6. Conclusions

Being the largest favela of Rio de Janeiro, Rocinha is one of the most particular informal urban settlements of the world. Almost disconnected from the rest of the city, it is characterized by a super dense self-evolving morphology home to many of Rio's citizens who are struggling to meet their urban needs of the very basic kind. This paper presented a multidisciplinary perspective for viewing Rocinha as a resourceful system offering much not only for its own functional improvement but also for playing the role of a partial environmental absorber in Rio. It highlights the necessity to understand the systemic structure of the area and diagnose the potential opportunities rooted in the existing threats. Here, some of the mentioned opportunities in morphological flexibility, energy production, and waste treatment have been investigated, which from a holistic point of view for shaping a functional system with its own parts and relationships. The performing boundary of this system can be used for defining an appropriate scale of the possible interventions. The next step will be to identify the morphological subsystems and their complex connection mechanisms.

Acknowledgements

The authors are grateful to all the components of Politecnico di Milano's research team composed by Angela Colucci, Håkon M. Rensaa, Silvia Ronchi, Stefano Salata, Lorenza M. Sganzetta, Anita Tatti, Francesca Villa for the diligence, the hard work dedication demonstrated. Then the whole Politecnico di Milano research team wishes to thank prof. Gabriella Rossi of the Urban Engineering Program of Escola Politécnica, for her immensurable support, participation and contribution in the results achieved in this preliminary phase.

References

[1] United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects - The 2014 Revision. New York: United Nations; 2015.
[2] World Resources Forum. From COP 21 to Habitat III – Towards low carbon, resource efficient and sustainable cities. World Resources Forum; 2017.
[3] HABITAT III. Issue papers 22 – Informal Settlements; 2015.
[4] Perlman J. Favelas: Four decades of living on the edge in Rio de Janeiro, Oxford: Oxford University Press; 2010.
[5] World Bank. The (1999-2001), Case Examples: Favela-Bairro Project, Brazil; 2011. [http://web.mit.edu/ urbanupgrading/upgrading/case-examples/ce-BL-fav. html].

[6] Tadi M, Vahabzadeh Manesh S. Transformation of an urban complex system into a more sustainable form via Integrated Modification Methodology (IMM). The International Journal of Sustainable Development and Planning Volume 9, Number 4, WIT press Southampton, UK; 2014.
[7] Simpson M. Urbanising favelas, overlooking people: Regressive housing policies in Rio de Janeiro's progressive slum upgrading initiatives. DPU WORKING PAPER NO. 155. Development Planning Unit, The Bartlett, University College London; 2013.
[8] UN-Habitat. Streets as tools for urban transformation in slums; 2015.
[9] Oliveira NS. Favelas and ghettos: Race and class in Rio de Janeiro and New York. Latin American Perspectives; 2000. p. 71–89.
[10] Kastenhofer K, Rammel C. Obstacles to and potentials of the societal implementation of sustainable development: a comparative analysis of two case studies. Sustain Sci Pract Policy; 2005. 1(2):5–13.
[11] United Nations General Assembly. 2005 World Summit Outcome: resolution. 2005; A/60/1:38.
[12] Holling CS. Understanding the complexity of economic, ecological, and social systems. Ecosystems; 2001; 4(5):390–405.
[13] Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC, Lowe I, McCarthy JJ, Schellnhuber HJ, Bolin B, Dickson NM, Faucheux S, Gallopin GC, Grübler A, Huntley B, Jäger J, Jodha NS, Kasperson RE, Mabogunje A, Matson P, Mooney H, Moore BIII, O'Riordan T, Svedin U. Sustainability science. Science. 2001; 292(5517):641–642.
[14] Kostoff RN. Overcoming specialization. BioScience; 2002; 52:937–94.
[15] Porter AL, Rafols I. Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. Scientometrics; 2009; 81:719–745.
[16] Ethan D. Schoolman, Jeremy S. Guest, Kathleen F. Bush, Andrew R. Bell. How interdisciplinary is sustainability research? Analyzing the structure of an emerging scientific field; 2011. DOI 10.1007/s11625-011-0139-z.
[17] Mihelcic JR, Crittenden JC, Small MJ, Shonnard DR, Hokanson DR, Zhang Q, Chen H, Sorby SA, James VU, Sutherland JW, Schnoor JL. Sustainability Science and Engineering: The Emergence of a New Metadiscipline, Environ. Sci. Technol 37; 2003. p. 5314 – 5324.
[18] Tadi M, Vahabzadeh Manesh S, Mohammad Zadeh H, Gori G. Urban Morphology, Environmental Performances, and Energy Use: Neighborhood transformation in Rio de Janeiro via IMM. Journal of Architectural Engineering Technology; 2016; 5:180.
[19] Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen–Geiger climate classification, Hydrology and Earth System Sciences, 11; 2007. p. 1633-1644.
[20] https://energyplus.net/weather-location/south_america_wmo_region_3/BRA//BRA_Rio.de.Janeiro-Santos.Dumont.837550_SWERA.
[21] http://www.holiday-weather.com/rio_de_janeiro/averages/.
[22] Ministério de Minas e Energia, Empresa de Pasquisa Energética. Balanço Energético Nacional. BEN 2016 – Ano Base 2015. Rio De Janeiro: EPE/MME; 2016.
[23] Ministério de Minas e Energia, Empresa de Pasquisa Energética. Anuário Estatistico de Energia Elétrica 2016 – Ano Base 2015. Rio De Janeiro: EPE/MME; 2016.
[24] https://www.wec-policies.enerdata.eu/Documents/cases-studies/Measures-for-low-income-households.pdf.
[25] World Energy Council. Alleviating Urban Energy Poverty in Latin America: Three Cities – Three Approaches. London: World Energy Council; 2006.
[26] Francisco Ede R, Aranha F, Zambaldi F, Goldszmid. Electricity Consumption as a Predictor of Household Income: an Spatial Statistics approach. In Proceedings of: VIII Brazilian Symposium on GeoInformatics, Campos do Jordão, Brazil, November 19-22; 2006. p. 175-192.
[27] Rekow L., Fighting insecurity: experiments in urban agriculture in the favelas of Rio de Janeiro, Field Actions Science Reports, 8 (September); 2015. p. 1–8.
[28] Bosselmann P. Urban Transformation. Understanding city form and design. Washington: Island Press; 2009.
[29] Carmona M, Tiesdell S, Heath T, Oc T. Public Places Urban Spaces. Oxford: Architectural Press Elsevier; 2003.
[30] de Groot R, Wilson M, Boumans RMJ. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics; 2002. p. 393–408.
[31] Millennium Ecosystem Assessment. Ecosystems and human well-being, Ecosystems; 2000.
[32] TEEB. The economics of Ecosystems and biodiversity for National and International Policy Makers; 2009.
[33] Burkhard B, Kroll F, Nedkov S, Müller F. Mapping ecosystem service supply, demand and budgets. Ecological Indicators; 2012. p. 17–29.
[34] Balmford A, Beresford J, Green J, Naidoo R, Walpole M, Manica A. A global perspective on trends in nature-based tourism. PLoS Biology; 2009. p. 1–6.
[35] Arcidiacono A, Ronchi S, Salata S. Ecosystem services assessment using invest as a tool to support decision making process: Critical issues and opportunities. In: Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); 2015.
[36] UN Habitat. Enhancing urban safety: global report of human settlements. New York: United Nations Human Settlement Program; 2007.
[37] Gómez-Baggethun E, Kelemen E, Martín-López B, Palomo I, Montes C. Scale Misfit in Ecosystem Service Governance as a Source of Environmental Conflict. Society & Natural Resources; 2013. p. 1202–1216.
[38] Mclnnes G. CORINE Land Cover a key database for European integrated environmental assessment CORINE Land spatial, territorial, environmental; 1999.
[39] Coffey M, Coad A. Collection of Municipal Solid Waste in Developing Countries, UNHABITAT; 2010.
[40] Estado do Rio do Janeiro - EMOP, Relatório de Diagnóstico Urbano, Ambiental e Social, Diagnostico-Rocinha.pdf; 2012.
[41] Armazem do dados: http://www.armazemdedados.rio.rj.gov.br/.
[42] Diagnóstico preliminar de resíduos sólidos da Cidade do Rio de Janeiro, Prefeitura do Rio de Janeiro; 2015.
[43] Prefeitura da Cidade do Rio de Janeiro, Gerência de Pesquisas Aplicadas – IGP, 2012. Determinação do Peso Específico de diversos tipos de resíduos sólidos; 2012.
[44] Magalhães F, Di Villarosa F. Slum upgrading. Inter-American Development Bank; 2012.